**Low**
**Carbon**
**Innovation**
**Coordination**
**Group**

# Technology Innovation Needs Assessment (TINA)

## Industrial Sector
## Summary Report

November 2012

## *Background to Technology Innovation Needs Assessments*

*The TINAs are a collaborative effort of the Low Carbon Innovation Co-ordination Group (LCICG), which is the coordination vehicle for the UK's major public sector backed organisations in the area of 'low carbon innovation'. Its core members are the Department of Energy and Climate Change (DECC), the Department for Business, Innovation and Skills (BIS), the Engineering and Physical Sciences Research Council (EPSRC), the Energy Technologies Institute (ETI), the Technology Strategy Board (TSB), the Scottish Government, Scottish Enterprise, and the Carbon Trust. The LCICG also has a number of associate members, including the Governments of Wales and Northern Ireland, Ofgem, the Crown Estate, UKTI, the Department for Transport, the Department for Communities and Local Government, the Ministry of Defence, and the Department for Environment, Food and Rural Affairs.*

*The TINAs aim to identify and value the key innovation needs of specific low carbon technology families to inform the prioritisation of public sector investment in low carbon innovation. Beyond innovation there are other barriers and opportunities in planning, the supply chain, related infrastructure and finance. These are not explicitly considered in the TINA's conclusion since they are the focus of other Government initiatives, in particular those from the Office of Renewable Energy Deployment in DECC and from BIS.*

*This document summarises the Industrial sector TINA analysis and draws on a much more detailed TINA analysis pack which will be published separately.*

*The TINAs apply a consistent methodology across a diverse range of technologies, and a comparison of relative values across the different TINAs is as important as the examination of absolute values within each TINA.*

*The TINA analytical framework was developed and implemented by the Carbon Trust with contributions from all core LCICG members as well as input from numerous other expert individuals and organisations. Expert input, technical analysis, and modelling support for this TINA were provided by AEA Technologies.*

# Key findings

**Emissions abatement opportunities in UK industries offer tremendous potential to generate energy, save carbon and reduce cost of operations. The abatement potential in the key emitting industries in the UK is in the range of 270-500Mtonnes with cost savings of £17-32bn[1] to 2050. Innovation is critical to enable deployment and reduce cost as the technology commercialises. Public sector support for innovation is necessary to maintain UK industrial presence and competitiveness in the global market. Innovation will also boost the UK's share of global market demand and generate additional business value from these technologies. A number of potential public sector interventions have been identified based on value of emissions abatement, extent of market failure and opportunity to rely on others for innovation.**

| | |
|---|---|
| **Potential role in meeting UK's GHG emissions target and energy balance** | • Direct emissions from UK Industries were responsible for approximately one quarter of UK greenhouse gas emissions in 2008 and just under one-fifth of final energy consumed in the UK[2]. Total emissions from industry came to c.190Mtonnes with over 50% from the most emitting industries, the largest of which is the chemicals sector[3].<br>• There is an immediate need for innovation to ensure successful deployment of abatement technologies in the limited window of opportunity that exists at the time of refurbishment and new builds, which if missed, would lock non-green technologies in UK industries for the next operational phase.<br>• Review of abatement opportunities in the key emitting industries suggests an abatement potential of 270-500Mtonnes of $CO_2$ by 2050. This depends primarily on the rate at which these are deployed across UK industries and the overall demand for industrial output.<br>• With innovation the total emissions till 2050 can be reduced by an additional 13-24% compared to 'Business-As-Usual' (BAU) scenario. This will result in industrial emissions being 38-68% lower than BAU in the year 2050. |
| **Value of abatement potential** | • A comprehensive review of UK industries was carried out, based on abatement potential, importance to the UK economy and need for public sector intervention, to identify the key sectors for in depth analysis – Chemicals, Food & Drink, Iron & Steel and Cement.<br>• Based on industry interviews and research, a set of abatement technologies have been identified in the above mentioned sectors ranging from efficiency improvements, alternate process technologies, low carbon substitutes, recovery & recycling and additional technologies like CCS. Only technologies that are innovative and with a potential to decarbonise the industry in the most effective way are considered.<br>• Successful innovation in these technologies has tremendous potential to save energy cost (£4-10bn), especially as prices of conventional fuels rise. Together with savings in carbon abated (£13-22bn)[4], this could save the UK a total of £17-32bn by 2050.<br>• Learning by doing will further reduce implementation cost as the technology becomes mainstream. Based on the number of plants being operational till 2030 (2040 for cement, iron and steel, CCS), a 10-30% reduction in cost is estimated.<br>• Based on the net savings, chemical bio-processing, use of biomass for alternate heat generation in food & drink sector, smelt reduction and CCS in steel plants and the use of clinker substitutes along with low carbon cement offer maximum benefit to the UK. |

[1] Including savings in carbon abated of £13-22bn

[2] AEA (2010). Analysing the Opportunities for Abatement in Major Emitting Industrial Sectors , Final Report for CCC, Available from: http://www.theccc.org.uk/reports/fourth-carbon-budget/supporting-research/aea-report-a-peer-review

[3] Source: Digest Of UK Energy Statistics (DUKES)

[4] Savings in carbon abated are not included in other TINAs including the buildings energy efficiency TINAs. They are included here because energy-intensive industries are in the EU ETS and so the industry will directly benefit from emissions reductions

| | |
|---|---|
| **Green growth opportunity** | • Total industrial GVA reached £158bn in 2007[5], with food & drink and chemicals constituting the largest share of c.15% and c.12% respectively. Innovation is thus critical in order to avoid the risk of UK industries becoming uncompetitive, which in turn would move production overseas.<br>• Depending on the relative competitive advantage of different industries, the UK's share of the global market for innovation technologies is expected to range from 2 to 4% (higher in case of low carbon cement).<br>• If the UK successfully competes in the global market to achieve the expected market share, then innovation in industrial energy efficiency could contribute an additional £3.9bn (£1.5-6.5bn)[6] to the UK GDP up to 2050 (with displacement effect[7]). |
| **The case for UK public sector intervention** | • To capture the value from these technologies there is a strong case for targeted public sector intervention, especially where there is evident market failure.<br>• Review of market has identified significant barriers to innovation and the UK cannot exclusively rely on other countries to develop the technologies within the required timeframe.<br>– There are on-going market failures both on the supply and demand side, including lack of demand as $CO_2$ price is considered to be too low (negative externalities), lack of information regarding true $CO_2$ content of industrial output (asymmetric information), insufficient payback on early stage R&D and insufficient coordination and sharing of data (positive externalities/IP spillover). Other potentially short-term market failures include conservatism in the industry, constraint on capital availability and a protracted planning approval process for new industrial facilities.<br>– The high cost of abatement technologies further pose a barrier to greater diffusion in the industry. Thus public sector intervention is needed both for technology development and for early adoption by the industry in order to make the technology commercially viable.<br>– In most cases significant international activity exists and the UK could partly rely on innovation from elsewhere, except where there is local need identified or in areas where the UK has a history of innovation and strong R&D base (marked as unlikely or in part in Table 1).<br>– In case of the chemicals industry, while the UK can rely on others for innovation in alternate process technologies (membrane separation), there is a strong need to maintain competitive advantage in such a high value industry and build on existing skill base. Additionally, improved separation technologies are applicable across a wide range of industrial processes including food & drink and refineries. |
| **Potential priorities to deliver the greatest benefit to the UK** | • Innovation areas with the biggest benefit to the UK are:<br>• Chemicals – Bio-processing and alternative process technologies (membrane separation)<br>• Food & Drink – Alternative heat generation (biomass)<br>• Iron & Steel – Alternate process technology (Smelt reduction) and Top Gas Recycling (TGR) with Combined Capture and Storage (TGR with CCS)<br>• Cement – Low carbon cement and CCS<br>• While existing and planned UK activities cover a portion of these innovation needs, targeted public sector investment is needed to close this funding gap and leverage private investment. R&D support to foster research in novel technologies and support for early demonstration plants and industry adoption will be needed to commercialise the technology.<br>• Given cross-sector applicability of some technologies, learning from doing in one sector will benefit other sectors as well. Technologies such as CCS, alternative heat production and improved separation are applicable to a wide range of industrial applications apart from the ones prioritised for this study. Hence successful innovation in these areas has the potential to generate more savings, reduce cost of application and capture a larger share of global market.<br>• Supporting all the prioritised innovations would require a significant increase in public sector funding to UK industries in future funding periods. Resources will therefore need to be targeted on particular areas which will provide long term value to UK, as prioritised in Table 1. |

[5] Source: ONS Data: http://www.statistics.gov.uk/abi/2007-archive/section_d.asp

[6] Does not include carbon savings from innovation because most regions do not have carbon markets. Including carbon savings would increase economic benefit to the UK to £4-14.6bn.

[7] A displacement factor of 50% is applied to account for the loss of value in other sectors due to shift of resources away from them

***Table 1 Industrial sector TINA summary of shortlisted technologies***

| Sectors | Technology | Value in meeting emissions targets at low cost £bn[8] | UK competitive advantage | Extent of market failure | Opportunity to rely on others | Potential public sector activity/investment |
|---|---|---|---|---|---|---|
| **Chemical** | Alternative process technology (improved separation) | 3.0 (1.8 – 4.2) | ◔ | ◑ | Yes[9] | • Support for early adoption and demonstration of membrane technology as a replacement for distillation (olefin/alkane separation) or in combination with existing separation technologies (distillation/membrane hybrid techniques)<br>• Support for testing of new membrane materials being developed to provide high thermal stability and strength. |
| | Bio-processing | 1.9 (0.7 – 3.2) | ◑ | ◕ | Unlikely | • Support to demonstrate bio-processing technology at plant scale.<br>• Target research funding into new bio-catalysts. |
| **Food & Drink** | Alternative heat generation (biomass) | 4.3 (3.8 – 4.8) | ◑ | ◑ | In part | • Support for demonstration of large scale commercial plants.<br>• R&D support for development of cost effective equipment (e.g. low cost engines). |
| **Iron & Steel** | Smelt reduction | 2.6 (1.5 – 4.0) | ◔ | ◑ | Yes[10] | • Support UK companies to maximise the benefits from ULCOS and specifically the HIsarana project. Target funding to promote follow-on smelt reduction plant in the UK. |
| | Top gas recycling and CCS | 5.2 (4.1 – 7.0) | ◔ | ◑ | In part | • Support to UK companies to maximize the benefits from ULCOS and to encourage location of follow on demonstration plants in the UK. Target funding to adopt CCS with refurbishment schedule of existing BF fleet.<br>• Support industrial CCS programme to maximise collaboration and cross learning from demonstration of CCS in power sector and develop specific storage and transport technologies. |
| **Cement** | Low Carbon Cement | 2.4 (1.8 -2.7) | ◕ | ◕ | Unlikely | • R&D support for development and testing of low carbon cement technology (currently only 4 global players with patented technology, with 1 in the UK).<br>• Support for demonstrations of low carbon cement on low risk infrastructure projects (pavements, platforms etc). |
| | Carbon Capture and Storage | 0.9 (0.7 -1.0) | ◔ | ◑ | In part | • Support to facilitate early testing of CCS in cement plants.<br>• Support industrial CCS programme to maximise collaboration and cross learning from demonstration of CCS in power sector and develop specific storage and transport technologies. |
| **Total[11]** | **Value:** | **£20.3bn (14.4 – 26.9)** | | | | **5-15 year investment for R&D, early testing and demonstration of technology** |

| Benefit of UK public sector activity/investment[12] | |
|---|---|
| | High |
| | Medium |
| | Low |

Key: Low ○ ◔ ◑ ◕ ● High

Source: Carbon Trust and AEA analysis, expert interviews, industry research, IEA energy technology transition for industry, IEA 2009.

[8] 2010-2050 Low-Medium-High deployment with marginal cost of technology included to calculate value; includes value of abating carbon emissions

[9] While UK can rely on others for innovation, there is a strong need to maintain competitive advantage in such a high value industry and build on existing skill base. Additionally, improved separation technologies are applicable across a wide range of industrial processes including food & drink and refineries.

[10] Technology is being tested under ULCOS programme in TATA's plant in Netherlands. UK should seek to maximise the benefits from its participation in the programme

[11] Total of shortlisted technologies (so less than full value in meeting emissions targets at low cost of £17-32bn)

[12] Also taking into account extent of market failure, UK competitive advantage and opportunity to rely on other countries

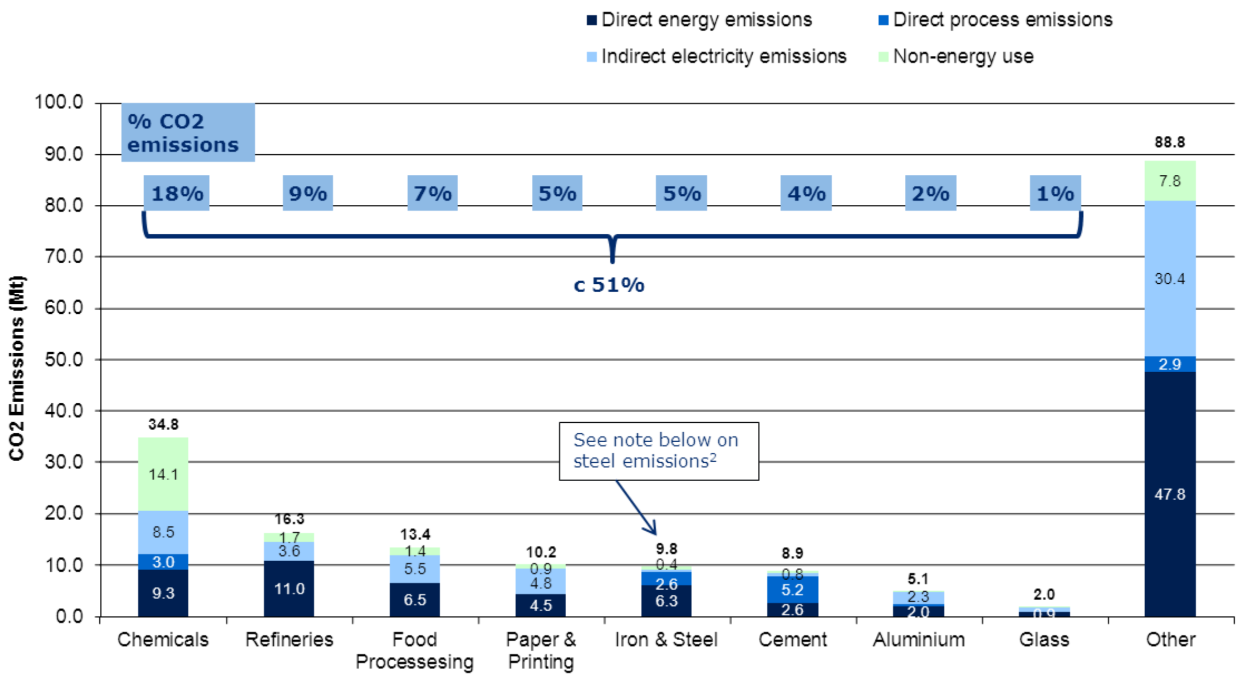
## Industrial sector has an important role to play in meeting UK's GHG emissions target

UK industries are responsible for a large portion of national emissions due to high fuel use and process emissions associated with its operations. Direct emissions from UK Industry were responsible for approximately one quarter of UK greenhouse gas emissions in 2008 and just under one-fifth of final energy consumed in the UK. Total emissions from industry came to c.190Mtonnes with over 50% from the most emitting industries, the largest of which is the chemicals sector (Fig 1). Hence there is a critical need to reduce emissions from the sector by retrofitting existing plants and promote greater adoption of abatement technologies in new builds. Additionally there is ongoing need for innovation in order to ensure deployment of abatement technologies in the limited window of opportunity that exists at the time of refurbishment and new builds. This would avoid locking in non-green technologies in UK industries for the current and future operational phases.

With successful innovation, the abatement potential in key emitting industries will be in the range of 270-500Mtonnes by 2050. Based on our analysis, the total cumulative emissions till 2050 could be reduced by 13-24% compared to 'Business-As-Usual' (BAU) scenario. This will result in industrial emissions being 38-68% lower than BAU in the year 2050.

However the abatement potential will depend on the level of demand for industrial output going forward and other external factors affecting the rate at which the technologies are being deployed such as cost of investment, availability of proven technologies, public acceptance and the availability of green field sites for new plant construction. To account for this, we have considered three indicative deployment levels of efficient technologies (low-medium-high) based on the year at which the technology becomes available and the extent of penetration in 2050. Depending on the industry structure, either a linear or a stepwise uptake rate is applied for the period 2010 - 2050. Stepwise uptake is used in line with the refurbishment schedule of existing plants and expected new build rate in the UK (detailed information on uptake rates of different technologies can be found in the TINA analysis pack). The medium penetration scenario was used for the following analyses.

***Fig 1: UK Industry direct and indirect $CO_2$ emissions***




Note: [1] Consists of direct process emissions, combustion and electricity emissions, and non-energy use of fuels.
[2] The DUKES analysis used for the data above uses a narrow definition of steel related emissions which does not include the emissions related to sintering and coking. In the analysis in this report we have used a broader definition and hence emissions are greater than those shown here for steel.
Source: Digest Of UK Energy Statistics (DUKES), Office of National Statistics' Purchases Inquiry (PI)

## Value of abatement potential

### Industry Selection

As there are a number of industries present in the UK with a range of outputs, we carried out a comparative review of the key emitting sectors to identify the ones which offer the greatest benefit of innovation to UK. Based on importance of carbon abatement, business creation potential and the need for UK public sector support we have selected Chemicals, Food & Drink, Iron & Steel and Cement for detailed analysis. Table 2 summarises the rationale behind the selection process. While refineries along with oil & gas exploration activities have substantial emissions, UK can potentially benefit from innovation carried out by international players. Given the cross sector applicability of some technologies, it is recommended to consider wider industrial application when initiating a technology application route map in order to realise its full potential.

***Table 2: Rationale for inclusion (Y) or exclusion (N) in this analysis***

| Sector | Y/N | Rationale |
|---|---|---|
| **Chemicals** | Yes | Largest sector in terms of emissions, 18% of total. Growing industry worldwide, significant UK presence and record of innovation. Provides inputs to a number of other sectors and has synergies with food and drink. |
| **Refineries** | No | Despite substantial emissions and subsequent abatement opportunities, longer term uncertainty persists around industry prospects in the UK. Additionally innovation is driven by international players and more than likely the UK will be able to benefit from developments from other territories. |
| **Food & Drink** | Yes | Third largest emitting industry with significant abatement potential estimated. Industry contribution to economy substantial and widely expected to persist into the longer term. Growth of the food industry worldwide is expected to fuel demand for abatement technologies and the UK is well positioned to capture thanks to a history of innovation. |
| **Paper** | No | Paper and pulping industry has a limited base in the UK having declined significantly over recent years. Although there are some abatement opportunities, applicability in the UK is questioned given uncertainty over long term industry presence. |
| **Iron & Steel** | Yes | Iron and Steel innovation in Europe is co-ordinated through Ultra-Low Carbon dioxide Steelmaking (ULCOS). Innovation and improvement linked to plant refurbishment schedules and allocation of demonstrations within ULCOS programme. UK should aim to maximise its return from its involvement in this programme. |
| **Cement** | Yes | A range of abatement opportunities are available. UK has a history and track record of innovation in the area and the cement industry is likely to be retained in the UK in the longer term. |
| **Aluminium** | No | Only a single primary aluminium plant remains in the UK. Innovation in new plants likely to take place in industrialising countries on greenfield sites. Industry may not be retained in the UK in the medium to long term. |
| **Glass** | No | Limited abatement potential identified, with key innovation areas concentrating only in incremental measures. Limited innovation base identified in the UK. |

Source: AEA, expert interviews, Carbon Trust analysis

## Abatement technologies

Based on industry interviews and research, a set of abatement technologies have been identified in the above mentioned sectors. The TINA focuses on technologies that are innovative and that have potential to decarbonise the industry in the most the effective way. There are other energy efficiency technologies (motors, pumps, boilers etc.) that could significantly reduce UK carbon emissions without the need for significant innovation. Other reports cover how the potential of these technologies might be realised[13].

The technologies are categorised as efficiency improvements, alternate process technologies, low carbon substitutes, additional technology and recovery and recycling. (Industrial reuse of heat is considered separately under the Heat TINA.) Table 3 lists the abatement technologies identified under each category. (Detailed description of all the technologies can be found in the TINA analysis pack.)

**Efficiency Improvements**: Technologies categorised as efficiency improvements include incremental improvement in products or process design to lower its energy use. In chemicals, the use of Oxygen Depolarized Cathodes (ODC) is investigated in the Chlor-Alkali process as it has the potential to lower energy use by c.30% for membrane cells. Similarly, improved process controls and neural network based technologies are analysed as an incremental improvement option for existing Blast Furnace (BF) and Electric Arc Furnaces (EAF) in the iron and steel industry. In the case of the food and drink industry, exemplars from different sectors have been used to illustrate efficiency improvements associated with modified food products and processes like non-homogenised milk, low process animal feeds, reduced thermal mass of baking tins. The savings from these exemplars are used as a proxy to represent the abatement potential for the sector.

**Alternate process technologies:** Includes abatement opportunities that offer an alternative way of carrying out an existing process more efficiently, for example the use of membrane technology to allow for improved separation at lower temperatures. For the food and drink sector, alternatives to existing heating, cooling and cleaning process technologies are investigated such as UV pasteurisation of milk, use of efficient gas engines for refrigeration and use of ice slurry for cleaning pipes (ice pigging). A number of alternative processes are investigated for iron and steel including smelt reduction, electrolysis and use of continuous strip production and charging in EAF. Smelt reduction has the potential to significantly lower coal use in BF and is also considered a flexible process that allows partial substitution of coal with biomass or natural gas. Further, there is potential to lower emissions across the whole process by producing iron using electrolysis. In the case of cement, fluidised bed kilns have been proposed as they efficiently combust low-grade coal and increase the heat recovery efficiency between the components.

**Low carbon substitutes**: The third category comprises of technologies to develop new low carbon products or new sources of fuel (biomass). The use of bio based feedstocks (monomers/polymers derived from crops, micro-organisms and fermentation products) and enzyme (bio-catalysts) to produce chemical products is investigated in the chemicals industry (bio-processing). For the food and drink sector the use of biomass to replace conventional heating fuels is considered (alternative heat generation)[14]. In the cement industry, there is substantial scope to reduce emissions by replacing clinker with alternatives (furnace slag, fly ash, volcanic rock, limestone etc) and use of low carbon cement produced from magnesium silicates, dolomite or geopolymers (sourced from blast furnace slag and pulverised fly ash).

**Additional technology**: Includes the use of carbon capture and storage in chemicals (ammonia and ethylene plants only due to high concentration of $CO_2$ in flue gas), steel and cement plants via chemical absorption or membranes. Further the use of pure oxygen for combustion rather than ambient air will produce higher concentration of $CO_2$ which will be easier to capture.

**Recovery and Recycling**: Lastly, the potential for advanced recovery and recycling is investigated in the chemicals sector to reduce demand for virgin polymers. The resulting chemical intermediates from plastic recycling are suitable for use as feedstock for new petrochemicals and plastics. Similarly, there is significant potential to save energy by re-using structural steel components and recycling steel scrap in EAF.

[13] A recent example commissioned by DECC is "Capturing the full electricity efficiency potential of the UK", 2012

[14] The use of biomass for alternative heat generation is applicable to many industrial processes. However considering biomass as limited resource, its application will be prioritised for sectors offering high mitigation potential and cost efficiency. Hence its unlikely that large-scale substitution of fossil fuel with biomass will occur in cement and iron & steel industry

***Table 3: Abatement technologies identified in each category***

| | Chemicals | Food & drink | Iron & Steel | Cement |
|---|---|---|---|---|
| **Efficiency improvements** | Chlor Alkali | New process design<br>New product design | Blast Furnace (BF) and Electric Arc Furnace (EAF) Incremental improvements | |
| **Alternative process technologies** | Improved separation technologies (e.g. Distillation and membranes)<br>Improved reaction technologies (e.g. catalysts) | Process Technologies:<br>- Cooling<br>- Heating<br>- Cleaning | Improved BF- Smelt reduction<br>Improved EAF<br>- Continuous charging<br>- Endless strip<br>Electrochemical steel production | Improved reaction technologies : e.g. fluidised bed kilns |
| **Low carbon substitutes** | Bio-processing<br>(Bio-based feed stocks and bio catalysts) | Alternative Heat generation<br>(Biomass) | | Clinker substitution<br>Low carbon cements |
| **Additional Technology** | Carbon Capture & Storage (CCS) | | Top Gas Recycling + CCS | CCS |
| **Recovery & recycling** | Advanced recovery and recycling | | Recycling and Re-use | |

Source: AEA, expert interviews, Carbon Trust analysis

Note: The list of abatement opportunities is not exhaustive and has been identified by considering the theoretical abatement potential, technology readiness level and applicability of the technology to UK industries.

## Current costs

The capital cost is estimated separately for retrofit and new build based on a standard plant capacity. These capital costs are annualised over the plant lifetime (15-30 years) using a discount rate of 3.5% and divided by throughput to give the capital cost per year per unit (tonnes) of output. The cost is then compared to current plant costs to estimate the marginal capital costs of innovation. The effect of increased deployment is captured by a reduction in current cost of innovation when the technology becomes commercial, with a few technologies achieving parity by 2050. Based on the number of plants being operational till 2030 (2040 for cement, iron and steel, CCS), a 10-30% reduction in cost is estimated. Marginal cost figures for each technology is reported in the TINA analysis pack as informed by AEA, OECD/IEA estimates, literature review and industry discussions. Technologies such as chemical bio-processing and alternative heat generation have negative or declining marginal costs due to additional income associated with the use of municipal solid waste (gate fee) and rising cost of conventional fuels.

## Net Savings

Based on cost of innovation, abatement potential and abatement penetration we have calculated the potential savings in energy system costs through innovation (Table 4). There is additional savings associated with value of carbon abated. Results of the analysis show a tremendous potential to save energy cost through successful innovation as the price of conventional fuels rise (£4-10bn). Together with savings in carbon abated (£13-22bn)[15], this could save the UK a total of £17-32bn by 2050. The net savings potential in each technology area is summarised below:

**Efficiency Improvements:** Both the savings and cost of technologies identified in this category are low across the sectors (except for use of ODC in chlor-alkali process). The savings are low primarily due to the limited potential of advanced control systems in the iron & steel sector and new product/new process design in the food & drink sector over and above BAU. In the case of the chemicals sector, while there is moderate savings potential, chlor-alkali is a small part of the overall chemicals output. The incremental cost of these technologies is also marginal compared to current processes (except for ODC).

**Alternative process technologies:** The cost of technologies identified in this category is marginal compared to current processes but the savings vary across the sector[16]. Both the chemicals and iron & steel sector have substantial savings potential via the use of membrane separation technologies and smelt reduction process respectively. There is limited savings achievable from alternative heating, cooling and cleaning process technologies in the food & drink sector and the use of fluidised bed kilns in the cement sector over and above BAU. In the case of the food and drink sector, it must be noted that where the examples involve a fuel switch from fossil fuel to electricity (alternative heating and cleaning process technologies), which is desirable given the assumed decarbonisation of grid electricity over the study period and the energy savings potential, the economic results are not generally beneficial. This is because the DECC energy price assumption has an electricity price that is 4 times higher than the gas price in equivalent kWh delivered terms.

**Low carbon substitute:** The savings potential of the identified technologies in this category is high across the sectors but the costs vary depending on the technology. The use of biomass for heat generation offers substantial energy and carbon savings in the food and drink sector, especially as heating fuel dominates the manufacturing process. In the case of the cement sector, clinker substitute and low carbon cement can be applied with any traditional cement manufacturing process to reduce the carbon content of the product. Similarly, chemicals bio-processing can be used to produce a range of chemical products. On the cost side, while additional capital investment for bio-processing plant is high there is operational savings associated with the use of Municipal Solid Waste (gate fee) which is estimated to be in the range of £25-£125/tonne of MSW. In the case of the food and drink sector, the initial capital cost of equipment is considered moderate however the operating cost of a biomass plant is expected to reduce over time as the price of conventional fuels rise. While there is no additional cost of using clinker substitutes, low carbon cement is more expensive to implement and is assumed to reach parity only by 2050.

**Additional technology:** Both the savings and costs of CCS is high across the sectors. While there is substantial potential to save carbon using CCS, there is an energy penalty associated with the technology[17]. The savings potential in the case of the iron and steel sector is particularly high due to efficient capture enabled by top

[15] Savings in carbon abated are not included in other TINAs including the buildings energy efficiency TINAs. They are included here because energy-intensive industries are in the EU ETS and so the industry will directly benefit from emissions reductions

[16] The incremental cost is moderate in the case of smelt reduction and UV pasteurisation of milk. Fluidised bed kilns are forecast to be 30% cheaper than standard state of the art dry process plant once commercialised

[17] The savings reported for CCS in table 4 is net of carbon savings minus the increase in energy cost.

gas recycling in the blast furnace. In the chemicals sector, the use of CCS technology is limited to ammonia and ethylene plants due to high concentration of $CO_2$ in the flue gas. In the case of cement sector, the technology penetration is limited by the refurbishment schedule of the dry state of the art plant (not economic to retrofit). On the cost side, the technology is considered additional and hence is not assumed to reach parity till 2050. The costs vary depending on the concentration of $CO_2$ gas in the flue stream and are overall in line with the power sector.

**Recovery and recycling:** While there is moderate energy and carbon savings potential in the chemicals sector using advanced recovery processes to produce new petrochemicals and plastics, the technology is much more costly compared to the current dominant process i.e. mechanical recovery and recycling.

Based on the net savings, chemical bio-processing, use of biomass for alternate heat generation in the food & drink sector, smelt reduction and CCS in steel plants and the use of clinker substitutes along with low carbon cement offer maximum benefit to the UK.

## Cross sector applicability

In the case of some technologies, the scope of abatement will be higher due to its applicability across different industries. Technologies such as CCS, alternative heat generation and improved separation are applicable to a wide range of industrial applications apart from the ones prioritised for this study. For example biomass can be used to replace industrial heat processes across most sectors. Hence successful innovation in the technology has the potential to generate even more savings, reduce cost of application and capture a larger share of global market. Similarly process emissions can be abated using CCS in chemicals, iron & steel and cement plants and innovation in new membrane technologies can be applied to the chemicals, food & drink sectors and refineries. The cross learning potential of these technologies across different industries needs to be investigated further in order to better inform the prioritisation of potential public sector activities/investments.

***Table 4: Net savings potential of abatement technologies (£17.3bn of carbon abated and £6.6bn of energy saved)***

| | Chemicals | Food & Drink | Iron & Steel | Cement |
|---|---|---|---|---|
| **Efficiency improvements** | £0.09bn (Chlor-Alkali) | £ 0.22bn (New product and process design) | £0.3bn (BF and EAF incremental improvements) | - |
| **Alternative process technology** | £3.0bn (Improved membrane separation) | £ 0.06bn (Alternative to heating, cooling and cleaning process technologies) | £2.6bn (Smelt reduction) | £0.18bn (Fluidised bed kilns) |
| **Low carbon substitute** | £1.9bn (Bio-processing) | £4.3bn (Alternate heat generation - biomass) | - | £2.4bn (low carbon cement)<br>£3.1bn (clinker substitute) |
| **Additional Technology** | £1.5bn | - | £5.2bn | £0.9bn |
| **Recovery and recycling** | £1.2bn | - | - | |

**Value of abatement potential**[18]
High
Medium
Low

Source: AEA, Carbon Trust analysis

[18] Cumulative net benefit till 2050. Source: Carbon Trust and AEA analysis

## Green growth opportunity

### A large domestic market

Although declining in recent years, the industrial output still constitutes an important share of the UK's economy. As shown in fig. 2, total industrial GVA reached £158bn in 2007, with the food & drink and chemicals sector contributing the largest share of c.15% and c.12% respectively. The chemicals industry in particular is the UK's manufacturing sectors' major international trader. With exports of £33.1 billion and imports of £28.7 billion, it earns a trade surplus of £4.4 billion (source: Chemical Industries Association, 2006). Additionally, industrial presence is critical in maintaining the level of current employment, with over 200,000 jobs in the chemical sector and more than 375,000 jobs in the food and drink sector. The UK food & drink industry is also the fourth largest in Europe and is responsible for c.6% of global production with turnover increasing over the years. While both iron & steel and cement sector's output is small compared to the global production, there is a critical need to maintain local presence in order to meet demand domestically as transport costs are relatively large. Without innovation there is a risk of production moving overseas due to high production costs in the UK.

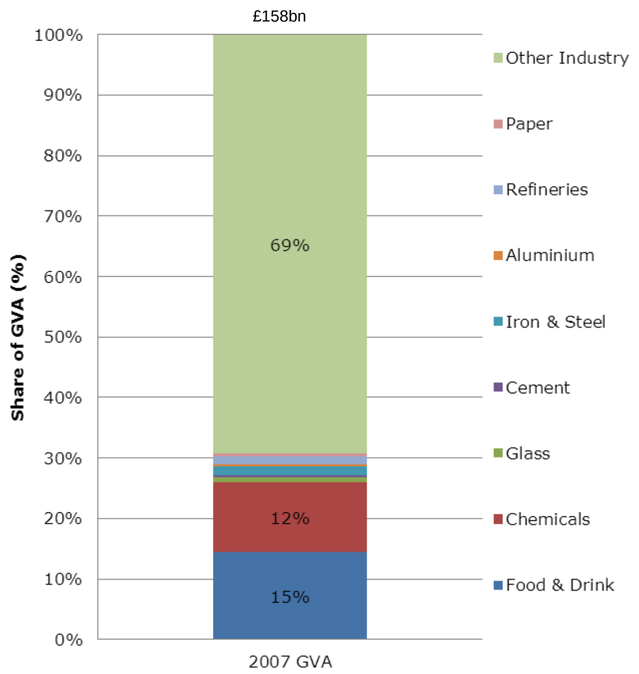
### A large global market

Demand for industrial output is projected to grow, especially in rapidly industrialising countries as the economy matures. While the demand in OECD countries will be relatively stable, growth in BRIC countries will dominate and drive innovation in industrial energy efficiency. Based on IEA's scenarios for low-medium-high consumption:

- The chemicals market is expected to grow at 2.28% p.a. to nearly 2.5bn tonnes by 2050.
- The food & Drinks market is expected to grow at 2.5% p.a. to nearly 4bn tonnes by 2050.
- The iron & Steel market is expected to grow at 1.66% p.a. to nearly 2.6bn tonnes by 2050.
- The cement market is expected to grow at 1.0% p.a. to nearly 4bn tonnes by 2050.

Using these projections and net savings from innovation, the increase in the global market size of abatement technologies is calculated by factoring in the current plant capacities and the modelled increase in plant capacities required to meet the world market demand till 2050. A 25% factor is applied to the net savings to calculate the market value of the abatement technology. The uptake rate of technology will mostly be greater outside of the OECD as focus will be on new build plants to meet increasing demands rather than refurbishment of existing plants in the UK. Based on low-medium-high scenario, the global market turnover of these technologies could grow to £260-1140bn by 2050.

*Fig 2: UK Industrial GVA by sector, 2007*[19]




### UK competitive advantage

An overall market overview suggests that the advantage on the demand side is low as growth is weaker than the rest of the world and innovation will occur in newly industrialising countries where new plant construction will occur. However, demand for speciality products like green chemicals, specialised food products and green construction materials is comparatively high, driven by favourable regulation and the need for the demand to be met domestically (especially in the case of cement). On the supply side, the UK has an advantage in some areas such as high value chemicals, innovative food products and cement due to its strong research base and regulatory framework. In the iron & steel industry, the UK's involvement in the ULCOS research programme offers some advantage for follow on pilot plants. CCS technology also offers some advantage due to UK construction and design expertise in the power sector and existence of storage sites (but the cross over benefit to industrial sector is considered limited). In the cement industry a strong history of innovation, academic base and presence of hosting company suggests high competitive advantage. However, lack of space for new plants suggest innovation will mainly be limited to incremental plant improvements and refurbishment on existing plants.

[19] Source: ONS Data: http://www.statistics.gov.uk/abi/2007-archive/section_d.asp

Depending on the relative competitive advantage in identified industries, the UK's share of the global market for innovation technologies is expected to range from 2 to 4% (higher in the case of low carbon cement).

## Contribution to the UK economy

The global market size of abatement technologies will not be fully tradable i.e. only IP/licensing and engineering design services are considered fully tradable whereas manufacturing, installation and O&M will mostly be done locally (regional in some cases). Hence the additional value to the UK from innovation will be reduced depending on the tradable portion in each technology area. Also, it may be appropriate to apply an additional displacement effect since part of the value created in the export market will be due to a shift of resources and thus partly cancelled out by loss of value in other sectors. Expert opinion has roughly assessed this effect to be between 25% and 75%, so we have applied a flat 50%.

Including this displacement factor, innovation in industrial energy efficiency could contribute an additional £3.9bn (£1.5-6.5bn) by 2050[20] if the UK successfully competes in the global market. The largest technology potential is in bio-processing, which is estimated to be worth £3.7bn to the UK (Table 5).

***Table 5: The additional economic benefit to the UK of innovation opportunities***

| | Chemicals | Food & Drink | Iron & Steel | Cement |
|---|---|---|---|---|
| **Efficiency improvements** | £0.02bn | < £0.01bn | < £0.01bn | - |
| **Alternative process technology** | £0.02bn | < £0.01bn | £0.07bn (Smelt reduction) | < £0.01bn |
| | | | < £0.01bn (EAF continuous charging and endless strip) | |
| | | | < £0.01bn (Electrochemical process) | |
| **Low carbon substitute** | £3.7bn | < £0.01bn | - | < £0.01bn (low carbon cement) |
| **Additional Technology** | - | - | - | - |
| **Recovery and recycling** | £0.07bn | - | - | |

| **UK competitive advantage** | |
|---|---|
| | High – 20% |
| | Low -Medium – 4% |
| | Low – 2% |
| | No < 1% |

Notes: UK market share based on no (<1%); low-medium (2%) and high (20% at subsector level) UK competitive advantage. Displacement factor of 50% is included in calculating UK GVA from UK market share. Source: Carbon Trust and AEA analysis

[20] Does not include carbon savings because most regions do not have carbon markets. Including carbon savings would increase economic benefit to the UK to £4-14.6bn

## The case for UK public sector intervention

To capture the value from these technologies there is a strong case for targeted public sector intervention, especially where there is evident market failure. The following section investigates the need for intervention based on the extent of market failure and the opportunity to rely on someone else for innovation.

### Market failures impeding innovation

A review of the market has identified significant barriers to innovation and the UK cannot exclusively rely on other countries to develop the technologies within the required timescales.

On the demand side, the key barrier to uptake of these technologies is the low and unstable price for $CO_2$ creating demand uncertainties (negative externalities). Also, there is asymmetric information regarding the true $CO_2$ content of the output thereby reducing the incentive to adopt green products and processes. The uptake of technologies in the limited time frame that exists at the time of refurbishment further poses a challenge, which if missed would lead to non-green technologies getting locked in for the next operation phase.

On the supply side there is significant market failure associated with early mover disadvantage. The high cost opportunity of financing due to the high risk involved with research in new fields makes the level of R&D investment sub-optimal. This also leads to insufficient coordination and sharing of data (positive externalities/IP spillover). Other potentially short-term market failures include conservatism in the industry, constraint on capital availability, lack of stable policy regime and protracted planning approval process for new industrial facilities.

The high cost of abatement technologies further pose a barrier to greater diffusion in the industry. Thus public sector intervention is needed both for technology development and for early adoption by the industry in order to make the technology commercially viable.

The market failure specific to each technology is detailed in Table 6 below along with key requirements to overcome these barriers.

### The UK could rely on innovation happening elsewhere in certain industries but at the risk of industry becoming uncompetitive

In most cases significant international activity exists and the UK can partly rely on innovation from elsewhere, except where there is local need identified or in areas where the UK has a history of innovation and a strong R&D base.

**Chemicals:** In the case of the chemicals sector, countries like the USA and Germany have a strong industrial base in membrane processes and separation technologies respectively. Along with the UK, pilot chemical bio-processing plant is also being planned for USA. Additionally, countries like Germany and France have abundant sources of biomass from agriculture waste compared to the UK.

However considering the importance of the industry to the UK's economy, there is a strong need to maintain competitive advantage in such a high value industry and to build on its existing skill base. Additionally improved separation technologies and bio-processing are applicable across a wide range of other industrial processes.

**Food and Drink:** The opportunity to rely on other countries for green food products might be limited given food preferences are country and region specific and success will require good local knowledge. Alternative heating, cooling and cleaning process technologies however can be traded globally and work is going on in this category in the USA.

**Iron and steel**: In this sector, the technologies are currently being tested at EU level under the ULCOS programme and the UK could benefit from its involvement, especially as TATA (Corus) is one of the core members.

**Cement:** In this case however, presence of companies like NOVACEM will drive innovation in low carbon cement as significant UK competitive advantage exists.

**CCS:** The technology will be mainly driven by the power sector. Apart from the UK, Norway, Germany and Netherlands also have access to massive storage reservoirs in the North Sea and might take advantage and develop CCS. However, there is a specific need to develop storage and transport technologies for the given application.

Table 6 further elaborates on the level of international activity in each technology area and if there is a potential for the UK to rely on innovation from elsewhere.

***Table 6: Summary of market failure and level of international activity in identified technology areas***

| Sub-area | Sectors | Extent of market failure | What is required? | Opportunity to rely on others |
|---|---|---|---|---|
| **Energy Efficiency** | **Chemicals** | • Early mover's disadvantage.<br>• High operating costs due to shorter refurbishment cycles.<br>• Lack of target regulation to foster innovation (similar to phase out of mercury cells in EU). | • Increased support to developing cathode materials and novel electrolysis cell designs.<br>• Coordinated policies at international or EU level to foster innovation in chemical processes. Need to disseminate information on $CO_2$ content of chemical processes. | In part. However, there is a need in UK to maximise efficiency of integrated plants to compete with new larger non OECD plants. |
| | **Food & Drink** | • Need for information on energy content of food products and lower energy alternatives with similar taste. Need for strong marketing.<br>• There is a lack of skills required for energy management and data monitoring (e.g. in animal feed manufacture). | • Increased support to development of low energy alternatives, independent testing and monitoring of new processes to verify their reliability.<br>• To get customers familiarised with new products and overcome their initial reluctance to use them. | Unlikely. Given food preferences are country and region specific and success will require good local knowledge. USA is carrying out research in innovative food processes. |
| | **Iron & Steel** | • Reluctance of plant operators to take on unknown equipment that may affect quality. | • Increase awareness of the technology and its application. | Yes. Equipment is being developed in USA and Japan. |
| **Alternative process technologies** | **Chemicals** | • Uncertainty around performance due to lack of long term testing under industrial conditions.<br>• The high cost of operation due to frequent of maintenance of membranes. | • Increased support to development and testing of new catalyst and membrane materials.<br>• Support for demonstration early adoption in order to make the technology commercially viable. | Yes. While USA is carrying out R&D in membrane technologies, there is a strong need to maintain UK competitive advantage in such a high value industry. |
| | **Food & Drink** | • Early mover's disadvantage makes it too risky to invest in R&D. High electricity prices will further hinder the electrification of process. | • Increased support to R&D investment.<br>• Incentives to move to lower carbon technologies (high carbon price, direct financial support). | Yes. Work is going on in this category in the USA and elsewhere. |
| | **Iron & Steel** | • Smelt reduction – Early mover disadvantage and credit rationing.<br>• Electrochemical process – Lack of demonstration at plant scale and high price of renewable electricity makes the process uneconomic.<br>• EAF improvements – Unlikely to be taken up in the UK as furnaces are unsuitable. The technology also not suitable for higher specification steel. | • Smelt reduction - Increased financial support to R&D and to pilot plant construction.<br>• Electrochemical process - Cost efficiency, long-term supply contract for electricity, reliable (indigenous) iron ore resource, electrochemical expertise, reliable electrolysis plant design and construction.<br>• EAF improvements - Reintroduction of shaft furnaces (not currently used in the UK) and need to produce high volume of one formulation of steel. | Yes. Smelt reduction is currently being tested in TATA's plant in Netherland under the ULCOS programme. Electrochemical process is currently being tested under ULCOS and in USA (MIT). |

| | | | | |
|---|---|---|---|---|
| | **Cement** | • Lack of information on technology and its commercial viability. | • Additional investment to scale-up plant size and achieve economic viability. | Yes. Japan is leading the technology with application in China. |
| **Low carbon substitutes** | **Chemicals** | • Lack of financial support for pilot and commercial scale plant construction, and uncertainty around the long-term availability of biomass feedstock. | • Increased financial support for pilot plant construction.<br>• Availability of biomass feedstock at an acceptable price (in comparison to petroleum based feedstock).<br>• Long term policy support (gate fee). | Unlikely. UK based INEOS is developing advanced bioprocessing plants both in UK and USA. |
| | **Food & Drink** | • Uncertainty around long term availability of biomass.<br>• Limited availability of suitable equipment. | • Increased support to R&D to reduce the upfront capital cost of CHP and biomass boilers.<br>• Increased reliability of biomass supplies. | In part. Scarcity of biomass supplies suggest that UK can partly rely on innovation from elsewhere although RHI will drive UK uptake. |
| | **Cement** | • Low carbon cement technology is not available at the current time. It requires further R&D, standards and regulations need to be adapted.<br>• Risk of product quality.<br>• For clinker substitutes there is a constraint around raw material supply. | • Assured long term availability at a suitable cost of materials to manufacture low carbon cements.<br>• Standards for low carbon cements and demonstration of long-term suitability and economic viability.<br>• For clinker substitutes - Assured long term availability of materials and information on the range of suitable applications. | Unlikely. Presence of companies like NOVACEM will drive innovation in low carbon cements.<br>Clinker substitution cements being widely applied in a number of countries. |
| **Additional technologies** | **CCS** | • High cost of installation and demonstration.<br>• Investments in CCS equipped plants potentially delayed by the lack of information on storage sites availability and transport routes. | • Financial support to develop pilot CCS projects.<br>• Demonstration of technology at plant scale for commercialisation.<br>• Providing legal framework for long-term liability over storage sites and mapping $CO_2$ pipelines routes and storage sites. | In part. Technology already under development in the power sector; Need to develop specific transport and storage applications. |
| **Recovery and recycling** | **Chemicals** | • High cost opportunity of financing as real cost of virgin polymers is not accounted for.<br>• Demand constraints: use of physically recycled plastics is restricted (e.g. non-food applications). | • Encourage plastics producers to implement closed-loop polymer-to-olefin recovery processes.<br>• Long term policy support: Increased rates of plastic waste recovery and enhanced sorting technologies. | Yes. Strong industrial base in separation technologies in Germany; waste to fuel technology developed in USA and elsewhere. |
| | **Iron & Steel** | • Recycling: Limited supply of suitable quality of recycled steel.<br>• Re-use: Limited secondary use of steel and its supplies. | • Supply of recycled steel of suitable quality, and new EAFs that can accept variable quality steel scrap.<br>• Standards, assurance schemes and regulations for re-use in construction and other industries. | Unlikely. Limited innovation elsewhere. New recycling strategy and delivery options will be required. |

Source: AEA, expert interviews, Carbon Trust analysis

| **Extent of market failure and opportunity to rely on others** | | |
|---|---|---|
| | Critical | Unlikely |
| | Significant | In part |
| | Limited | Yes |

## Potential priorities to deliver the greatest benefit to the UK

The UK needs to focus its resources on the areas of innovation with the biggest relative benefit to the UK and where there are not existing or planned initiatives (both in the UK and abroad). The LCICG has identified and prioritised these innovation areas.

### Innovation areas with the biggest relative benefit from UK public sector activity/investment

Supporting all the prioritised innovations would require a significant increase in public sector funding to UK industries in future funding periods. Resources will therefore need to be targeted on particular areas which will provide long term value to the UK. These are:

**Bio-processing and alternative process technologies (membrane separation) in the chemicals sector –** Both bio-processing and alternative process technologies (membrane separation) are applicable to a wide range of chemical products and processes and offer a high abatement potential (c300 $kgCO_2$/tonne of product using bio-based feedstock and c130$kgCO_2$/tonne of product using membrane separation technologies[21]). Based on our analysis the net savings potential from innovation in these technologies is in the range of £2.5–7.4bn till 2050. Of the two, bio-processing is polarised due to critical market failures associated with the high cost of the opportunity and uncertainty around availability of feedstock. Improved membrane separation technologies on the other hand require only incremental investment. There is also medium competitive advantage in bio-processing as the UK based company INEOS is developing pilot plants both in the UK and the USA. While the USA is carrying out R&D in membrane technologies, there is a strong need to innovate and maintain UK competitive advantage in such a high value industry.

**Alternative heat generation (biomass) in the food & drink sector –** There is a tremendous potential to abate carbon using biomass for industrial heat processes (c100$kgCO_2$/tonne of product based on replacing gas, greater if off gas grid[22]). Based on our analysis the net savings potential from innovation in the food & drink sector is in the range of £3.8–4.8bn till 2050. Additionally there is significant market failure due to uncertainty around long-term availability of biomass and the high cost of the equipment. Scarcity of biomass supplies suggests that the UK can partly rely on innovation from elsewhere although Renewable Heat Incentive (RHI) will drive the uptake domestically.

**Alternative process technology (Smelt reduction) and TGR with CCS in the iron & steel sector –** Both the technologies are being tested under the EU wide ULCOS programme and the UK should aim to maximise the benefit from its involvement by promoting follow on pilot plants in the UK. Based on our analysis the net savings potential from innovation in these technologies is in the range of £5.6–11bn till 2050. However the UK competitive advantage remains low in the technology area and hence the benefit of UK public sector activity is lower compared to the other three sectors.

**Low carbon cement and CCS in the cement sector -** There is tremendous potential in abating carbon via innovation in low carbon cement and implementation of CCS in cement plants (c560$kgCO_2$/tonne of cement using low carbon cement and c500$kgCO_2$/tonne of cement using CCS[23]). Based on our analysis the net savings potential from innovation in these technologies is in the range of £2.5–3.7bn till 2050. Of the two, the UK has high competitive advantage in low carbon cement due to presence of NOVACEM whereas CCS will be mainly be led by the power sector. However, there is need to develop specific storage and transport technologies suitable for the cement plants. Additionally, there is critical market failure in low carbon cement due to conservatism in the industry and the risk of product quality. Hence there is a need for public sector intervention to demonstrate long-term suitability and economic viability of the product.

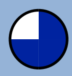
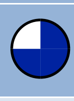
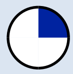
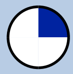
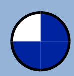
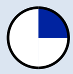
Lastly, there is opportunity for industry wide programmes such as CCS and alternative heat generation to maximise the benefit and capture a larger market via innovation.

[21] From US department of energy reports

[22] NERA/AEA work on Renewable Heat Incentive for DECC

[23] Savings are based upon savings of the Novacem system with respect to the SoA Dry process and AEA analysis of CCS in cement plants

***Table 7: Benefit of UK public sector activity/investment of shortlisted technologies***

| Sectors | Technologies | Value in meeting emissions targets at low cost £bn[24] | UK competitive advantage | Additional Value in business creation | Extent of market failure | Opportunity to rely on someone else | Benefit of UK public sector activity/investment |
|---|---|---|---|---|---|---|---|
| **Chemicals** | Alternate process technology (membrane separation) | 3.0 (1.8 – 4.2) | Low | £0.02bn | Significant | Yes[25] |  |
| | Bio-processing | 1.9 (0.7 – 3.2) | Medium | £3.7bn | Critical | Unlikely |  |
| **Food & Drink** | Alternate heat generation (biomass) | 4.3 (3.8 – 4.8) | Medium | <£0.01bn | Significant | In part |  |
| **Iron & Steel** | Smelt reduction | 2.6 (1.5 – 4.0) | Low | £0.07bn | Significant | Yes[26] |  |
| | Top gas recycling and CCS | 5.2 (4.1 – 7.0) | Low | - | Significant | In part |  |
| **Cement** | Low Carbon Cement | 2.4 (1.8 -2.7) | High | <£0.01bn | Critical | Unlikely |  |
| | Carbon Capture and Storage | 0.9 (0.7 -1.0) | Medium | - | Significant | In part |  |
| **Total** | **Value:** | **£20.3bn (14.4 – 26.9)** | **Low-Medium** | **£3.8bn** | **Significant-Critical** | **In part** | **High relative to other technologies** |

| Benefit of UK public sector activity/investment | |
|---|---|
| | High |
| | Medium |
| | Low |

[24] 2010-2050 Low-Medium-High deployment with marginal cost of technology included to calculate value

[25] While UK can rely on others for innovation, there is a strong need to maintain competitive advantage in such a high value industry and build on existing skill base. Additionally, improved separation technologies are applicable across a wide range of industrial processes including food & drink and refineries.

[26] Technology is being tested under ULCOS programme in TATA's plant in Netherlands. UK should seek to maximise the benefits from its participation in the programme

## Existing innovation support

Existing and planned UK activities cover a small portion of these critical needs. Summary of existing policies and programmes to stimulate demand and 'push' technology is presented in table 8. Target public sector investment is needed to close this funding gap and leverage private investment. Specifically, R&D support to foster research in novel technologies and support for early demonstration plants will be needed to commercialise the technology.

**Table 8: Summary of UK public sector activity**

| Market pull (stimulate demand) | Market push (support supply) | Enablers |
|---|---|---|
| • Climate Change Levy<br>• EU-ETS carbon price | • **Chemicals** - £8million grant from One North East into bio-refinery activities.<br>• **Chemicals** - Government sponsored Chemistry Innovation Knowledge Transfer Network (KTN).<br>• **Chemicals** – BIS funding of £12 million in a Wilton Centre-based project that will further develop industrial biotechnology and One North East has earmarked up to £1.5 million to support the project.<br>• **Chemicals** – Technology Strategy Board (TSB) is running a competition to fund the development and commercialization of innovative processes that will generate high value chemicals through industrial biotechnology. An indicative £2.5m is being invested to support feasibility projects, particularly those led by SMEs.<br>• **Food & Drink** - Two Carbon Trust Industrial Energy Efficiency Accelerator Programme projects supported (sugar confectionery manufacturing and industrial bread baking).<br>• **CCS -** £1billion for commercial scale CCS equipped power plants has been committed by the UK Government.<br>• **Cement -** The TSB provided £1.5million to NOVACEM for an R&D project to prove the technical and commercial viability of its low carbon cement.<br>• **Cement** - The Carbon Trust have provided support to NOVACEM in developing their business plan.<br>• Research and Development (R&D) relief is a corporation tax relief that reduces company's or organization's tax bill by more than the actual expenditure on allowable R&D costs, alternatively, small or medium-sized organisations may choose to receive tax credits.<br>• Collaborative R&D grants: uncertainty at present as funding switches between RDAs and TSB. Grants for R&D ranging from £20,000 to £ 500,000 available for smaller companies (25-75% support).<br>• Intellectual Property Right protection.<br>• Climate Change Agreements allow for reduction of the CCL in return for energy efficiency targets. | • BIS and DECC are the lead Government departments.<br>• In England - Regional Development Assistance funding. However RDAs to be closed by end of 2012 and replaced by local enterprise partnerships but some funding will flow through TSB.<br>• Knowledge Transfer Partnerships (KTPs) enable businesses to benefit from the expertise of organizations like further education colleges, universities or research institutes. |

## Potential priorities for public sector innovation support

In the sections above, we have identified the key innovation needs and the market barriers hindering these innovations. Based on the analysis there is need for improved financial support, capacity building, changes to the UK structural system and co-ordinated international action in order to drive innovation in the industrial sector. Specifically, at the technology level there is a need to demonstrate the technology potential via extending support for early testing and "top-up" support for pilot plants to commercialise the technology. Table 9 outlines the key innovation priorities and potential public sector intervention against each technology sub area along with an estimate of the scale of public sector funding required.

To realise the full benefit from innovation over the next 5-15 years will require on-going support to existing areas, scaling up a subset as they move from design to demonstration, as well as adding a prioritised set of new programmes. Supporting all the prioritised innovations would require a significant increase in public sector funding to UK projects in future funding periods, however the required investment is a fraction of the savings that industrial energy efficiency innovation could deliver to the UK economy.

***Table 9: Potential industrial innovation priorities and support***

| Sub-area | Sectors | Technologies | Key requirements | Current intervention | Potential public sector intervention | Indicative scale of public funding[27] |
|---|---|---|---|---|---|---|
| **Efficiency Improvements** | **Chemicals** | Chlor Alkali | • Testing ODC technology in UK and reduce upfront cost through novel cell design / new cathode materials. | | • Support for the demonstration of ODC technology to encourage the transition from research to development stage.<br>• R&D support to develop cathode materials and novel electrolysis cell designs in order to reduce operational cost. | Tens of millions of pounds |
| | **Food & Drink** | New product design and processes | • Audited case studies to increase customers confidence for new products.<br>• Incentives to carry out R&D in new products.<br>• Demonstration and testing to verify the reliability of new processes. | UK Government funding of Knowledge Transfer Networks. Carbon Trust IEEAs, Industry Advice, loans, ECA scheme | • R&D support in new food product development and testing.<br>• Support for implementation and testing of new processes.<br>• Research grants for development of energy management and data monitoring equipment and processes. | Tens of millions of pounds |
| | **Iron & Steel** | BF and EAF incremental improvements | • Increase awareness of technology by incentivising deployment. | | • None required – energy saving and carbon reduction will drive uptake. | |
| **Alternative process technologies** | **Chemicals** | Improved separation technologies | • Demonstration and adoption of improve separation processes at commercial scale.<br>• Development of new membrane materials for specific processes. | | • Support for early adoption and demonstration of membrane technology as a replacement for distillation (olefin/alkane separation) or in combination with existing separation technologies (distillation/membrane hybrid techniques).<br>• Support for testing of new membrane materials being developed to provide high thermal stability and strength. | Tens of millions of pounds |

[27] Provides an order of magnitude perspective on the scale of public funding potentially required over the next 5-15 years to address each need

| | | | | | | |
|---|---|---|---|---|---|---|
| | **Food & Drink** | Alternate to heating, cooling and cleaning process technologies | • Demonstration support at plant scale in a range of potential applications. | Possible Enhanced Capital Allowance (ECA) technology | • Support for research into improving the efficiency of non-electric cooling technologies (e.g. gas engines) and testing of non-electric alternatives to heating technologies (e.g. UV pasteurisation).<br>• Support for research in energy assessment of cleaning processes and testing of alternative cleaning technologies (e.g. ice pigging). | Millions of pounds |
| | **Iron & Steel** | Smelt reduction; EAF improvement and electrochemical steel production | • Smelt reduction - Demonstration of the integrated process at plant scale.<br>• Electrochemical process - Small scale pilot plant to demonstrate feasibility and costs.<br>• EAF improvement – Not suitable for UK furnaces. | Smelt reduction - Hlsarna project in ULCOS Electrochemical process - technology being developed in ULCOS and MIT | • Support UK companies to maximise benefits to UK from ULCOS and specifically the Hlsarana project. Target funding to promote follow on plant in UK.<br>• Support a project to outline cost of electrochemical steel in the UK using renewable energy and UK ores. | High tens of millions of pounds |
| **Low carbon substitutes** | **Chemicals** | Bio-processing | • Development of bio-catalysts.<br>• Demonstration of bio-processing technology at commercial scale. | £ 8million grant from One North East and DECC. BIS funding of £12 million £2.5m from TSB for SMEs | • Support to demonstrate bio-processing technology at plant scale.<br>• Target research funding into new bio-catalysts. | Tens of millions of pounds |
| | **Food & Drink** | Alternative heat generation (Biomass) | • Programme to reduce upfront investment cost of equipment and improve availability of biomass (prioritization of biomass use to stabilize market for future investment). | Renewable Heat Incentive<br><br>Enhanced Capital Allowance (ECA) scheme | • Support for demonstration of large scale biomass fired food processing plant.<br>• R&D grants for development of cost effective equipment (e.g. low cost engines). | Tens of millions of pounds |
| | **Cement** | Low carbon cement and clinker substitution | • Specifications and standards combined with wider appreciation of where clinker replacement cements can be used.<br>• Demonstration of long term stability and economic viability of low carbon cement .<br>• Development of plant and equipment to manufacture low carbon cement. | £1.5 million grant from TSB to NOVACEM to prove the technical and commercial viability of its low carbon cement; Carbon Trust has provided support to Novacem in developing their business plan | • Increased support and coordination to expand range of applications where clinker substitute cements are suitable.<br>• R&D support for development and testing of low carbon cement technology (currently only 4 global players with patented technology, including one in UK).<br>• Support for demonstrations of low carbon cement on low risk infrastructure projects (pavements, platforms etc). | High tens of millions of pounds |

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| **Additional technologies** | **CCS** | CCS (TGR with CCS in iron and steel) | • Support financing of the upfront investment.<br>• Demonstration technology at plant level along with mapping of pipeline routes in UK and identification of storage sites. | DECC is providing funding to CCS demo projects in the power sector in UK (NER300) | • Support to facilitate early testing of CCS in chemical and cement plants.<br>• Support to UK steel companies to maximize benefits to UK from ULCOS and to encourage location of follow on plants in the UK. Target funding to adopt CCS with refurbishment schedule of existing BF fleet.<br>• Support industrial CCS programme to maximise collaboration and cross learning from demonstration of CCS in power sector and develop specific storage and transport technologies. | High tens of millions of pounds |
| **Recovery and recycling** | **Chemicals** | Advanced recovery and recycling | • Support financing of the upfront investment.<br>• Scale up of laboratory processes for monomer recycling. | Government support to “Plastics 2020 Challenge”. | • Support early testing of recovery processes (e.g. pyrolysis, methanolysis, glycolysis, hydrolysis) from plastic. | Millions of pounds |
| | **Iron & Steel** | Recycling and re-use | • Testing of low grade steel and development of standards for suitable re-use applications. | | • Recycling - Programme to produce lower grade steel from recycled material in select UK furnaces to initiate development of a technology route map by industry.<br>• Re-Use - Support academic work in the UK to develop a strategy for re-use target , applicable sectors and assessing suitability for re-use applications. | Millions of pounds |

Source: AEA, expert interviews, Carbon Trust analysis

| Benefit of UK public sector activity/investment | |
|---|---|
| | High |
| | Medium |
| | Low |

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