Barriers to improving energy efficiency within the process industries with a
focus on low grade heat utilisation

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Abstract

Process industries are significant global energy consumers, contributing substantially
to global greenhouse gas emissions. There is a need to reduce the energy intensity of
production and corresponding greenhouse gas emissions, but there are significant
technical and non-technical barriers to achieving this. Consultation with industrial and
academic stakeholders in the UK established that cost, return on investment and
technology performance were key barriers to process industry energy efficiency
improvements. However, for low grade heat utilization, stakeholder engagement and
strategic mapping found that ‘location’ and the need for capital support for
infrastructure were the most critical factors. A large number of institutional issues
were also identified which help to explain why, even when efficiency measures
deliver environmental and economic benefits; they are not implemented by industry.

Key Words: industrial efficiency; barriers; low grade heat; mapping

1. Introduction

Process industries consume 37% of global primary energy and contribute about 25%
of global greenhouse gas (GHG) emissions (Metz et al., 2007). Despite an globally
accepted need to reduce energy use and associated GHG emissions, global industrial
GHG emissions are projected to increase from around 12 Gt CO2 in 2004 to 14 Gt
CO2 by 2030 (ibid.), with much of the growth taking place in developing countries.
Historically substantial reductions in industrial energy and emission intensity have
been achieved through adoption of energy efficiency technologies, but full use of
(financially viable) mitigation options is not currently being made. (ibid.).

It is therefore vitally important to identify the barriers that are preventing uptake.
While previous studies have identified some barriers, such as financial constraints, the
perceived risks associated with process alteration, the availability of relevant
information and other issues (Dyer et al., 2008; Henriksson and Sölderholm, 2009;

1 Abbreviations: EEM refers to energy efficiency measures. LGH refers to low grade heat, GHG refers
to greenhouse gas, CHP refers to combined heat and power.
Howarth and Andersson, 1993; Jaffe and Stavins, 1994; Luken and Van Rompaey, 2008; Lutzenhiser, 1994; Reddy, 1991; Schleich, 2009, Umstattd, 2009; Zhu and Geng, 2011) few have involved stakeholders to verify the applicability of different barriers. Those who have, generally focus on very specific industry sectors eg. CHP in New York (Bourgeois, 2003) small industry clusters (Nagesha and Balachandra, 2006), Swedish non-intensive manufacturing industries (Rohdin and Thallander, 2006) and small Greek industries (Sardianou, 2008). This paper adds to existing knowledge by illuminating why so many industries consistently ignore mitigation options and by highlighting the most strategic barriers for policy interventions.

2. Background: reported barriers to energy efficiency improvements in the process industries

The viability of potential energy efficiency measures (EEMs) depends on the nature of the specific processes involved, the industrial sector serviced, specific fuel or feedstock demands, the lifespan of installed equipment etc. (USEPA, 2007). Therefore identifying technical barriers to process energy efficiency improvements is complicated by the huge array of technical options available within the heterogeneous process industries sector.

This can be simplified by considering four very broad categories of EEMs (USEPA, 2007):

- Use of cleaner or more efficient fuels.
- CHP or onsite generation.
- Equipment/process retrofit or replacement.
- Research and development.

While it could be argued that these categories are not entirely compatible, utilisation of existing waste low grade heat (LGH) can usefully be considered as involving process retrofit with the possibility of onsite generation or CHP, which are discussed further below. Mc Kenna and Norman (2010) suggest that the industrial market for surplus heat in UK is 108 PJ, in comparison to a total heat use of 650 PJ (the latter concentrated in key sectors such as steel and chemicals). While the former figure has been suggested as a potential estimate for heat recovery in the UK, concrete evidence for the actual extent of waste heat utilisation is very lacking. In examining the European heat market, Werner (2006) suggests that the delivery of heat in the Netherlands, Finland and the UK amounts to 97.7, 159 and 75.1 PJ per annum. In the Netherlands heat is normally delivered from local (mostly industrial) combined heat and power plants to a third party. The Finnish estimate includes heat delivered to both industrial and domestic customers. It is estimated that district heating represents about 50% of the domestic heating market, 80% of which being produced from both CHP and traditional power plants. In the UK it is suggested that most heat deliveries are due to local CHP plants. (Although more traditional district heating systems exist in Sheffield and London-Whitehall).

2.1 Generation of energy onsite

The generation of electricity for onsite consumption is often unattractive for smaller industries because of security of supply and/or grid access issues. However, depending on demand, small-scale electricity generation at the point of consumption can be viable and reduce losses during transmission from supplier to consumer.
Combined heat and power (CHP) generation suffers from similar barriers and additionally the temperature of the heat is often too low to facilitate process integration. While the heat could be useful for space heating, the lack of a consistent heat sink is a considerable barrier, particularly given the high engineering costs (DTI, 2006). While most industrial installations have optimized heat use at higher temperatures often through complex heat exchanger networks, the recovery of LGH is generally an under-exploited resource. While optimisation in the process industries could decrease the amount of low grade heat available in future, this has not been the case historically and seems unlikely to have a major impact within the next 5-10 years.

Barriers to LGH utilization include the amount of heat available and the efficiency of recovery, but the quantity of heat recovered and associated primary energy cost savings must be sufficient for financial viability (Crook, 1994). In instances where there is no use for heat recovered onsite, ‘over the fence’ solutions are required and dispatch of heat to users can involve a variety of techno-economic barriers related to the heat distribution network (Reidhav and Werner, 2008).

2.2 Process improvement or retrofit

Where systems are well established there may be a perception that existing process inefficiencies constitute normal plant operation or ‘business as usual.’ Sardianou (2008). Also the adjustment costs associated with process disruption, lack of physical space, the limited window for installation, the non-depreciation of primary equipment and the condition of ancillary equipment may impede process improvement. Often the additional complexities associated with process modification are perceived as reducing the flexibility of existing systems (Ren, 2009). Similarly reliance on proven configurations and maintaining operation control is perceived as more important than the potential benefits from adopting EEMs. In some cases increasing capacity may be perceived as more economical than improving energy efficiency/reducing demand.

Therefore the existence of technologically and financially viable EEMs may not provide sufficient incentives to act (Gillet, 2006). This could also be influenced by differing perspectives on what constitutes financial viability and stakeholder views on this are reported in section 3.4.3. However, it is also important to understand the other barriers that deter process industries from implementing energy efficiency improvements. This paper combines both direct stakeholder engagement and a theoretical framework by involving stakeholders in a barrier identification and prioritization process, utilizing categorization and mapping techniques to classify the barriers and then using stakeholder engagement to develop a more detailed understanding of the nature of and relationship between key identified barriers. However, first a review of the existing state of knowledge in relation to barriers to EEMs is given in section 2.3.

2.3 Review of applicable barriers

In assessing stakeholder opinions, Nagesha and Balachandra (2006) highlight a lack of reliability, financial support mechanisms and proper training or management. (In contrast, Mitchell et al. (2006) describe how the misapplication of financial support may engender ‘donor-dependence’, such that firms take a passive role in changing
their management and operational behaviours.) Overall Nagesha and Balachandra 
(2006) found financial and economic barriers to be the most ‘intensive’. Interestingly, 
it was seen that firms do not operate in the same way as individuals, so they tend to 
act in a way that satisfies their profitability objectives or targets, rather than 
attempting to maximise the profits from their activities. Rohdin and Thollander 
(2006) consider the barriers to energy efficiency within the Swedish (non-energy 
intensive) manufacturing industry and emphasize uncertainty regarding the potential 
balance of risk and rewards, since respondents were unconvinced that future energy 
prices would rise. Hidden costs were considered significant particularly given the 
time involved in investigating and evaluating potential EEMs. This was corroborated 
by Rohdin et al. (2007) in relation to privately owned foundries. However the main 
barriers faced among the group-owned foundries (apart from access to capital) related 
to organizational problems such as process disruption, long decision chains, the 
buyer/user divide and a lack of priority within management. Sardianou (2008) 
highlighted the lack of funds, high costs and slow investment return as barriers to 
investment in EEMs. The lack of information (70% of respondents cited a lack of 
awareness of new or existing technologies) meant that investing in EEMs was not 
recognised as being essential or as providing a sufficient return.

While cost concerns are also highlighted within theoretical frameworks, further 
emphasis is placed on the difficulties in generating and diffusing information. Jaffe 
and Stavins (1994) demonstrate that the market is unlikely to sufficiently compensate 
the investor for knowledge creation resulting in a positive externality. This is 
complicated when the most relevant information (such as process data) is held by a 
single entity, which may be reluctant to disclose energy data to third parties as it is 
perceived as endangering their competitive advantage (Henriksson and Solderholm, 
2009). Massoud et al. (2010) also identify the “uncertainty of outcomes and benefits” 
as a significant barrier to introducing environmental management systems within 
industry. Other barriers include uncertainties regarding future energy prices which 
impede effective cost benefit calculations or may necessitate a high discount rate. 
Dyer et al. (2008) specify how inaccurate baseline energy and cost data may fail to 
illustrate the potential revenue and result in economically viable projects being 
rejected. In effect this means that the actual costs of current (material and energy) 
efficiencies are not clearly recognised and therefore firms often do not accept the 
value of EEMs (Mitchell, 2006). This is chiefly relevant in instances where the 
qualitative attributes of the new technologies (such as reliability/availability) may 
make existing, less efficient (but perhaps better understood) technologies preferable.
The diversity of process industries themselves means that an EEM which is deemed to 
be financially viable, “on average” will not be acceptable for a large number of 
installations which may have a significant cumulative energy demand.

A summary of the barriers discussed above is shown in Figure 1, classified by 
whether they have been recognized by theoretical frameworks, practical studies or 
both (e.g. finance or knowledge based barriers). In other cases barriers identified by 
one methodology could be considered as manifestations of a related barrier identified 
by the other approach. For example, the theoretical frameworks may note that the new 
technology has less desirable performance attributes, but that this is seen by 
stakeholders as loss of availability, reliability or disruption. Similarly the inadequate 
investment in knowledge may be because of the lack of management appreciation or 
focus on production delivery not efficiency.
It is possible that industrialists tend to see the closest, most relevant barrier to their daily experience. However, where barriers are linked, with one leading to another, the most obvious/evident barrier may not necessarily be the “root cause” (Thornley and Prins, 2009). For example, while finance is a common barrier from both approaches, practical studies focus on acquiring finance, while theoretical studies note the cost of acquiring knowledge and making the adoption decision. Both aspects merge in consideration of financial viability, which can be thought of as a balance between the risks and financial rewards associated with implementing an energy efficiency measure.

This paper presents views on barriers to energy efficiency measures gained from the experience and views of stakeholders, but analyzes their views in a framework that will highlight the root causes rather than the effects, facilitating identification of the most productive points for intervention.

Figure 1: Classification of barriers to improving industrial energy efficiency.

3. Stakeholder priorities

The stakeholder views reported in this paper are those of participants at a workshop on process industry energy efficiency, held by the PROTEM Network in Middlesborough, UK in March 2010. The PROTEM Network was established in 2009 to further stakeholder involvement and interaction in advancing energy management and efficiency within the thermal processing industries, including interdisciplinary research. The stakeholders include representatives of process industries or engineering research groups in the UK with an interest in process industry operation, energy efficiency or energy management, who had chosen to attend the open workshop. The main objective of the workshop was to obtain up-to-date (un-led) perspectives from the stakeholders on addressing and prioritizing the barriers associated with improving energy efficiency in industry. The rest of the meeting was taken up with breakaway sessions which focused on the most significant barriers with specific relevance to utilization of LGH in the process industries. However wider issues, more generally applicable to EEM’s were also raised. Therefore the results discussed below provide a comprehensive overview of barriers to (low grade) heat recovery generally and give some considerations relevant to EEM’s generally.

3.1 Stakeholder Identification of barriers.

Stakeholders were asked to identify what they considered to be the key barrier(s) to the adoption of EEMs (such as LGH recovery) in the thermal process industries. Tables 1.2 show the raw responses received in the first column. Identical raw responses are depicted as multipliers, and as many of the points raised are essentially duplicates and they are aggregated into consolidated categories in the second column.

Table 1.1-1.3 about here.
Tables 1.1-1.3: Barriers to EEMs as identified by workshop participants.

Tables 1 and 2 about here.

From Table 1, the issues of cost, location, technology performance and return on investment generated most responses. The issues of cost and return on investment are closely linked and their prioritisation is consistent with section 2, where financing was noted from theoretical studies and the risk/return balance was a common theme in both theoretical and practical studies. Location does not feature in any of the literature reviewed and this is an issue which appears to be either particularly applicable to low grade heat or to the process industries. It focuses on the difficulties associated with the mismatch between the typical location of industrial processes and the potential demand for LGH. This reflects the perception that internal process optimisation has, in many cases, already been performed and remaining opportunities lie in matching surplus heat to external users.

3.3 Ranking of barriers.

Figure 2 shows how participants at the workshop ranked the importance of the collated barriers to process energy improvements identified above.

Figure 2 about here.

In general terms, the lack of infrastructure, financial support, capital costs and the problems associated with location were considered the main impediments. Lack of infrastructure relates primarily to the (non) existence and quality of piping for the transportation of heat, although in electrical generation it may also pertain to the local electricity grid infrastructure.

Capital costs incorporate equipment, engineering and operational costs associated with technological measures to improve energy efficiency. Financial support incorporates the existence of financial structures to reduce the risks in altering existing processes or integrating new technologies and the establishment of adequate incentives for improving energy efficiency. Support may be provided at plant or company level and may be provided externally though government initiatives such as grants or rational energy (or carbon) pricing. Alternatively a number of companies may enter a risk sharing initiative which reduces the risks anticipated by any one company. Such initiatives may also include the availability of loans and guarantees including innovative financing solutions tailored to the specific funding requirements.

The issue of location may reflect the often disparate locations of process industry heat availability and heat demand, once on-site opportunities have been exhausted, and transporting LGH over large distances to end-users may be unfeasible or costly (Reidhav and Werner, 2008). The physical and institutional gaps associated with heat infrastructure in the UK was highlighted by stakeholders, particularly in relation to issues of ownership, initiative, liability and cost.

3.4 Stakeholder discussion of key barriers
Detailed discussions with stakeholders were held in small, self-selecting groups, in order to allow participants to:

- Elaborate on the nature and applicability of the barriers that had been identified.
- Identify areas where barriers may be linked or influence each other.
- Make suggestions of possible methods of addressing barriers.

Guided by the prioritization above, one discussion group focused on finance and incentive based barriers (which covers 2 of the top 3 rated items), one on communication and user-based barriers (based on consideration of the issue of gaps between industry and end-users discussed above) and one on technology and performance risk, which, it was considered, was one of the key contributors to financial risk.

However, as anticipated, the open nature of the discussions resulted in each group actually also discussing some of the other related issues, which was a key objective of the session. A summary of the main observations and conclusions in each area is given below.

**3.4.1 Technology and performance risks**

The industrialists within the group discussing technology and performance based risks reaffirmed the importance of proving the efficacy of any new technology before adoption. Concerns were voiced regarding how existing processes would be affected by any new technology or process modification. Specifically in relation to LGH processing it was mentioned that many modern industrial processes are configured such that the continuous rejection of heat is vital in order for the process to maintain operation. Therefore it was the general view that the recovery of LGH represented significant risks, with small perceived rewards. It was considered important to establish if the process can be reversed or has a proven track record before making process alterations. The group was asked whether any risk-sharing mechanisms would be appropriate for addressing these concerns. While some participants would consider a consortium based approach with financial risk sharing, it was generally regarded as unfeasible as the financial benefits were insufficient to justify accepting such a risk, even collectively. An adaptable, modular process was preferred, ideally supported by flexible EEMs which are sufficiently flexible to work with a number of process configurations without reducing operating capabilities. Timescales were discussed briefly. It was felt that new ideas or technologies would need to be introduced gradually, which contrasts with the quick decisions that appear necessary in order for commercial success. However, the respondents felt that larger companies require assurances (particularly for investors) that their company is in “safe hands.” Finally it was pointed out that it was important to first build confidence at small scales with energy efficiency measures. This may be difficult if the environmental and financial benefits are less and less significant at smaller scales.

**3.4.2 Communication and user based barriers**
Stakeholders felt there was a need for a clear indication of who will (or can) lead on establishing infrastructure for low grade heat use, perhaps with a division of responsibility between the generator and users of recovered energy. Industry was considered unlikely to act without some form of government intervention. Companies are very unlikely to engage in a process that is not profitable, although it was agreed that companies need to be made aware of additional benefits; such as improved public relations or reduced environmental impact. It was also suggested that the environmental benefits such as greenhouse gas reductions are experienced by the end user, not the LGH provider. Therefore the industrial partner, who is more likely, for example, to be engaged in emissions trading schemes or environmental audits or reports does not record any direct environmental benefit from provision of LGH “over the fence”. Suitable end users in close proximity will invariably already have a form of energy supply and so may not be readily identified as potential customers by the process industries or have much incentive to change things. In contrast, one view expressed was that many of these issues can be solved if sufficient support or demand is available. Potential users need to be made aware of the existence of LGH and its benefits. This was seen as a problem that is best tackled on a regional basis. It was agreed that there is a need to identify which processes have the optimal capacity to supply LGH and market towards these areas. Energy mapping is extolled as means of addressing location based constraints and pre-empt the communication/awareness issues outlined in Figure 3.

Stakeholders within this group felt that academic or regulatory bodies need to appreciate that energy suppliers are generally conservative. There was an accepted need for constructing demonstration plants along with guarantees for both suppliers and users. It was suggested that the costs associated with such a project may be offset by the issuing of green certificates, which may alleviate industrial concerns regarding process disruptions. One of the participants felt that the presence of an under-exploited yet available resource constitutes a market failure. Therefore the responsibility ultimately rests with the government who needs to be made aware of the issues at hand and how it could intervene.

3.4.3 Finance and incentives.

The discussion of this topic revolved around the pros and cons of regulatory versus voluntary measures. A participant from an industrial background argued in favour of voluntary measures to incentivise LGH recovery including accounting for carbon emissions. A participant from an academic background argued for penalties and regulation as well as incentives. This included taxes which, it was felt, are currently inadequate. The importance of reducing the pay-back period (and aiding cost-effectiveness) was highlighted. A payback period for return of investment of five years is considered by industry to be too long, in many cases two years is expected. Although another participant issued a caveat on putting too much faith on such estimates, stating that companies set rate of return benchmarks essentially to prioritise projects as opposed to a belief that the calculations are accurate. It was suggested that energy projects with similar rates of return are not being invested in, while for comparable rates, acquisitions are being invested in that may not perform as well as expected. For that reason, it was also suggested that firms should be required to declare their investment returns. This was agreed but wider support could formalise a mandatory requirement for a declaration of rates of return. This may lead to greater
awareness amongst shareholders and provide weight to the arguments of non-governmental organisations pressuring for change. This would allow for different standards for different types of project, accepting differences between firms and project scales.

Other participants felt that there is ample existing regulation and further persuasion or if necessary “arm-twisting” should be considered. Another participant agreed that manipulating incentives can work, but it is important that they are correctly applied. Another view was that “short-termism” pervades society, including government authorities, which promotes “carbon badge hunting”.

4. Analysis of barriers

One method of classifying barriers is to focus on their origin and this can be valuable in providing insights into how strategically important barriers cited by stakeholders actually are and what techniques can most appropriately be deployed to address them (Thornley and Prins, 2009; Thornley et al., 2009). The classification of the barriers into the following broad categories can give some indication of the most likely solutions that can be adopted to address the barriers.

**Structural barriers** – These apply when a new entity is attempting to develop within a space that was fashioned to suit a previous incumbent. As the characteristics and needs of the new entity are different, its progress will be impeded by boundary conditions that were previously not material, for example any existing infrastructure that impedes the integration of the EEM. Structural barriers to EEMs may be physical (i.e. infrastructural) or less tangible such as the existent capacity to trade heat or electricity.

**Market barriers** - Another reason for barriers to many new technologies is that the new technology addresses a need or provides societal benefits that are not valued by the current market, making it difficult for the new technology to compete. For example, the current market might not adequately value the carbon savings or energy conservation effected by implementing an energy efficiency measure. Unless carefully targeted, government assistance or initiatives fail to result in self-regulation at the factory level (Shi et al. 2008).

**Interaction barriers** - A third cause of barriers is that the developing entity draws upon the knowledge, skills and products of different sectors and industries which are not strongly bound with a common goal. This results in development being delayed or obstructed by a lack of knowledge transfer and/or non-alignment of the different parties’ objectives. This is relevant, for example, where process industries lack the knowledge or insight to make an implementation decision on new energy efficiency measures. Alternatively interaction barriers may not be the result of company level reluctance to implement EEM targets, but denote a lack of engagement with the company in formulation of targets (Mitchell, 2006).

**Performance barriers** – These are areas where the technology falls short in some way in delivering the end user’s requirement. These are likely to be particularly important in energy efficiency measures in the process industries where the efficiency measure will normally be integrated into the overall process scheme and so there is
the potential to impact on the existing process performance.

Shi et al. (2008) state that it is also important to make the distinction between internal and external barriers. In that regard structural and market barriers may be considered externally influenced, while interaction and performance barriers may be considered internal barriers. Addressing structural barriers generally requires readjustment of the space that suited the previous industry to be more accommodating to the developing alternatives. Often this requires direct intervention within the industry by capital investment, reorganisation or legislation. Market barriers will generally respond to policy interventions, which attempt to adjust the market to take into account the non-economic attributes of fuels or technologies. Performance barriers either require technical development or a readjustment of market focus to circumvent a technical constraint. Addressing interaction barriers is challenging as open communication between diverse bodied may be perceived as being commercially damaging. A forum for communication and exchange is needed but also a common alignment of objectives so that participants see both the benefits to themselves and the need for involvement of other parties to more effectively achieve their own joint objectives.

4.1 Barrier Mapping

Figure 3 shows a map of the barriers identified at the workshop based on the barrier categories discussed above. This was initially carried out at the workshop and presented to stakeholders. However, it is important to realize that stakeholders will often report the item that is most relevant to their own experience and this may not necessarily be the root cause or barrier. Barriers are generally linked and understanding the linkages can help in identifying the most strategic barriers and the most appropriate points for intervention to address barriers. Reddy (1991) cautions against the dangers of a ‘one-barrier-one-measure’ approach to improving energy efficiency as each in effect consists of a number of interconnected sub-barriers. Therefore the barriers map was subsequently revised, based on further consideration of linkages and, in particular, based on the reports from the parallel discussion groups, outlined in sections 4.1-4.3. Revision included insertion of arrows to connect those barriers which directly contribute to each other. For example, a lack of infrastructure is in itself a barrier to implementing EEMs, but it also results in increased capital costs for implementation and increased levels of project risk. This is an example of a particular barrier being linked to multiple other barriers, suggesting that it could be strategically important to address since doing so should yield multiple benefits. Also, understanding the linkages can help in identifying the most appropriate point to intervene in a chain, while the categorization can inform which type of intervention will be most effective.

Figure 3 about here
Considering figure 3, the most highly linked barrier is “Lack of pipes or infrastructure” and the only identified barrier further “upstream” that contributes to this is “Location”. “Infrastructure/financial support” is also highly linked so that addressing it could yield multiple benefits. However, the only barrier that directly precedes “Infrastructure/financial support” is “Lack of pipes or infrastructure”. This suggests that addressing infrastructural barriers would be most effective but requires a caveat as this will have location specific constraints and may necessitate a wider response than purely on-site actions. The next most highly linked barriers are “lack of investment return” and “capital cost”, which are also directly linked to each other. This would suggest that addressing the lack of investment return or the high capital cost would be particularly effective (although high capital cost in part contributes to the lack of investment return and so may be the more productive issue to address).

5. Discussion

The barrier mapping exercise suggests that “lack of pipes or infrastructure” is the most strategic barrier to address in order to increase deployment of energy efficiency measures in the process industries. With the exception of Shi et al. (2008), this has not been highlighted in any previous studies and is reinforced by infrastructure financial support being rated as the most important barrier by the workshop participants. This is particularly pertinent to LGH but is also a general issue for process industries, which are often located remotely from other developments. As stated above addressing structural barriers generally requires readjustment via direct intervention within the industry by capital investment, reorganisation or legislation. Organisation of investment partnerships (perhaps with local or regional bodies) for heat distribution infrastructure may be an effective way of addressing this barrier. Although it is also recognized that establishment of LGH infrastructure has the potential to create technology “lock-in”, where its existence becomes a barrier to future energy efficiency measures.

It seems clear that industry will not act on this issue without some form of government intervention, and there is a need to establish who can lead on infrastructure establishment. Adjustment of legislation to allow companies to claim credit for emissions avoided by others utilizing their waste heat might also help. Finally an energy mapping initiative could be an effective support measure that intercepted the linkage from location to lack of market interest, lack of corporate capacity and communications/awareness issues, as illustrated in figure 3.

It is estimated that 2% of homes in the UK are connected to district heating (DECC, 2009). In a recent planning policy statement the department of Communities and Local Government (DCLG) emphasised the need for proper heat mapping in order to inform spatial development, particularly in informing developers during the planning and zoning procedure (DCLG, 2010). For example, integrating existing buildings into new developments which include district heating can provide economies of scale. The lifecycle costs associated with establishing district heating systems exceed individual gas condensing boilers and electric heating. However once infrastructure is in place, the heat supplied is generally at a lower cost (DECC, 2010). This may help explain the stakeholder’s expressed need for clarification on how infrastructure costs will be met and justify some public investment or sharing of costs. The next most highly linked barriers are “lack of investment return” and “capital cost”, which are also
directly linked to each other. Capital cost is characterized as a structural/performance barrier and so could be addressed by direct intervention within the industry by capital investment, reorganisation or legislation, while performance barriers either require technical development or a readjustment of market focus to circumvent a technical constraint. Options to address this barrier include readjustment of the scope of energy efficiency measures to effectively reduce the impact of the capital expenditure e.g. further development of common infrastructure facilities for process industries. Such measures could also help address the issue that taken individually, projects are small and results insignificant, but when the outputs of a number of facilities are combined there is a much higher impact.

The mismatch between the focus of the barriers mapping on investment return, but the industrialists on capital cost is interesting. Ultimately investment return is dependent upon several of the other barriers identified: namely energy/carbon price, risk, capital cost and performance/quality. Therefore it seems that the issue of lack of investment return is important, but that stakeholders perceived the component parts as the discrete barriers. The price of energy/carbon can be addressed by a variety of economic policy measures mostly focused around taxation or permits and there have been many different taxes and subsidies applied by the UK government over the years. Analysing the perspectives and experiences of workshop participants seems to indicate that these measures are insufficient to offset the impact of the very significant barrier of capital cost, which requires a more direct approach, especially given the importance with which it is ranked by stakeholders. It is perhaps worth noting that many process industries operate as distinct commercial, manufacturing entities. However, many of these have emerged from larger state or private organisations. Within such larger structures there may have been more opportunities for physical cross-industry links e.g. sharing of energy, utility and infrastructure services. However individual process industries operate as single commercial entities usually providing their own raw material and energy requirements. In many cases the balance between risk and reward may only be assessed at aggregated scales such as company level reviews. This may not place risk in proper context, particularly in instances where the potential gains may be advantageous to the specific process in question, but small. Also from an investor’s perspective, the lack of quantifiable risk may act as a significant hindrance to assessing prospective investments. Historically, different regions have capitalised on the benefits of co-locating different industrial processes in a single site such as Wilton in the UK and Schwarzeplume in Germany. Indeed the Chinese government has historically adopted a strategy of co-locating industrial sectors partly so they can support each other. Specific policy initiatives focused around such integration may be one way to encourage improved process industry energy efficiency in the future.

When comparing the barriers identified and prioritised by UK based stakeholders to those previously reported in the literature the importance of location and associated infrastructure costs is very significant and has been discussed in some depth above. However, another significant difference is the importance of timescales in addressing barriers to EEMs. For example, the paramount importance of continuous process operation may result in a restricted time window in which EEMs can be implemented. The group discussions reaffirm the conservative backdrop in which these decisions are made. New ideas will likely have to be introduced gradually in order to allay the fears of process managers. By contrast, emerging or novel technologies face a
struggle in order to be successfully demonstrated within a specific time scale, and will not be afforded a subsequent opportunity if not successful. This “short-termism” was seen as a significant barrier as it means that EEMs may not be considered in the earliest planning stages or may not fully reflect the longer term benefits of improving energy efficiency.

In discussing timescales it is important to clarify that the supply and demand for LGH utilization is not static. Technical improvements and process alterations may reduce both the supply of and demand for recovered heat. Given the demand for surplus heat (McKenna and Norman, 2010) it is unlikely that this LGH will become wholly unavailable in the future, but the demand for LGH may be modified by efficiency gains in other areas, which can negate the relative benefit of LGH recovery. It is therefore difficult to predict the nature of the future market for recovered heat (either in the UK or elsewhere). Consequently, while it is clear that utilizing LGH offers opportunities to improve fuel efficiency and reduce greenhouse gas emissions there are also very substantial non-technical barriers to its implementation. Addressing such barriers will necessitate both policy initiatives and flexible infrastructure development, but care must be taken to ensure that potential trade-offs e.g. with respect to waste heat availability and efficiency gains are taken into account.

6. Conclusions and Recommendations

Barrier analysis for process industry energy efficiency measures and low grade heat utilization has reinforced previously identified barriers e.g., balancing risks with rates of returns. A strategic mapping exercise found barriers relating to location, cost and the availability of infrastructure to be the most significant, augmented by a number of institutional issues relating to company strategy and priority. Barrier mapping and stakeholder engagement both reinforce the key importance of appropriate infrastructure availability if energy efficiency measures, including utilisation of low grade heat, are to be implemented in the UK. Stakeholders confirmed that there is little commercial appetite in this area and this was echoed by the importance laid by stakeholders on the barrier of capital cost rather than project rate of return. Therefore some strategic lead or policy framework that encourages private investment in this area would be needed to facilitate deployment. Regional heat load mapping may be an effective method of identifying the most promising regions for such infrastructure development and could also help to match suppliers and potential users. Process interruption risk is a major disincentive to implementing energy efficiency measures in the process industries and a key technology differentiator was perceived to be the ability to extract/remove an EEM during and after installation. The combination of process interruption risk with new technology and financial risks are sufficient to deter alteration to existing processes, based on the current risk-reward balance. This could be addressed by incentivisation of deployment. However, to justify this environmentally, it is essential to be confident of the actual fuel and greenhouse gas savings being delivered by the EEM’s. Specific quantitative research is therefore recommended to investigate this for different process industries and EEM’s by combining energy, life-cycle and techno-economic analysis to identify the most promising options.

References.


Department of Trade and Industry (DTI). 2007. A call for evidence for the review of barriers and incentives to distributed electricity generation, including combined heat and power. A joint UK government and Ofgem review. London, United Kingdom. Note: DTI was replaced with the announcement of the creation of the ‘Department for Business, Enterprise and Regulatory Reform’ and the ‘Department for Innovation, Universities and Skills’ on 28 June 2007.


Figure 2: Classification of barriers to improving industrial energy efficiency.

*From surveys/practical studies*

**Financial**
- Financing

**Strategic/motivation**
- Firms satisfy not maximize profits
- Lack of management appreciation
- Focus on production as opposed to efficiency

**Capacity**
- Focus and attention
- Lack of specialist knowledge and resources

**Technology**
- Availability, reliability and disruption

*From theoretical frameworks*

**Financial**
- Risk/return balance from adopter’s perspective

**Knowledge**
- Lack of information to facilitate decision
- Lack of technology knowledge

**Knowledge transfer**
- Inadequate transfer and diffusion

**Capacity**
- Institutional inertia

**Technology**
- Less desirable qualitative attributes

**Knowledge**
- Inadequate investment in knowledge establishment
- Not incentivised by ordinary markets
Figure 2: Ranking of barriers to process energy efficiency.
Figure 3: Mapping of barriers identified for utilization of low grade heat to improve process efficiency
<table>
<thead>
<tr>
<th>Raw responses</th>
<th>Collated responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of long term view re project payback periods. (Industrialists do not have</td>
<td>Corporate capacity and strategy</td>
</tr>
<tr>
<td>long term confidence they will still be in business to make long term energy</td>
<td></td>
</tr>
<tr>
<td>investments</td>
<td></td>
</tr>
<tr>
<td>Company strategy (interaction)</td>
<td></td>
</tr>
<tr>
<td>Lack of time for considering creative activities</td>
<td></td>
</tr>
<tr>
<td>High cost of moving/extracting/upgrading low grade heat vs. its value</td>
<td>Cost to process and supply</td>
</tr>
<tr>
<td>Development costs of new technology and risks (big bet)</td>
<td></td>
</tr>
<tr>
<td>Cost of implementation</td>
<td></td>
</tr>
<tr>
<td>Temperature and therefore the cost of heat exchange equipment</td>
<td></td>
</tr>
<tr>
<td>Cost (X6)</td>
<td></td>
</tr>
<tr>
<td>Low pay back/cost</td>
<td></td>
</tr>
<tr>
<td>Cost effective technology</td>
<td></td>
</tr>
<tr>
<td>Putting a value on energy efficiency best practice</td>
<td>Policy incentives</td>
</tr>
<tr>
<td>Price for carbon</td>
<td>Price of energy/carbon</td>
</tr>
<tr>
<td>No rate return investment for low value commodity e.g. DH (X7)</td>
<td>Lack of investment return</td>
</tr>
<tr>
<td>Project cost (capital/payback)</td>
<td></td>
</tr>
<tr>
<td>Low value</td>
<td></td>
</tr>
<tr>
<td>New technology doesn't fit industry payback times</td>
<td></td>
</tr>
<tr>
<td>Payback constraints</td>
<td></td>
</tr>
<tr>
<td>Use = market</td>
<td>Lack of market interest</td>
</tr>
<tr>
<td>Lacking interest</td>
<td></td>
</tr>
<tr>
<td>Low demand</td>
<td></td>
</tr>
<tr>
<td>Difficulty finding partners to use LGH</td>
<td></td>
</tr>
<tr>
<td>Capex/availability/lack of funding (X2)</td>
<td>Access to capital</td>
</tr>
<tr>
<td>Independent government policy!</td>
<td>Policy inconsistency</td>
</tr>
<tr>
<td>Long term regulatory framework is uncertain - no interagency joined up thinking</td>
<td></td>
</tr>
<tr>
<td>Regulatory uncertainty - lack of confidence in the legal framework that governs</td>
<td></td>
</tr>
<tr>
<td>key “?” E.g. revenue stream (green credits)</td>
<td></td>
</tr>
</tbody>
</table>

Table 2.1: Barriers to EEMs as identified by workshop participants.
Table 1.2: Barriers to EEMs as identified by workshop participants.

<table>
<thead>
<tr>
<th>Raw responses</th>
<th>Collated responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can’t use the heat recovered anywhere</td>
<td>Location</td>
</tr>
<tr>
<td>Distance to end user of low grade heat and cost of supply infrastructure (X 7)</td>
<td></td>
</tr>
<tr>
<td>Lack of customers with correct requirements in close proximity</td>
<td></td>
</tr>
<tr>
<td>Physical location – distance</td>
<td></td>
</tr>
<tr>
<td>Expensive to export off-site</td>
<td></td>
</tr>
<tr>
<td>No consumer in close proximity</td>
<td></td>
</tr>
<tr>
<td>Distribution infrastructure</td>
<td></td>
</tr>
<tr>
<td>No one wants it/needs it nearby the source</td>
<td></td>
</tr>
<tr>
<td>Transport of energy from low grade heat technology</td>
<td></td>
</tr>
<tr>
<td>Distribution</td>
<td></td>
</tr>
<tr>
<td>Logistical</td>
<td></td>
</tr>
<tr>
<td>Geography of the existing plants</td>
<td></td>
</tr>
<tr>
<td>Risk (X3)</td>
<td></td>
</tr>
<tr>
<td>Low capital return combined with business interruption</td>
<td>Capital cost</td>
</tr>
<tr>
<td>Capital cost of investment in new technology (X 4)</td>
<td></td>
</tr>
<tr>
<td>Capital effectiveness</td>
<td></td>
</tr>
<tr>
<td>Production/process constraints (X2)</td>
<td>Effect on process</td>
</tr>
<tr>
<td>Lack of technical solutions to heat recovery/the cost of the technologies</td>
<td></td>
</tr>
<tr>
<td>Too expensive to recover, size, corrosion</td>
<td></td>
</tr>
<tr>
<td>Quality of low grade heat: too low temp/too corrosive (X 2)</td>
<td></td>
</tr>
<tr>
<td>Use of new technology for production of electricity</td>
<td></td>
</tr>
<tr>
<td>Proving new low grade heat recovery devices off-line so that they can be</td>
<td></td>
</tr>
<tr>
<td>installed with confidence during a shutdown</td>
<td></td>
</tr>
<tr>
<td>Extraction?</td>
<td></td>
</tr>
<tr>
<td>Performance</td>
<td></td>
</tr>
<tr>
<td>Performance: whether one available process/manufacturing will be selected</td>
<td></td>
</tr>
<tr>
<td>depends on its performance or customer whether accepts it</td>
<td></td>
</tr>
<tr>
<td>Adequate frequency of supply</td>
<td></td>
</tr>
</tbody>
</table>

Tables 3.2: Barriers to EEMs as identified by workshop participants.
<table>
<thead>
<tr>
<th>Raw responses</th>
<th>Collated responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appropriate infrastructure</td>
<td>Lack of pipes or infrastructure</td>
</tr>
<tr>
<td>Transport</td>
<td>Infrastructure financial support</td>
</tr>
<tr>
<td>Infrastructure</td>
<td></td>
</tr>
<tr>
<td>Structural</td>
<td></td>
</tr>
<tr>
<td>Who pays for infrastructure - what legislates to drive investment?</td>
<td></td>
</tr>
<tr>
<td>Infrastructure of networks not available/affordable to distribute low grade heat to suitable users</td>
<td></td>
</tr>
<tr>
<td>Ageing current equipment not fit for technology</td>
<td>Ageing equipment</td>
</tr>
<tr>
<td>Reuse; integration with other processes</td>
<td>Alternative internal use</td>
</tr>
<tr>
<td>Degradation of process if used internally?</td>
<td></td>
</tr>
<tr>
<td>Need to compromise our operating practices to enable economic downstream use of low grade heat</td>
<td></td>
</tr>
<tr>
<td>Unproven technologies i.e. capital risks</td>
<td>Technology and performance risk</td>
</tr>
<tr>
<td>Risk of new technology</td>
<td></td>
</tr>
<tr>
<td>Flexibility of application</td>
<td></td>
</tr>
<tr>
<td>Reliability of supply</td>
<td>Reliability of long term supply</td>
</tr>
<tr>
<td>Long term viability of low grade heat customers - risk of changing markets</td>
<td></td>
</tr>
<tr>
<td>Having guaranteed long-term users next door to long-term low grade heat suppliers</td>
<td></td>
</tr>
<tr>
<td>Awareness</td>
<td>Suitable end-users</td>
</tr>
<tr>
<td>What technology would use it?</td>
<td></td>
</tr>
<tr>
<td>Lack of users for the type of heat available</td>
<td></td>
</tr>
<tr>
<td>Finding suitable consumer for LGH</td>
<td></td>
</tr>
<tr>
<td>Matching source to consumer</td>
<td></td>
</tr>
<tr>
<td>Use of low grade heat (structural)</td>
<td></td>
</tr>
<tr>
<td>Communication</td>
<td>Communication and awareness</td>
</tr>
<tr>
<td>Difficulty in all working together for common good</td>
<td></td>
</tr>
<tr>
<td>Co-operation between parties</td>
<td></td>
</tr>
<tr>
<td>Interaction</td>
<td></td>
</tr>
<tr>
<td>Awareness</td>
<td></td>
</tr>
<tr>
<td>Communication/interaction between different disciplines</td>
<td></td>
</tr>
<tr>
<td>Communication difficult across range of independent commercial organizations</td>
<td></td>
</tr>
</tbody>
</table>

Table 1.3: Barriers to EEMs as identified by workshop participants.