Friends of the Earth Cymru

Information to assist submissions to the National Assembly for Wales enquiry into energy policy and planning in Wales

Summary

Friends of the Earth Cymru has examined the potential for Wales to move away from fossil fuels and nuclear power to become a fully renewably powered country by 2050. We find that not only is it possible, but that a future powered by anything other than 100% renewable energy is both undesirable and highly improbable, a view shared by the Intergovernmental Panel on Climate Change[1].

This future for a Wales powered entirely by renewables would address energy security and climate concerns much better than a future using new-build nuclear. Pursuing nuclear power would lock Wales in for a century or more to a technology that will start down the road of becoming obsolete by the early 2020s (for example, solar PV is projected to reach grid parity[2] in the UK by 2019[3]).

We have concluded that it will be challenging but possible for Wales to acquire all its energy needs by 2050 from renewable sources – a view that should provide some relief for the Welsh Government, given the Tyndall Centre report[4] on decarbonisation in Wales. However, the need to take action is pressing, and the Welsh Government appears to lack the urgency that is dictated by the need to drive a sixteen-fold increase in renewables by 2025.

The Committee's enquiry

The National Assembly for Wales‟ Environment and Sustainability Committee is undertaking an inquiry into energy policy and planning in Wales. The terms of reference for the review are as follows:
The Committee will consider how the current devolution arrangements for energy policy and planning affect the delivery of the Welsh Government‟s desired future ‟energy mix‟ in Wales, as set out in ***A Low Carbon Revolution – Energy Policy Statement*** and the ***UK Renewable Energy Roadmap***.

- What are the implications for Wales if responsibility for consenting major onshore and offshore energy infrastructure projects remains a matter that is reserved by the UK Government?
- How does this affect achievement of the Welsh Government‟s aspirations for various forms of renewable and low carbon energy as set out in the Energy Policy Statement?
- How does this affect delivery of the Welsh Government‟s target for a 3 per cent reduction in Green House Gas emissions per annum from 2011?
- What will be the impact if consenting decisions on major infrastructure projects and associated development are not all taken in accordance with Welsh planning policy?

Alongside these questions, the Committee will also consider the two petitions about Welsh Government planning guidance as it relates to onshore wind energy and the impact on local communities and infrastructure.

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[1] Intergovernmental Panel on Climate Change, May 2011, *Special report on renewable energy sources and climate change mitigation*
[2] The point at which the cost of generating energy is the same as the price of energy from the electricity grid
[3] European Photovoltaic Industry Association, September 2011, *Solar photovoltaics competing in the energy sector*
[4] Tyndall Centre for Climate Change Research, December 2009, *Towards a 2oC future: Emissions reduction scenarios for Wales*

The response of Friends of the Earth Cymru

What are the implications for Wales if responsibility for consenting major onshore and offshore energy infrastructure projects remains a matter that is reserved by the UK Government?
How does this affect achievement of the Welsh Government's aspirations for various forms of renewable and low carbon energy as set out in the Energy Policy Statement?

This question depends to a large extent on the relative commitment of the UK and Welsh governments to moving Wales to a fully renewably-powered future. While Welsh *policy* has been pro-renewables, achieving the aims of 4 TWh of renewable electricity generation by 2010 and 7 TWh by 2020 has largely been dictated by large energy generation infrastructure. This means that the timetable and agenda have both been set by Whitehall, not Cathays Park. It is clear that the 2010 target has been missed by a huge margin: renewable generation was 1.6 TWh in 2009[5]. It is equally clear that without very large amounts of new renewable infrastructure the 2020 target will likewise be missed. The aim to generate twice as much electricity annually by 2025 as we used in 2010 is also already in doubt[6], predicated as it probably was on a half share of output from a Severn barrage.

It seems inane to have ambitious policy targets when the levers to effect the necessary interventions lie in a different political jurisdiction. How could Wales achieve these ambitious targets? We would need to have control over interventions relating to renewable energy developers – the planning regime and Renewable Obligation Certificates being the obvious candidates.

The other significant point is that this lack of responsibility provides the Welsh Government with a convenient scapegoat. When Rhodri Morgan called for a public inquiry into the Gwynt y Môr scheme[7], he could do so quite comfortably in the knowledge that the scheme would in all probability go ahead, contributing to Wales" renewable energy targets, at the same time as he could gain political kudos by attacking the system that would provide the benefit. This lack of accountability is undemocratic and destabilises the political discourse around renewables in Wales. It makes it easy for Welsh politicians to avoid even discussing large renewable infrastructure with the refrain that those decisions are made in Westminster. As a result the visible support by National Assembly politicians for large scale renewables is close to nil.

When the powers over large electricity generating infrastructure are eventually devolved to Wales, this lack of discourse and visible support could be very problematic. Politicians need to become considerably more vocal in their support for renewables – and all the jobs that these will bring. Failure to do so could result in even less progress being made than is currently the case.

The distinction between offshore and onshore generation infrastructure is also unhelpful and confusing. It seems arbitrary that offshore generating infrastructure greater than 1 MW should be the purview of the IPC/DECC.

Turning to non-renewable power generation, since Wales is already generating far more electricity than we use, and considering the large new-build that will come on stream in the next few years, it is rather unlikely that further new large fossil fuel stations will be needed or proposed in the coming years. We

[5] Department of Energy and Climate Change, December 2010, *Electricity generation and supply figures for Scotland, Wales, Northern Ireland and England, 2006 to 2009.*
[6] Wales' consumption of electricity in 2009 was 17,740 GWh – an estimate of the 2025 target is therefore 25.5 TWh
[7] BBC, 30 April 2007, *Inquiry call on offshore windfarm*

anticipate that activity will reduce and that DECC will no longer see the need to retain control over planning for large electricity generating infrastructure.

There is of course one outlier: Wylfa. Clearly, this is the principal reason for Westminster‟s refusal to devolve powers over planning for large generation infrastructure. At least three parties in Wales are opposed to a new nuclear power station in Wylfa (even if individual politicians are in favour) and the fourth does not appear to have a clear policy viewpoint. DECC are aware that devolving the powers over planning would kill the proposed new nuclear power station at Wylfa immediately. They will wait until the power station has been approved before allowing those powers to be devolved. This will of course leave Wales with a legacy of horrendously expensive construction, decommissioning, and radioactive waste that will leave Welsh taxpayers out of pocket for hundreds of years. Furthermore, investment in nuclear diverts funds away from zero-carbon generating infrastructure.

How does this affect delivery of the Welsh Government's target for a 3 per cent reduction in Green House Gas emissions per annum from 2011?

If responsibility for electricity generation were fully devolved it would have an enormous impact. In 2008, electricity generation accounted for 35 per cent of total Welsh CO2 emissions[8]. Clearly it would be far easier for the Welsh Government to achieve substantial reductions in CO2 from electricity generation than from other sectors because small relative changes in a few large generators could have very large absolute impacts. As it stands the 3 per cent annual target is already looking unachievable. Given the lack of clear direction and action from the Welsh Government on reducing emissions currently, devolving the powers over electricity generating infrastructure is probably the *only* realistic way that the Welsh Government can achieve its targets.

What will be the impact if consenting decisions on major infrastructure projects and associated development are not all taken in accordance with Welsh planning policy?

This remains to be seen. We can speculate that it would lead to democratic failure in that Welsh planning policy would be subverted by policy for electricity generating infrastructure. It makes Welsh planning policy effectively redundant as it currently applies to any electricity generating infrastructure over 50 MW and presumably asks the question: why should the Welsh Government propose any policy relating to a field over which it has no control?

However, there is at least one important ongoing case in point that relates to infrastructure that generates electricity yet logically falls under a different policy field. The proposed incinerator between Merthyr Tudful and Fochriw should logically be treated as a waste facility, but because the proposed capacity of the plant takes it slightly above the 50 MW threshold it is treated as major electricity generating plant and the consent decision will be taken by the IPC. This plant is clearly first and foremost a waste treatment plant that happens to produce electricity as a byproduct of operation. Some commentators have suggested that the capacity of the plant has been overspecified *specifically* to avoid the policy and planning regime in Wales.

Furthermore, this proposal places the Welsh Government‟s waste policy under threat. We have introduced evidence to the IPC examination that the proposal would undermine effective implementation of the National Waste Strategy for Wales and is not in accordance with the waste hierarchy as defined

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[8] National Assembly for Wales, July 2011, *Greenhouse gas emissions in Wales*

by „Towards Zero Waste"[9]. It does not take account of waste arisings in Wales or targets to reduce and recycle waste. We enclose this report as Appendix 1 for the committee"s consideration.

Whilst we hope that this evidence is fully taken into account by the IPC, the UK"s „National Policy Statements" are ultimately the documents given the most weight in the decision making process and we are concerned that a proposal that is not in accordance with Welsh policy despite being in a devolved policy area would go ahead regardless.

Whilst the impact on the local community and Welsh policy is extremely serious in this case, there are currently no consequences for this action, as the decision maker will be following the requirements of the 2008 UK Planning Act to adhere to the Energy NPSs above all else.

The consequence of this and other decisions being taken in England, particularly when the field of policy is so clearly devolved, is a potentially severe erosion of trust in Welsh governance.

The role of the different consenting agencies, how they inter-relate and how the current system could be improved, both with and without further devolution (Infrastructure Planning Commission, Planning Inspectorate, Local Planning Authorities, National Parks, Welsh Government, Marine Management Organisation, Environment Agency).

Government organisations based in England have a poor track record in providing information in the Welsh language. DECC, for example, provided Welsh language documents relating to a nuclear consultation more than three and a half months after the closing date. In relation to the proposed Merthyr incinerator, all the documentation supplied by the applicant is in English only. These 104 documents include environmental information and a Health Impact Assessment that are clearly of critical importance in understanding the potential impacts of such infrastructure. The Århus Convention[10] requires that with regard to all documentation relating to applications for large electricity generating infrastructure (such as the Merthyr plant):

> "The public shall have access to information, have the possibility to participate in decision-making and have access to justice in environmental matters without discrimination as to citizenship, nationality or domicile..."

Friends of the Earth Cymru is concerned that the current process undertaken by the IPC does not conform to the UK"s obligations under the Convention, and moreover that UK government bodies have always taken this approach regardless of Århus and now of the official status of the Welsh language.

Regrettably, we have to include the Environment Agency in the same bracket. Despite having an all-Wales limb, it has failed to ensure Århus compliance in any recent case (e.g. Pembroke power station, Hinkley Point).

Because the level of trust between the Welsh language community and UK government bodies is particularly low, this is an additional reason for us to support the devolution of powers over electricity generating infrastructure (the presumption being that Welsh language provision would become an integral part of the consultation procedure were those powers to be exerted by the Welsh Government).

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[9] Welsh Government, *Towards zero waste*
[10] UNECE, 25 June 1998, *Convention on access to information, public participation in decision-making and access to justice in environmental matters*

The current infrastructure planning process is frustrating and places numerous barriers in the way of meaningful participation. The Brig-y-Cwm incinerator is one of only two applications to reach the examination stage of the IPC process so far, and the only one in Wales, and as Friends of the Earth Cymru has been involved in the process from the beginning we will comment on the process in relation to our experience and that of local residents.

The process is largely based on written submissions, which places people with low levels of formal qualifications and problems with literacy and numeracy at a significant disadvantage. This has been a substantial challenge with communities in the Merthyr Tudful and Rhymney Valley area.

The process is led by the developer, and although there are requirements in the 2008 Planning Act to consult widely and on the basis of thorough information, the pre-application stage was passed despite incomplete and draft application documents and a few poorly attended public meetings which had been badly advertised.

Anyone who wishes to engage in the process of an application, give evidence at a later date or be kept informed of developments has to register as an „interested party", filling out an intimidating six page form within a six week registration period, and giving reasons justifying their interest in the application.
The application itself consisted of 10,000 pages of documents and only a few paper copies have been available to view in local libraries, without the possibility of borrowing a copy and therefore available for limited periods and only within normal working hours. All documents were available online but given problems with broadband connection and some documents being as large as 460MB this was inaccessible for many people. The final option is to buy a copy for £1,500, which is clearly beyond the means of NGOs and interest groups let alone local residents. Friends of the Earth Cymru considers this a restriction on participation, and potentially a failure to observe the requirements of the Ǻrhus Convention.

The strict timetable for examination mean that even those that have successfully registered as „interested parties" face almost weekly deadlines for notifying the IPC if they wish to attend a meeting or to submit written materials.

Even when the UK Localism Bill abolishes the Infrastructure Planning Commission in favour of a Major Infrastructure Planning Unit with the final decision transferred to a Minister, there is a danger that the process of consultation and examination, with all its problems, will remain the same.

Without further devolution, local authorities, statutory agencies and Welsh Government should take a more robust and active approach to engaging in the IPC process in relation to any proposal likely to affect Wales.

With further devolution, Friends of the Earth Cymru would suggest, as a first and quick step, referring decisions on energy infrastructure to Welsh Ministers rather than UK Ministers. However given that the unsatisfactory examination and consultation process would remain the same, we support the full devolution of powers for all energy generation infrastructure over 50MW as soon as possible.

The relationship between the UK Government's Energy National Policy Statements and Welsh national and local planning policies (including Planning Policy Wales, Technical Advice Note 8 and Local Development Plans) and whether or not these policies can achieve the Welsh Government's aspirations, including whether or not a formal review of TAN 8 is now required.

Although Welsh planning, energy and waste policy can be a consideration in the IPC"s examination the final recommendation has to be in line with the UK National Policy Statements (NPSs) even if they are in contradiction to a Welsh policy area.

These NPSs were designated following a very short debate in parliament before the summer recess, with inadequate time for discussing the consequences or for amendments. They are very powerful documents and have the potential to undermine Wales" plans to cut carbon emissions and become a one planet nation. There is no reference to having regard for the UK"s carbon budgets or the UK Committee on Climate Change"s recommendations on decarbonising the energy sector and emissions target for 2030, let alone the Welsh Government Climate Change Strategy.

According to the Overarching Energy NPS EN-1 the "need" for any power station should not be taken into account by the decision maker because there is a need for all types of energy generation (EN-1, para 3.1.3). In terms of Wales" carbon footprint, EN-1 states that "*The IPC does not need to assess individual applications in terms of carbon emissions against carbon budgets*" (EN-1 para 5.2.2).

We have stated our opposition to new nuclear build at Wylfa and we oppose new nuclear at Hinkley. We would like to see a more formal position adopted by the Welsh Government on its opposition to new nuclear because the current lack of clarity[11] enables the UK Government to pursue its nuclear ambitions in Wales without a structured and principled opposition viewpoint from the Welsh Government.

The principles underpinning TAN 8 – a coherent approach to planning for renewable wind energy – were laudable. However, we consider the spatial planning aspect to have been a somewhat politically immature way of conflict avoidance that has enabled successive Welsh Governments to avoid discussing wind farms in an open and transparent manner. We would now support an approach that extended the potential area for onshore wind farms to the whole of Wales so that applications can be determined on a case-by-case basis throughout Wales. Friends of the Earth Cymru responded to the initial consultation on TAN 8 – a response attached as Appendix 3. The following excerpts are as true today as they were in 2004:

> "we think that the current SSAs in the draft TAN may be placing excessive pressure and potentially unreasonable expectations within certain SSAs while excluding suitable sites outside the SSAs".
>
> "The proposals as they stand also beg the question about the policy for windfarm proposals outside the SSAs"

You have not elsewhere requested a contribution about National Grid. Friends of the Earth Cymru believe National Grid to be an inherently conservative organisation that is resistant to new ideas and has a tendency to over-specify the grid connections it believes are necessary to connect generating infrastructure. National Grid knows how to erect pylons and overhead transmission wires and doesn"t want to move from this comfort zone. See our separate paper (Appendix 2) for further information on how this relates to proposed wind farms in mid Wales.

[11] "We remain of the view that the high level of interest in exploiting the huge potential for renewable energy reduces the need for other, more hazardous, forms of low carbon energy and obviates the need for new nuclear power stations".

The potential contribution and likelihood that different types of renewable and low carbon energy (offshore wind, tidal, onshore wind, hydro-power, nuclear, bio-energy/waste, micro-generation, community energy projects) will be capable of delivering the Welsh Government's aspirations for energy generation as set out in A Low Carbon Revolution – Energy Policy Statement and the UK Renewable Energy Roadmap.
The potential contribution of these different types of renewable energy to meeting the Welsh Government's annual target for Green House Gas emission reduction.

See our detailed report (Appendix 4) for information on these points.

The potential role of other forms of energy production in Wales e.g. existing fossil fuel energy generation, proposed nuclear generation and newer technologies such as coal-bed methane and shale gas.

Fossil fuel generation: In 2008, Wales exported 26 per cent of all electricity generated to England[12]. Wales has clearly been viewed by successive Westminster governments as a convenient location to build large power plants (both nuclear and fossil fuel). Friends of the Earth Cymru considers that all new electricity generation infrastructure in Wales should now be zero-carbon. As the generation from these renewable sources increases, it will replace fossil and nuclear power stations that reach the end of their useful lives until the energy generated is entirely zero carbon, fulfilling Welsh energy and sustainability policies.

Shale gas: Friends of the Earth Cymru is strongly opposed to the development of shale gas. This is a technology that has caused serious water pollution in aquifers in the USA and can trigger earthquakes. Until the industry can provide reassurance that the techniques used will not be environmentally damaging, the precautionary principle should be applied (i.e. no drilling for shale gas in Wales). The fuel released is a fossil fuel that contributes to climate change. Fossil fuel reserves hitherto identified worldwide (before shale gas was a serious consideration in Wales) already contain twice the amount of carbon that would be necessary to cause dangerous climate change[13]. George Monbiot has pointed out the lack of regulation enjoyed by the shale gas industry[14]. The Welsh Government should press DECC and the Environment Agency to ensure that the shale gas industry is regulated to the same degree as any other resource/extraction industry.

Nuclear power: Friends of the Earth Cymru is delighted that a judicial review has begun, challenging DECC"s decision to press ahead with nuclear new build in the absence of a thorough and critical review of the events surrounding the nuclear disaster at Fukushima. Like Chernobyl before it, Fukushima has reminded people around the world that nuclear reactors are subject to human failure. Human failure in relation to nuclear reactors can lead to catastrophic nuclear meltdown with wide-scale impacts, including a genetic legacy that passes through the generations.

Nuclear power is expensive – if it had not received billions of pounds from the taxpayer it would never have generated a single kWh – and over coming decades will continue to enjoy billions of pounds" worth of implicit and explicit subsidies from the taxpayer. Friends of the Earth Cymru is concerned that the UK government appears to be pressing ahead with large subsidies for nuclear power despite an agreement that such facilities would only proceed "provided that they receive no public subsidy". Aside from the

[12] National Assembly for Wales, July 2011, *Greenhouse gas emissions in Wales*
[13] George Monbiot, 18 July 2011, *If it really wants to cut carbon, why is the coalition issuing licences to drill?*
[14] George Monbiot, 31 August 2011, *Shale fail*

subsidies highlighted by the Energy and Climate Change Select Committee[15], the following subsidies exist[16]:

- Limitations on liabilities: operators" insurance liabilities are limited to the first £140M of claims. The UK Government is responsible for insurance for the following £300M. It is not clear if there is insurance that would cover any amount above and beyond £440M: certainly, the insurance industry itself would be unlikely to take on the full risk associated with nuclear insurance. There is no equivalent subsidy for renewables.
- Underwriting of commercial risks: the UK Government has underwritten most of the commercial risks of nuclear power. The UK Government"s bailout of British Energy to the tune of £5bn is a good example. The fact is that if a nuclear operator goes out of business there is no one else other than the government (i.e. the taxpayer) who can step in to avoid failure of the nuclear industry. In the meantime, generous dividends are paid to private shareholders in an example of a business model that follows the banking sector: socialising the losses and privatising the profits. There is no equivalent subsidy for renewables.
- Protection against terrorist attack: the UK Government established the Civil Nuclear Constabulary to protect nuclear resources from attack. There are more than 1,100 police officers in this body, earning an average £35,600, which has a budget of more than £83 million in 2011-12[17]. 95 per cent of this budget is from public sources: the Nuclear Decommissioning Authority (NDA) and British Energy. There is no equivalent terrorist threat for renewables.
- Costs of disposing of nuclear waste: charges levied on nuclear operators for disposal of waste by the Nuclear Decommissioning Authority are substantially below commercial rates[18]. A commercial rate would kill any prospect of new nuclear build. The costs arising from dealing with highly reactive nuclear waste will be borne by future generations who will receive no compensatory benefit. There is no equivalent waste issue with renewables.
- Decommissioning costs: it is clearly impossible for government to shed responsibility for decommissioning to the private sector because of the ever-present risk that nuclear companies will fail. Government is therefore forced into *de facto* underwriting of these uninsurable costs. Indeed, these costs are to a large extent inestimable because many sites "had not been designed with decommissioning in mind, and record-keeping particularly in the early days of nuclear development had not always been sufficiently detailed to inform decommissioning several decades later"[19]. In just two years between 2005 and 2007, the NDA"s estimate of future costs increased 18 per cent (accounting for inflation) to £73bn. Investing in nuclear power captures governments in a cycle of expenditure that once started will take centuries to exit. There is no equivalent decommissioning problem with renewables.
- Institutional subsidies: many institutions funded entirely or partially by the taxpayer prop up the nuclear industry, including the National Nuclear Laboratory[20], a „nuclear academy"[21], the Office for Nuclear Development[22], the Nuclear Development Forum[23], the West Cumbria Strategic Forum[24], the Geological Disposal Implementation Board[25], the Nuclear Decommissioning Authority[26]

[15] Long-term contracts at a guaranteed price for nuclear power. See: House of Commons Energy and Climate Change Committee, 27 April 2011, *Electricity market reform*
[16] Many of these examples are taken from Energy Fair, September 2011, *Nuclear subsidies*
[17] Civil Nuclear Constabulary, September 2011, *Freedom of Information request*
[18] Nuclear Engineering International, April 2008, *Buried costs*
[19] National Audit Office, January 2008, *The Nuclear Decommissioning Authority: Taking forward decommissioning*
[20] Which, although "fully customer funded", has a list of clients that is almost entirely public (the Ministry of Defence, Office for Nuclear Regulation, Nuclear Decommissioning Authority etc.)
[21] National Skills Academy Nuclear, see http://www.nuclear.nsacademy.co.uk/about-us/structure-academy
[22] Office for Nuclear Development, see http://www.decc.gov.uk/en/content/cms/meeting_energy/nuclear/new/office/office.aspx
[23] Nuclear Development Forum, see http://www.decc.gov.uk/en/content/cms/meeting_energy/nuclear/forums/develop_forum/develop_forum.aspx
[24] West Cumbria Strategic Forum, see http://www.decc.gov.uk/en/content/cms/meeting_energy/nuclear/forums/west_cumbria/west_cumbria.aspx
[25] Geological Disposal Implementation Board, see

(currently swallowing nearly half of DECC"s budget[27]), the Committee on Radioactive Waste Management[28], the Nuclear Advanced Manufacturing Research Centre[29], the Nuclear Legacy Advisory Forum[30], nuclear research under the Engineering and Physical Sciences and Natural Environment Research Councils, the Environment Agency for its regulatory function, the Nuclear Energy Agency[31], the International Atomic Energy Agency[32], Euratom Supply Agency[33] and the Office for Nuclear Regulation[34]. The institutional support for renewables is incomparable.

The transport issues relating to wind turbines and other forms of renewable energy including their impact on roads, traffic and tourism.

Evidence indicates that wind farms have a negligible effect on tourism[35] and that the effects can be positive. For example, a survey by the University of the West of England into the impact of a wind farm in Devon on tourists concluded that "wind farms are a positive draw for tourists and most tourists would not boycott areas of natural beauty just because a wind farm was positioned nearby"[36]. Certainly the net employment effects of wind farms are overwhelmingly positive.

Other forms of renewable energy are less visually intrusive and Friends of the Earth Cymru sees no reason why they would have any impact on tourism.

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http://www.decc.gov.uk/en/content/cms/meeting_energy/nuclear/forums/geo_disposal/geo_disposal.aspx

[26] Nuclear Decommissioning Authority, see http://www.nda.gov.uk

[27] One quarter of the NDA's £3bn annual income is proposed to come from commercial sources over the coming four years, see http://www.nda.gov.uk/news/arac-2010-2011.cfm . Total annual budget for DECC in 2010-11 was £6.3bn, see http://www.official-documents.gov.uk/document/hc1012/hc10/1009/1009.pdf

[28] Committee for Radioactive Waste Management, see http://corwm.decc.gov.uk/

[29] Nuclear Advanced Manufacturing Research Centre, see http://namrc.co.uk/

[30] Nuclear Legacy Advisory Forum, see http://www.nuleaf.org.uk/

[31] Nuclear Energy Agency, see http://www.oecd-nea.org/

[32] International Atomic Energy Agency, see http://www.iaea.org/

[33] Euratom Supply Agency, see http://ec.europa.eu/euratom/contacts.html

[34] Office for Nuclear Regulation, see http://www.hse.gov.uk/nuclear/

[35] The 'worst case scenario' of the impact of wind farms on tourism employment in Scotland is 0.1% of employment. See Glasgow Caledonian University, March 2008, *The economic impacts of wind farms on Scottish tourism*

[36] University of the West of England, 2007, *Wind farms are good for tourism*

Planning Act 2008
Infrastructure Planning (Examination Procedure) Rules 2010

Energy from Waste Generating Facility at Brig Y Cwm, Near Merthyr Tydfil, Wales

By
Alan Watson (C.Eng)
Public Interest Consultants

ON BEHALF OF
FRIENDS OF THE EARTH CYMRU
(FOEC)

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Introduction

1. This objection is submitted on behalf of Friends of the Earth Cymru and addresses the following concerns:

   1) The proposal is not sustainable and would undermine effective implementation of the National Waste Strategy for Wales. It would undermine recycling, increase waste transport and result in waste being treated lower in the waste hierarchy than would otherwise be the case. This is not consistent with the local, national and European policy objectives.
   2) The total environmental costs of the proposal outweigh the benefits of the scheme.
   3) The assessments of climate change impacts presented in support of the proposal are flawed and over-state benefits.
   4) The visual impacts of the proposal on this greenfield[1] site would be large and unacceptable.
   5) Lack of effective consultation and the failure of the process to facilitate meaningful public participation.
   6) The proposal is premature in relation to the emerging waste policy framework for commercial and industrial wastes in Wales.

[1] The site is not, in planning terms, previously developed land due to the restoration conditions on the current planning permission.

Ground 1 – Policy, Sustainability and Need

The proposal is not sustainable and would undermine effective implementation of the National Waste Strategy for Wales. It would undermine recycling, increase waste transport and result in waste being treated lower in the waste hierarchy than would otherwise be the case. This is not consistent with the local, national and European policy objectives.

The Waste Hierarchy, Need and Sustainability

2. The application acknowledges[2] that compliance with the National Waste Strategy for Wales means that "*there will be far less need for 'energy from waste' plants with the number and/or capacity required progressively reducing from 2025 to 2050*". In fact the Strategy envisages no requirement for Energy from Waste at the end of this period as this is the target date for "*One Planet Living*".
3. The implications of the proper implementation of the National Strategy are profound, in line with the urgent need to reduce the environmental and social impacts associated with over-consumption of resources and the related over-production of wastes. The applicant fails to grasp the significance of these changes and the proposal would dramatically undermine the effectiveness of the National Strategy. Whilst there is some room for discussion about the threats to recycling from incineration it is self evident that incineration, relying as it does on a continuous supply of relatively high calorific value feedstock, is incompatible with an ambitious programme of waste reduction as incorporated in the Welsh Strategy.
4. The application therefore fails to properly address the implications and obligations arising from policy for high recycling, waste reduction and the associated phase out of energy-from-waste.
5. The provision of a single, extremely large, incineration facility which inevitably lacks flexibility would be a retrograde step at a time when levels of waste in Wales are falling rapidly, Landfill Directive obligations are being comfortably met, the waste streams are changing rapidly and energy is being directed at achieving the highest possible levels of recycling consistent with an ambitious programme of waste reduction. In the event the application was approved then the inevitable consequence of reducing inputs from the proposed Welsh collection area would be the unsustainable longer distance haulage of waste from English Authorities to allow continued operation of the facility.

Waste Planning in Wales and 'Need':

> *'Our Vision of a Sustainable Wales is one where Wales: lives within its environmental limits, using only its fair share of the earth's resources so that our ecological footprint is reduced to the global average availability of resources, and we are resilient to the impacts of climate change' (Source: One Wales: One Planet (Welsh Assembly Government 2009)).*

6. Planning Policy Wales says (Para 12.5.3):

[2] Engineering Design Statement para 4.1.4

Waste should be managed (or disposed of) as close to the point of its generation as possible, in line with the proximity principle. This is to ensure, as far as is practicable, that waste is not exported to other regions. It also recognises that transportation of wastes can have significant environmental impacts. The waste hierarchy, the proximity principle and regional self-sufficiency should all be taken into account during the determination of the BPEO for the network of waste management installations that provides the best solution to meet environmental, social and economic needs.

7. The requirements to demonstrate that a proposal represents the BPEO (Best Practicable Environmental Option) and that waste is disposed of in line with the proximity principle are not material considerations in waste planning in England. Crucially the BPEO assessment must deliver the dramatic reductions in waste arisings which are essential to assist the transformation to sustainability from the current deeply unsustainable society. The applicant does not appear to have fully appreciated these enormous differences from the English policy framework.

8. "Towards Zero Waste"(Welsh Assembly Government 2010), the "*overarching waste strategy document*" and the more detailed implementation in the sector plans, of which that for municipal waste has already been published (Welsh Government 2011), align with the Welsh Government's Sustainable Development Scheme "*One Wales: One Planet*"(Welsh Assembly Government 2009).

9. The key outcomes of the Strategy are:

   - A sustainable environment where the impact of waste in Wales is reduced to within our environmental limits (one planet levels of waste) by 2050.
   - A prosperous society, with a sustainable, resource efficient economy
   - A fair and just society, in which all citizens can achieve their full human potential and contribute to the wellbeing of Wales through actions on waste prevention, reuse and recycling.

10. They Strategy and plans have been prepared under section 79 of the Government of Wales Act 2006, which places on the Welsh Government a duty to promote sustainable development - the ultimate test of which is the to live within our environmental limits which demands the achievement of "One planet living".

11. The strategy sets a high standard for the protection of the environment in Wales and it is hoped that the IPC would aim for at least equivalent environmental standards.

12. 'Towards Zero Waste' therefore includes targets for levels of recycling which are significantly more ambitious than those in England. It is important to note, however, that they are the minimum levels the Welsh Government has recognised need to be achieved as part of the path to transfer from the deeply unsustainable way we live today towards the "one planet" goal.

13. The recycling targets for Wales are statutory targets set in the Waste (Wales) Measure 2010 supported by the Recycling, Preparation for Re-use and Composting Targets (Definitions) (Wales) Order 2011. As the minimum recycling targets are already achieved and even exceeded in parts of Europe it can be confidently predicted that significantly higher levels than the minimum targets can be achieved in practice if they are not undermined in practice by inappropriate policy decisions.

14. Crucially, and unlike in England, the recycling targets are integrated with ambitious, but necessary, targets for waste reduction.

One Planet Living

15. Achieving a "one planet goal" means reducing the ecological footprint of Wales to a 'fair earthshare' of c.1.88 global hectares/ capita from the 2003 level of 5.16 global hectares/ capita. This was the basis of the 2009 consultation "*Towards Zero Waste– One Wales: One Planet*" and the subsequent policy targets.
16. A reduction of nearly three-fold in our footprint requires major changes in the way we live, work and consume. Inevitably this will have profound impacts on the production of waste. The current targets in the Welsh Government strategy aim to achieve this by 2050.
17. The current Welsh Government targets, however, take no account of the fact that the per capita 'fair earthshare' reduces with increasing global population. Thus targets set for 2050 should be based on the projected population of the earth at that time rather than the population in 2003 from which the earthshare in the consultation and current targets was calculated.
18. The global population is anticipated to increase from the 2003 population of c. 6 billion to between 7.3 and c.10.7 billion in 2050 (Heinberg 2007):

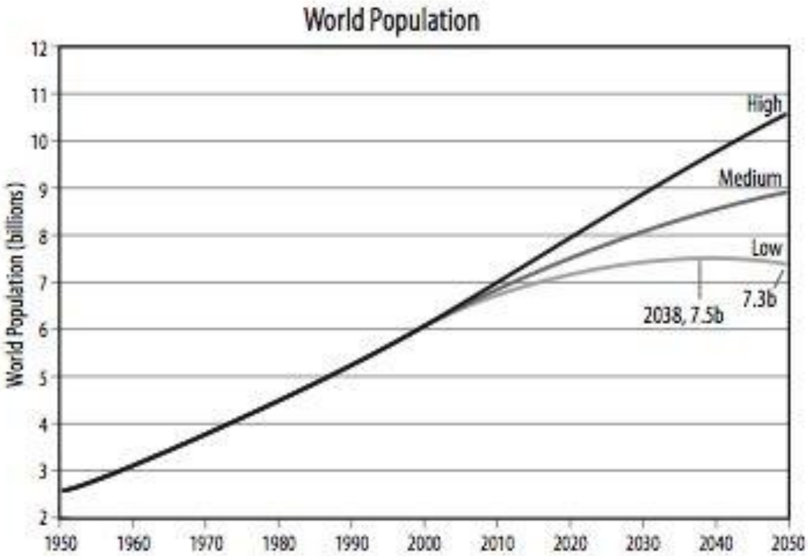


Figure 11. World population, history and forecast. Credit: United Nations Population Division, World Population Prospects

19. The consequence is that if the current targets, including those for reduction in total waste, are achieved and a footprint 1.8 gha/ capita is achieved by 2050 this will not be sufficient to achieve sustainability or "*one planet living*". The fair earth share in 2050 will be 1.03 to 1.48 gha/ capita and so Wales would still be consuming between 20% and 80% too many resources with a most likely scenario of c.50% overconsumption. Obviously this makes a significant difference to the levels of waste reduction required to achieve a 'fair earthshare' and the current targets for the reduction in waste certainly cannot be seen as conservative. Future reviews are likely to have to increase the current targets for waste reduction and thus waste management infrastructure must be flexible enough to cope with these changes.

Waste Reduction Targets and 'Need'

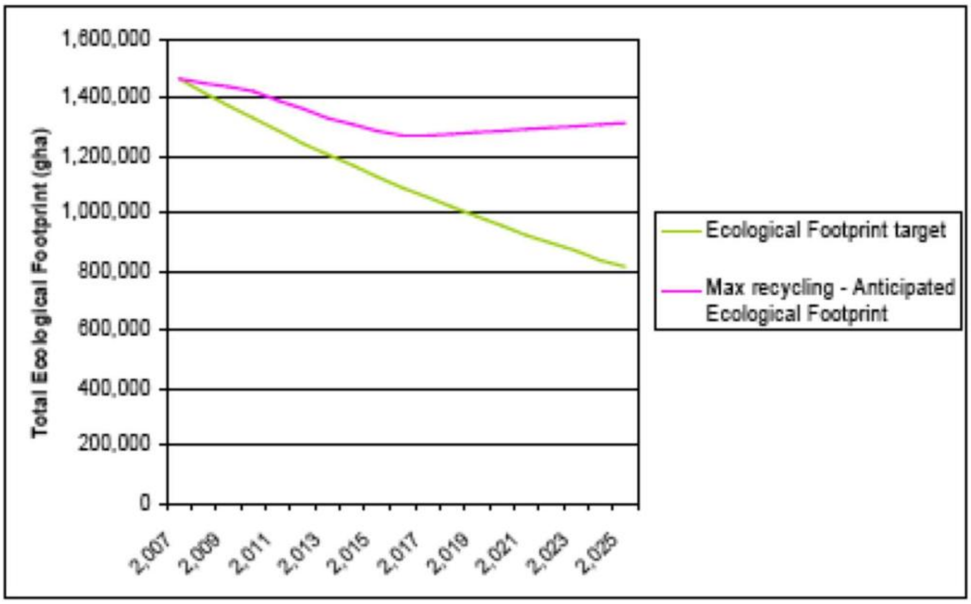
20. The report by consultants Arup assessing the ecological footprint associated with the Welsh waste strategy (Arup for Welsh Assembly Government 2009) emphasised that to significantly reduce the size of the ecological footprint:

    "*it is fundamental that recycling becomes an option for waste management only after reduction and reuse*" (*emphasis in the original*).

21. The Arup report shows that with recycling alone, even with the relatively high targets in Wales the total impact of waste arising will only be reduced by 10% for municipal waste, 6% for commercial and industrial waste and 14% for construction and demolition waste, based on a 2007 baseline.

22. This is best illustrated graphically and the figure below, taken from the Arup report, shows how even 70% recycling by 2025 fails to meet even the trajectory necessary to achieve the current 2050 ecological footprint target unless accompanied by very significant waste reduction:

Figure 22: Comparison of the reduction in EF that can be achieved through the targets in the proposed waste strategy versus that required to reduce the EF to sustainable levels



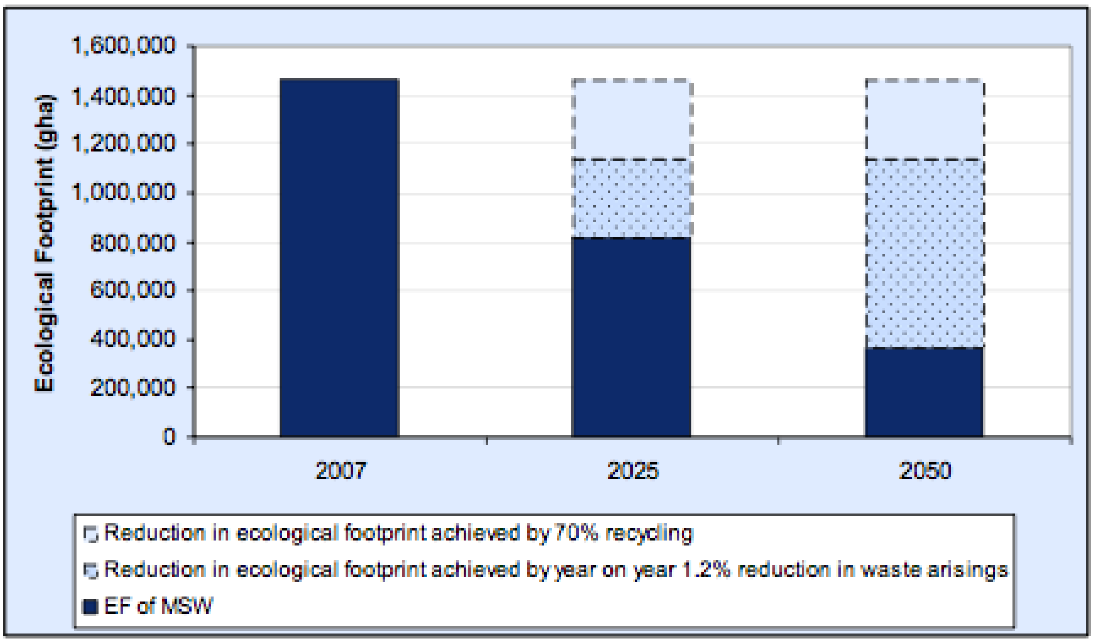
23. Furthermore this report confirms "*although the proposed recycling targets will help to reduce the EF* [Ecological Footprint] *of waste that can be recycled, research suggests that high statutory recycling targets can lead to local authorities focussing on recycling at the expense of waste prevention.*"

24. Towards Zero Waste (page 4) attempts to address these concerns and says that by 2025, there will be "*a significant reduction in waste (of around 27% of 2007 levels)*" and (page 5) that by 2050 there will be a reduction of "*roughly 65% in waste compared to current levels*".

25. The key steps that will need to taken towards the 2025 milestone include the "*need to reduce our waste by around 1.5% (of the 2007 baseline) each year across all sectors"* in order to achieve the one planet goal for 2050.

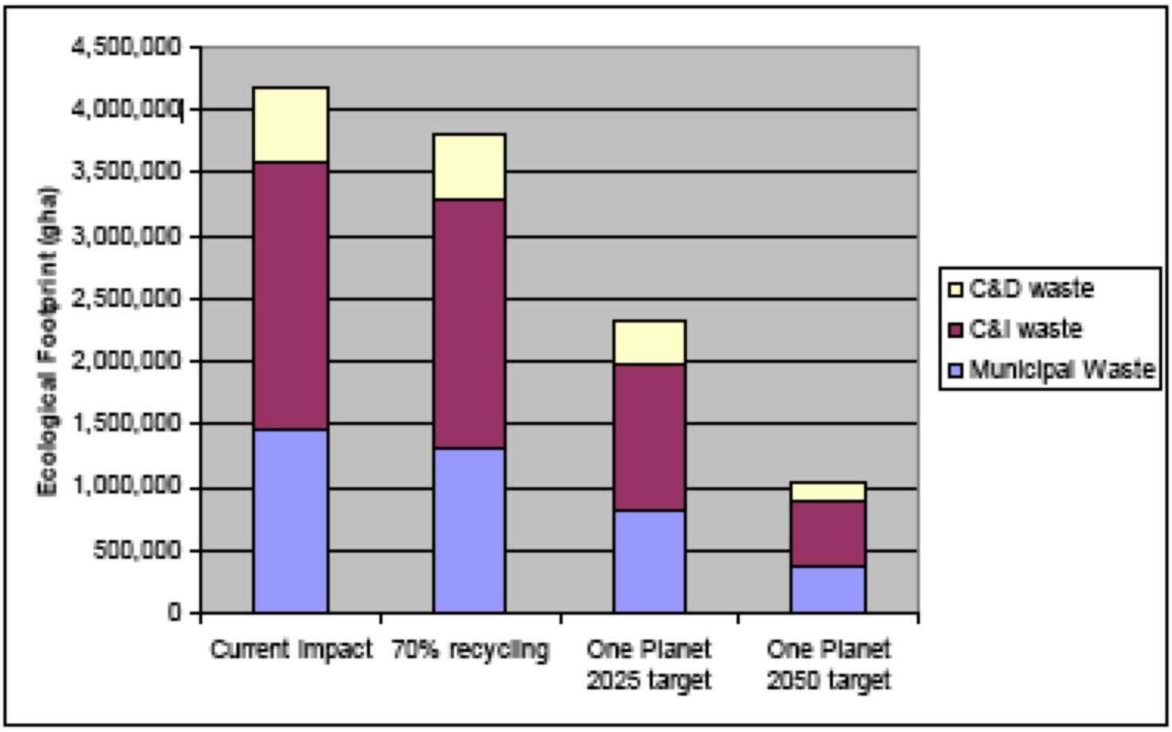
26. The targets are to be included in the sector plans and 'Towards Zero Waste' says "*we will consult on annual waste prevention targets of -1.2% for household waste, -1.2% for commercial waste, -1.4% for construction and demolition waste, and around -1.4% for industrial waste (in each case this will be a percentage of the 2007 baseline)*".

27. To date only the sector plan for municipal waste has been published. This includes a reduction target of 1.2% pa and the importance of the waste reduction contribution to the sustainability goals can be seen to be equivalent to the 70% recycling target up to 2025 and then very much greater in the period 2025 to 2050:



Ecological footprint (EF) of municipal solid waste (MSW) showing the impact of meeting the waste prevention and recycling targets (Welsh Government 2011)

28. A graph in the earlier Arup report (Arup for Welsh Assembly Government 2009) supporting the 2009 consultation more clearly shows the scale of mismatch between a 70% recycling target and the "One planet" goals without the recommended waste reduction targets:



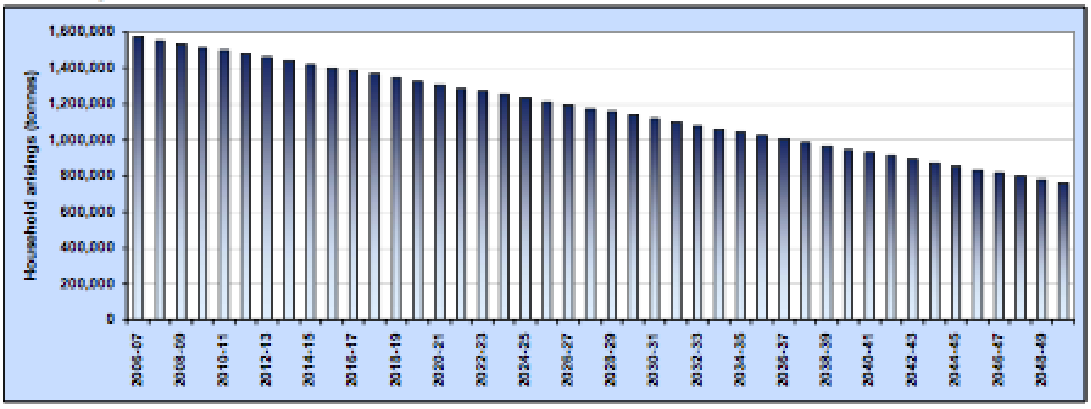
29. To reduce the Ecological Footprint to even 1.8 g/ ha capita at current population levels was assessed to require a further reduction in the footprint, on top of the 70% recycling targets, of:

    i Municipal waste - 34% by 2025 and 65% by 2050.
    ii Commercial and Industrial waste - 39% by 2025 and 69% by 2050

    iii Construction and Demolition waste - 28% by 2025 and 59% by 2050

30. These figures show that the final targets are pitched lower than is likely to be required to achieve the one planet goal.

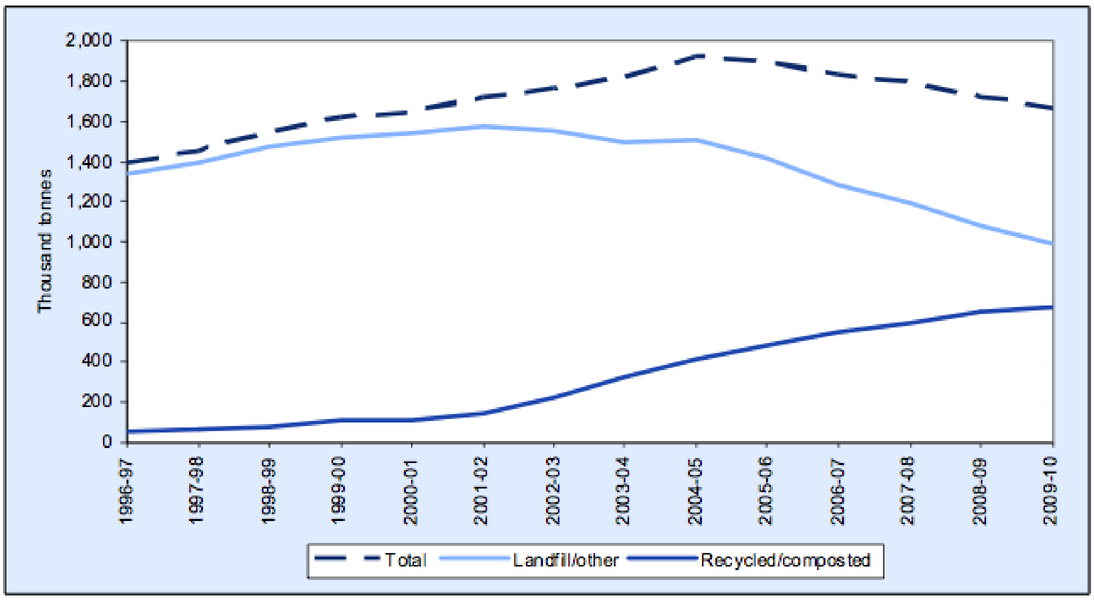
31. The effect of the adopted reduction target on household waste production over the period from 2007 to 2050 is illustrated graphically:



32. The applicant, by contrast, has largely relied on the excessive growth rates in the regional plans which pre-date the new national strategy and therefore have little relevance in relation to the long-term targets.

33. Current performance towards the recycling and reduction targets is promising and underlines how irrelevant the growth rates in the regional strategies have become.

34. The MSW Sector Plan confirms an average annual reduction in household waste of -1.7% that has already occurred between 2004-05 and 2009-10 – comfortably above the target reduction rate. MSW has fallen at a similar rate to household waste:



MSW waste arisings in Wales – source Wastedataflow and Municipal Waste Management Report for Wales, 2009-10 - November 2010 (Welsh Government 2011).

35. At the same time there has been an increase in the percentage of municipal waste recycled, reused and composted in Wales, from 37 per cent in January to March 2010 to 43 per cent in January to March 2011 and the provisional overall reuse/ recycling/ composting rate for 2010-11 was 44 per cent[3].

36. With a construction period of c.44 months (Supporting Statement Para 8.7) operation would be unlikely to start before 2016 and probably later by which time the total household arisings for Wales should be c. 1.4 million tonnes, less than twice the capacity of the incinerator. By 2025 with 70% recycling the residual household waste would be less than 360,000 tonnes and by 2040 residual household waste would be less than 270,000 tonnes.

37. In April 2011 the partnership of the five councils in north Wales named a reduced shortlist for its £800 million long-term residual waste treatment contract and did not include Covanta[4]. The contract will run for 25 years and includes approximately 150,000 tpa of waste – this already leaves a major shortfall in the Covanta need case which could only realistically be met by importing waste into Wales. The assessments and modelling in the application cannot therefore be relied upon as a robust assessment to support a BPEO case as the sourcing and transport of the additional waste to make up for the loss in north Wales could have a profound effect on the outcomes.

38. It can, in any case, be seen that at the outset the proposed incinerator would have the capacity to burn far more than the total residual household wastes for the whole of Wales, even if that was all available to the operators, which it is not, and if it was all suitable for incineration – which it wouldn't be.

39. Consequently increasingly large tonnages of C&I waste would be required but, as these wastes are far more price sensitive than MSW and tend to reduce quickly as prices rise, the collection areas would become much larger than just for Wales.

40. It is obvious that flexibility of future waste management options is the key if there is to be any prospect of achieving the necessary policy goals. The currently proposed incinerator represents an excessively large plant that would provide a substantial impediment to delivering even the higher recycling levels – and is completely incompatible with the levels of waste reduction that are necessary to achieve the Welsh Government targets.

Displacing Landfilled Waste?

41. It is claimed that the proposed facility "*would only target residual waste generated within Wales which would otherwise be disposed of to landfill*". This provides another way to assess the waste available for the facility by examining the trends in landfilled waste in Wales.

42. The latest Environment Agency data shows that landfilled waste in Wales is falling much faster than the reductions in MSW waste arising. This is probably largely due to the effectiveness of the landfill tax driver and is

[3] http://wales.gov.uk/topics/statistics/headlines/environment2011/110628/?lang=en

[4] http://www.letsrecycle.com/news/latest-news/councils/three-left-in-running-for-major-welsh-waste-contract

reducing due to commercial and industrial wastes being reduced, reprocessed or recycled. The consequence is that the total level of non-hazardous household, industrial and commercial waste landfilled in Wales has fallen from 2,370,000 tonnes in 2000/ 1 to 1,274,000 in 2010[5].

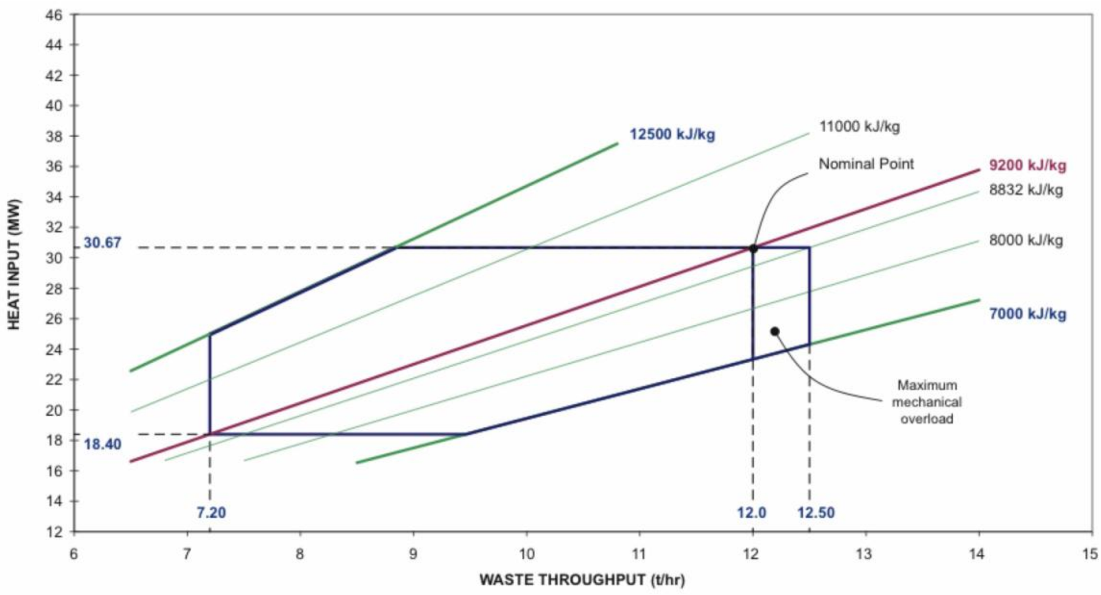
43. This landfill stream fell by 11% just between 2009 and 2010.

44. Further falls are inevitable as a result of the continuing escalation of landfill tax – furthermore a significant part of this waste is likely to be unsuitable for incineration in any case because it doesn't burn.

45. Taking these two factors together and plotting current trends indicates that by 2015/ 16 there would be less than 750,000 tpa of incinerable waste landfilled in Wales.

46. It is clear, therefore, that proper interpretation of policy shows that the waste arising projected to be available for the facility from Wales are seriously over estimated.

47. If the incinerator was built it would need 'feeding' as the operating range of modern incinerators is rather narrow as shown by an indicative Stoker diagram from the IPPC application for another recent application (at Rufford, refused on appeal):



48. The waste throughput would be larger on the Covanta plant but the principle is the same and shows that the proposed incinerator can only operate if it is fed waste with a combination of calorific value and quantity which lies within the blue area of the Stoker Capacity Diagram.

49. It is important to be confident, therefore, that the quantities and calorific value of the waste would fall within the operating parameters of the stoker diagram, and ideally be close to the 'nominal point' over the next twenty five or more years. The consequence of failing to do so is that waste which should be reduced or recycled would have to be fed to the incinerator to keep it operating.

Use of Commercial and Industrial Waste

50. Covanta claim that any shortfall in MSW can be made up by using

[5] Excluding, for simplicity, closed gate landfill sites – wastes disposed at these sites are very unlikely to be available for incineration in any case.

commercial or industrial wastes. This argument cannot be valid when, as shown above, the total levels of household, commercial and industrial wastes suitable for incineration and landfilled in Wales will be smaller than the plant capacity by the time it was constructed.

51. Furthermore experiences of Veolia in Sheffield provides a warning about how failure to address the waste stream properly at the application stage can prejudice local management of waste in the future and increase transport distances.

52. In 2001 Veolia had claimed in response to objections that their new incinerator was too big that any shortfall could be met by the use of commercial and industrial wastes, as with Covanta. In 2008, however, Veolia made an application to vary a condition attached to the planning permission for their Sheffield Incinerator[6] to allow municipal waste to be collected from Barnsley, Doncaster and Chesterfield and to increase the waste collected outside Sheffield to 75,000 tonnes because the commercial and industrial waste was unsuitable for combustion in the plant due to the higher calorific value than municipal waste and so was unsuitable for the plant.

53. In a letter from the Technical Director of RPS (Covanta's consultants), Jonathan Standen, dated 13th May 2008, Veolia provides responses to questions posed by Sheffield City Council's Planning Department, as follows[7]:

> ***The submission should review the original incinerator capacity assumptions and clearly explain the reasons why the actual throughput as turned out to be different. Is this all down to the growth in recycling?***
>
> *With planning permission granted in 2002 for the now operational Sheffield Energy Recovery Facility, it is evident that waste arisings have not grown as quickly as was assumed at the time the planning application for that development was made. Recycling rates have exceeded projections and will continue to do so particularly with Sheffield City council's desire to increase recycling well beyond 25%.*
>
> ***I am not clear as to why the burning of higher calorific value trade waste is a problem for the district heating system. I understand it produces the same amount of heat but with less waste. Is the concern that the lower waste throughput means lower gate fees for Veolia? When the original application was considered the incinerator capacity was tested against higher recycling rates, up to 45%. It was argued that if this were to occur...the capacity gap could be filled with up to 80,000 tonnes of commercial waste. It is now being arguing that this level of commercial waste is a problem.***

[6] Application to vary Condition 3 attached to permission 01/ 10135/ FUL (Bernard Road Energy Recovery Plant) 01/ 10135/ FUL (Bernard Road Energy Recovery Plant)

http://planning.sheffield.gov.uk/publicaccess/tdc/DcApplication/application_detailview.aspx?keyval=K1L2Z7NY09T00

[7] http://planningdocs.sheffield.gov.uk/WAM/doc/Application%20(Other)-290491.pdf;jsessionid=6C9528E686E34AB4F12A35A0EA16A7F0?extension=.pdf&wmTransparency=0&id=290491&wmLocation=0&location=Volume3&contentType=application%2Fpdf&wmName=&pageCount=3

Essentially the classification of wastes as set out within the Waste Framework Directive determines how wastes are defined. The composition commercial wastes today do not reflect the circumstances which prevailed in 2001.

54. Given the differences in composition and calorific value between municipal and commercial/ industrial waste then it is not a straight forward matter to change them over to fill any shortfall that faces Covanta.

55. It is also notable that Covanta's consultants, RPS, say that in just seven years the composition of commercial waste has changed to the extent that it is no longer possible to incinerate waste assessed to be suitable for incineration in 2001 then it is practically inevitable that the changes over the life of this proposed facility will have even more serious implications.

56. This experience demonstrates that reliance on commercial and industrial wastes to replace future reductions in municipal waste arisings is not a robust approach. A more likely outcome is that Covanta would attempt to fill the shortfall in Wales by importing MSW from England with unsustainable long distance haulage contrary to the proximity principle.

Recycling levels and targets:

57. Another consideration which may further reduce the quantity of waste available to Covanta is that the current recycling targets in Wales may be increased further – as has happened so many times since the "*aspirational*" 25% targets set in the 1990s.

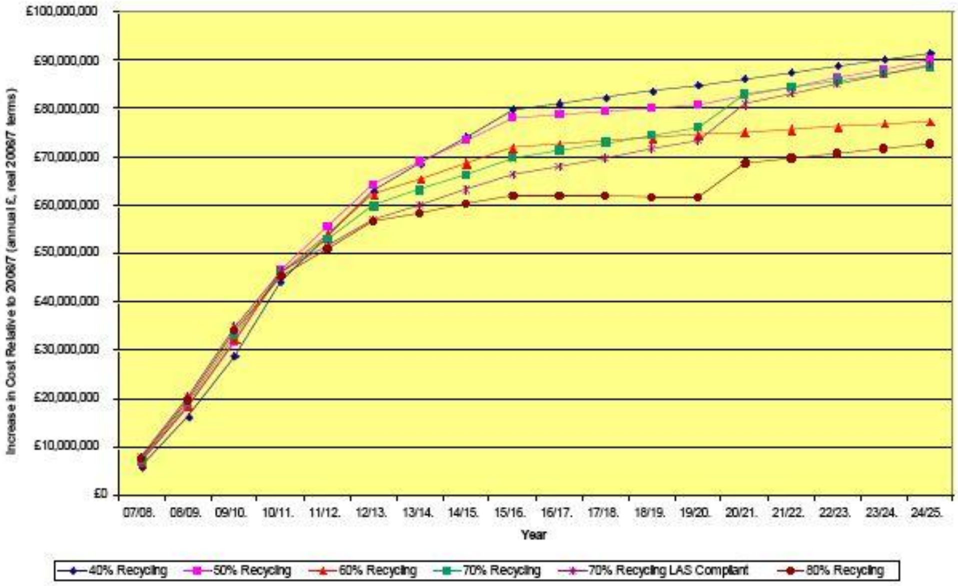
58. The current recycling targets are set as minimum targets in any case and the BPEO is likely to have higher levels of recycling than are current targeted. WRAP reports (WRAP 2010) A recent report by Environment Agency in Wales for the Welsh Assembly Government identified that up to 90% of MSW in Wales could potentially be recycled. They say:

    The 90% figure includes more paper, plastic film, disposable nappies, other glass, other organics and fines. Some of the other organics (such as wood based cat litter) and fines could be placed into an organics collection, but further developments in recycling technology, together with additional recycling infrastructure (particularly for disposable nappies) would be required in order for up to 90% of MSW to be classified as being potentially recyclable or compostable.

59. It is clear that recycling has not been maximised with the statutory targets for Wales. Whilst collection at that level currently presents difficulties the increasing pressures on fuel and resources over the coming decades will inevitably mean that more materials will be designed for easy recyclability. The changes in product design have already started to take effect but increasing cost, consumer and regulatory pressures will inevitably accelerate the process. The need for infrastructure to support the BPEO is therefore in appropriate recycling capacity and not for incineration.

60. This is reinforced by the fact that the original 2009 Welsh policy consultation reports (Welsh Assembly Government 2009) showed that the most cost effective recycling level over the period to 2024/ 25 would be 80% of the waste:

Figure 3: Evolution in Annual Increases in Cost Relative to 2006/7 (annual increase in real £ 2006/7)

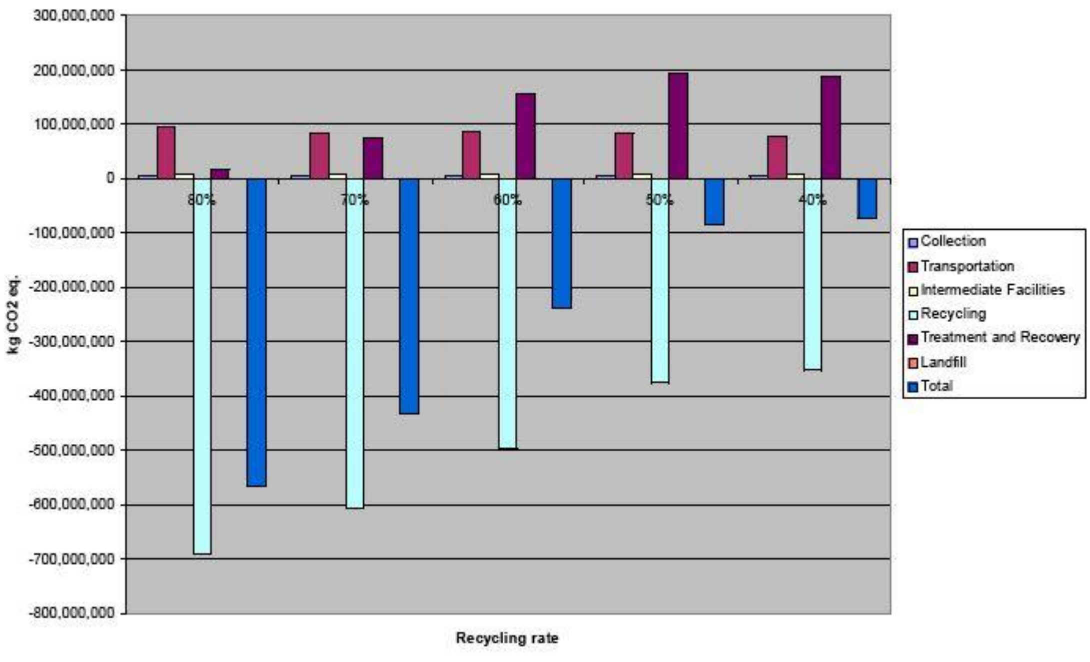


61. Again the changes in product design are likely to increase the cost effectiveness of recycling at the highest levels.

62. In addition to the cost savings there are also major environmental advantages in achieving these levels of recycling compared with the minimum levels of recycling required by current policy and legislation.

63. The projected greenhouse gas savings in Wales are shown to more than double (from a net c.250,000 tonne saving to a net 550,000 tonne saving) when recycling levels increase from 60% to 80%:

Figure 1 – Global warming potential for each recycling target option for 2024/25 (a negative figure means greenhouse gas emissions are displaced).



64. This modelling was carried out by the Environment Agency using the

WRATE model and this is based on the indicated recycling targets with incineration of the residual wastes. It can be seen that whilst recycling has a strong carbon dioxide benefit the emissions from incineration with CHP are assessed as being a net carbon dioxide producer.

65. Properly assessed, with appropriate assumptions about, for example, the displaced electricity generation, the proposed incinerator would similarly be a net producer of carbon dioxide (especially as at the proposed site there is little realistic prospect of CHP ever being applied to the plant).

Incineration vs Recycling

66. The question of whether incineration undermines recycling is clearly an important one. Firstly there is little doubt that in the majority of circumstances recycling is environmentally beneficial.

67. In their evidence to the Environmental Audit Committee for their report into Climate change and local, regional and devolved Government (House of Commons Environmental Audit Committee 2008), WRAP drew attention to their specialist review of international studies "*Environmental Benefits of Recycling*" (WRAP 2006) which shows how increased recycling is helping to tackle climate change and emphasises the importance of recycling over incineration and landfill as the appropriate way forward. The evidence from WRAP said:

    i In the vast majority of cases, the recycling of materials has greater environmental benefits than incineration or landfill.

    ii The UK's current recycling of these materials saves 18 million tonnes of CO_2 equivalent greenhouse gases per year, compared to applying the current mix of landfill and incineration with energy recovery to the same materials.

    iii This is equivalent to about 14% of the annual CO_2 emissions from the transport sector and equates to taking 5 million cars off UK roads.

68. WRAP concluded:

    14. The message of this 2006 study is unequivocal. Recycling is good for the environment, saves energy, reduces raw material extraction and combats climate change. It has a vital role to play as waste and resource strategies are reviewed to meet the challenges posed by European Directives, as well as in moving the UK towards more sustainable patterns of consumption and production, and in combating climate change by reducing greenhouse gas emissions.

69. WRAP tabulated the results of their review showing the numbers of studies in each category:

Table ES 4: Overall environmental preference of waste management options across all reviewed scenarios

	Recycling v Incineration			Recycling v Landfill		
Material	Recycling	Incineration	No preference	Recycling	Landfill	No preference
Paper	22	6	9	12	0	1
Glass	8	0	1	14	2	0
Plastics	32	8	2	15	0	0
Aluminium	10	1	0	7	0	0
Steel	8	1	0	11	0	0
Wood						
Aggregates				6	0	0
Totals	80	16	12	65	2	1

	Incineration v Landfill			Recycling v Mixed			Grand Total
Material	Incineration	Landfill	No preference	Recycling	Mixed	No preference	
Paper	1	0	0	12	0	0	63
Glass							25
Plastics	2	0	1				60
Aluminium	2	0	0				20
Steel							
Wood	7	0	0				7
Aggregates							6
Totals	12	0	1	12	0	0	201

70. It is clear that for all material streams recycling was assessed as being preferable to incineration. This is remarkable considering that several of the original papers were supported by the waste disposal industry in an attempt to justify less recycling and more disposal. For paper just six out of 37 papers reviewed by WRAP supported incineration over recycling. When the original papers are examined it is clear that these tended to make assumptions that are known to favour incineration such as the displacement of high carbon electricity generation - as in the WAG/ Environment Agency WRATE assessment. When future projected carbon intensities of displaced generation are substituted then few if any of the papers maintain the support for incineration over recycling.

71. In 2010 WRAP updated this 2006 review of waste management options (Michaud, Farrant et al. 2010). They assessed 55 'state of the art' LCAs on paper and cardboard, glass, plastics, aluminium, steel, wood and aggregates.

72. The conclusion, they said again "*was clear – most studies show that recycling offers more environmental benefits and lower environmental impacts than the other waste management options*". It is particularly relevant that recycling has been re-confirmed by as being the best option for the plastics upon which Covanta would be increasingly reliant given the reductions in paper and bio-waste:

- The results confirm that mechanical recycling is the best waste management option in respect of the change potential, depletion of natural resources and energy demand impacts. The analysis highlights again that these benefits of recycling are mainly achieved by avoiding production of virgin plastics.
- The environmental benefits are maximised by collection of good quality material (to limit the rejected fraction) *and by replacement of virgin plastics on a high ratio (1 to 1).*

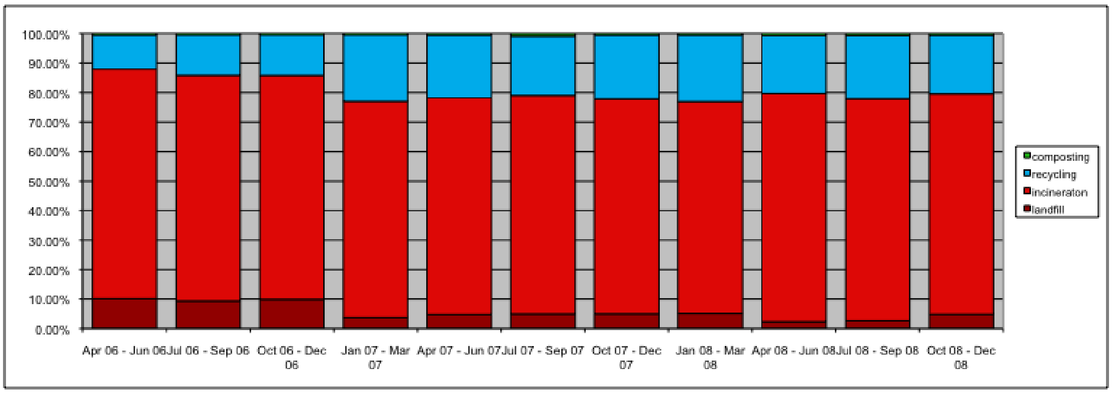
- *Incineration with energy recovery performs poorly with respect to climate change imp*act, but pyrolysis appears to be an emerging option regarding all indicators assessed, though this was only analysed in two LCA studies.
- Landfill is confirmed as having the worst environmental impacts in the majority of cases.
- As the UK moves to a lower carbon energy mix, recycling will become increasingly favoured.

73. WRAP concludes that:

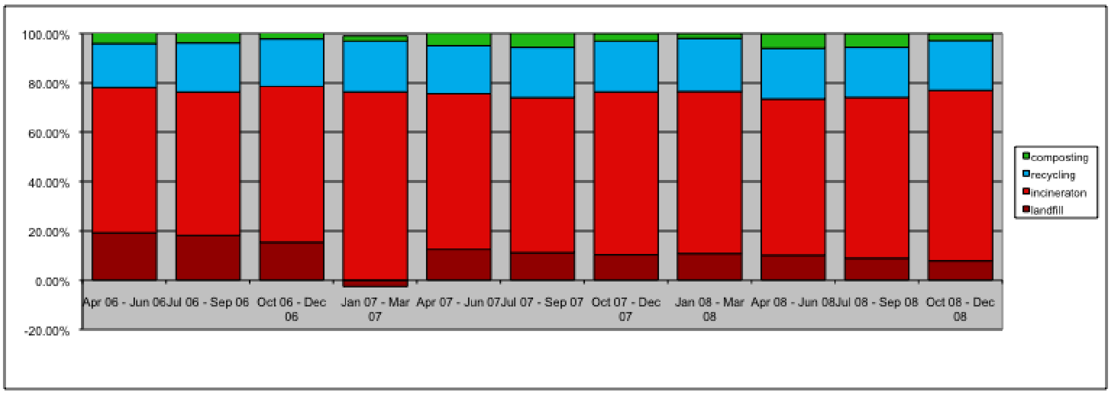
> *"Looking to the future, as the UK moves to a lower carbon energy mix, collection quality improves and recycling technology develops, then recycling will become increasingly favoured over energy recovery for all impact categories".*

74. The specific benefits of recycling in relation to climate change are addressed below. The results show that with the possible exception of waste wood incineration is not the preferred option for any element of the waste stream and that recycling should be maximised.

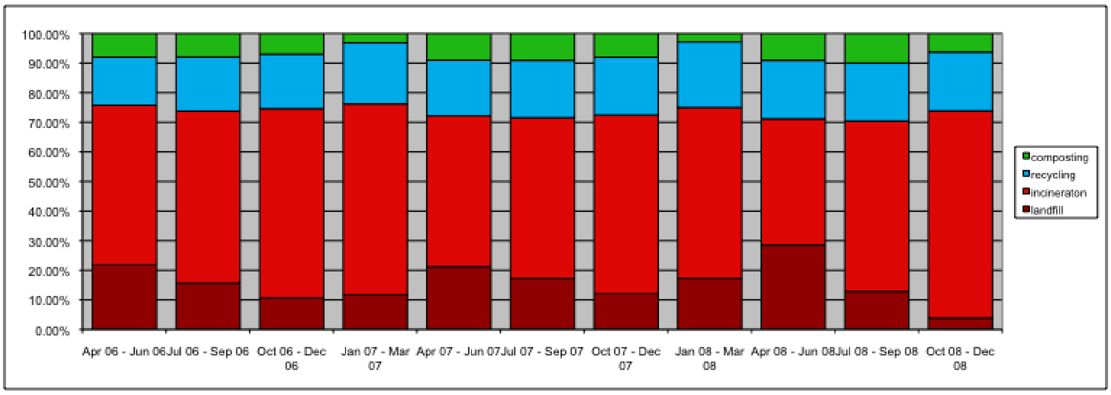
75. There is increasing evidence that higher levels of incineration undermine recycling. This is not surprising as incinerators rely particularly on paper and plastic waste to provide the homogenous waste stream with a stable calorific value that is necessary to achieve stable combustion. There is little doubt that this can, and does, happen. In Lewisham, for example, Veolia's (inaccurately named) SELCHP plant and the contract with the local authority has resulted in very low local recycling levels:



76. A similar situation with poor recycling rates arises in Portsmouth where Veolia has another incinerator:



77. Even Sheffield, one of the original "*recycling cities*" of the early 1990's has ground to a halt and needs to dramatically reduce the proportion of waste incinerated if even modest recycling targets are to be achieved:



It can be seen from the above tables that incineration causes significant local depression in recycling rates. In each case the future growth of recycling is severely constrained and incineration capacity will need to reduced - this is likely to involve contractual penalties and to increase the collection area from which the incinerator must source waste in order to continue operations.

Other examples of conflicts of Incineration and Recycling:

78. It is often claimed that there is no evidence that incineration competes with recycling for waste. In reality, there is of course a link – there is only so much waste available, so the amount processed through all treatment techniques must add up to 100% of the waste. Regional data for household waste from Denmark, often claimed to be an exemplar for incineration, in 2005 clearly shows that regions with high incineration have lower recycling and vice versa:

Region	*Recycling*	*Incineration*	*Landfill*
Hovedstaden	21%	77%	2%
Nordjyllnad	29%	63%	8%
Sjælland	31%	59%	10%
Midtjylland	40%	53%	7%
Syddanmark	41%	52%	6%

79. A study by the Zero Waste New Zealand Trust[8] reported that thermal conversion technologies need a constant supply of materials, often with a high fuel value (like paper and plastics), which can shift the focus away from recycling programs. The study stated that developing thermal conversion technologies can "*result in the creation of long-term contractual agreements with local authorities guaranteeing a certain tonnage of waste per year. This situation effectively destroys incentives for local decision-makers to minimize waste or lead resource recovery programs*."

[8] Zero Waste New Zealand Trust, *Wasted Opportunities – A Closer Look at Landfilling & Incineration*,
http://www.zerowaste.co.nz/default,33.sm

80. The Guardian reported that East Sussex County Council is "*so worried it may not be able to fulfil its contract that it has now capped Lewes and Wealden's recycling levels - effectively penalising them if they recycle more than about 30% of their waste*" (Vidal 2006). The incinerator would be operated under a contract with Veolia. Local MP Norman Baker raised the issue in Parliament[9] saying:

Norman Baker (Lewes) (LD): The Government rightly promote recycling, but is the Minister aware that Lewes district council's recycling levels have effectively been capped at 27 per cent by East Sussex county council, which will not provide further recycling credits because it wants a waste stream to feed its incinerator? Is it not about time that East Sussex county council was pulled out of the stone age and that councils that want to recycle more, such as Lewes council, which believes it can increase recycling by 50 per cent., were allowed to get on with it?

81. In 1995 Cleveland County Council signed a contract to supply waste for incineration. A 12,000 tonnes 'shortfall' in the first year led to penalties of £147,000 (ENDS 1996). The Associate Director of Environmental Services at Stockton Borough Council said "*essentially we are into waste maximisation… constrained from doing even a modest amount of recycling*".

82. Environmental Data Services (ENDS 2002) reported that an application to expand the Edmonton incinerator was rejected by Energy Minister Brian Wilson "*on the grounds that it might squeeze out recycling*". A larger incinerator, the Minister said, would give the local authority "*little incentive to do more recycling over and above the statutory minimum; and meeting or bettering recycling targets would lead to a shortfall… [resulting in] waste being imported from other areas, in contradiction of the proximity principle*". ENDS said "*Mr Wilson spelled out that it is the Government's policy that "waste should be minimised and recycling and composting undertaken before energy from waste is considered.*"

83. The Inspector's report from the Ridham Dock Incinerator inquiry[10] concluded that if permission were granted the "*provision of greater incineration capacity than necessary would tend to undermine efforts to increase waste recycling and recovery locally, and encourage the transportation of waste from a more widespread catchment area*".

[9] Hansard 2 July 2009 : Column 477

[10] Ridham Dock, Kent, 17 Oct 02: APP/ W2275/ A/ 01/ 1061392

Ash Generation and Disposal

84. The proposed incinerator would both produce 'bottom ash' and 'air pollution control residues'('APC') (including both boiler ash and bag filter dust).

85. The application proposes that the bottom ash from the facility, which constitutes c.25% of the original waste by mass or c. 187,500 tpa, would be carried by rail to an ash recycling facility located at Newport, Gwent.

86. It appears that this proposal is speculative and that no site has actually been identified. The WRATE report (Doc 8.5) says:

    "Covanta intends to use a rail- linked ash recycling facility (ARF) in south Wales; we have assumed this site to be adjacent to the Newport WTS to enable the WRATE assessment to be undertaken realistically as this is currently an option under consideration".

87. The actual distance moved, and even whether by road or rail, could therefore change significantly and given the large tonnage of waste involved this can have significant effects on the modelling results and the overall environmental impacts of the scheme.

88. The application also indicates that it would be expected to export fly ash equivalent to approximately 4% of the incoming waste mass i.e. 15,000 tpa.

89. The intention with the APC residues is to transport them by rail to a Newport transfer station for onwards bulk transport by road for disposal at Wingmoor Farm Landfill, Bishops Cleeve, Gloucestershire. There is no doubt that the 'fly ash' is hazardous waste and there is no facility in Wales able to deal with these wastes.

90. The ES is silent on both the environmental impacts of the bottom ash treatment and on the health and environmental impacts of fly ash disposal.

91. The treatment of bottom ash is clearly either a direct or indirect impact of the application and schedule 4 of the Environmental Assessment Regulations[11] require that all 'direct and indirect' impacts of an application should be assessed. As this has not been done it is not possible to 'second guess' the significance of the omission.

92. Similarly the long-term impacts of the disposal of APC residues, which represent a large increase in the production of hazardous wastes from Wales, should have been considered as part of the environmental statement.

93. The omission of such consideration is potentially serious in the light of recent research relating to emissions from the proposed Bishop's Cleeve landfill site (Macleod, Duarte-Davidson et al. 2006; Macleod, Duarte-Davidson et al. 2007).

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[11] The Town and Country Planning (Environmental Impact Assessment) (England and Wales) Regulations 1999 SI 1999 No. 293 Sched 4 Para 4. Requires:
A description of the likely significant effects of the development on the environment, which should cover the direct effects and any indirect, secondary, cumulative, short, medium and long-term, permanent and temporary, positive and negative effects of the development, resulting from:
(a) the existence of the development;
(b) the use of natural resources;
(c) the emission of pollutants, the creation of nuisances and the elimination of waste,
and the description by the applicant of the forecasting methods used to assess the effects on the environment.

94. Whilst it is described in the application as being 'inert' this is incorrect – bottom ash is never classed as 'inert'. The bottom ash is currently taxed as "inactive" waste for landfill tax purposes although this may be about to change as the default position in the recent Customs and Excise consultation is that the bottom ash should be taxed at the standard rate of landfill tax.

95. In practice the designation of bottom ash is either as non-hazardous or hazardous waste. At the end of 2006 the Environment Agency indicated that they had tested some bottom ash samples and:

"Levels of lead and zinc in a number of isolated compliance monitoring samples have exceeded the hazardous waste threshold for H14."

96. H14 is the hazardous waste criteria for ecotoxicity. Veolia has indicated (Veolia Environmental Services 2007) that when they had tested for metals and then used the Environment Agency WM2.2 assessment methodology to determine the whether the wastes were hazardous wastes about 40% of the samples from UK incinerators were found to be hazardous waste under the H14 criteria.

97. This follows increasing concern about the environmental impact of combustion residues in disposal and utilisation, especially for the release of toxic substances such as heavy metals (such as arsenic, cadmium, chromium, copper, mercury, molybdenum, nickel and, particularly in relation to ecotoxicity, lead and zinc) together with soluble salts from the residues (Stegemann, Schneider et al. 1995; Hartenstein and Horvay 1996; Hunsicker, Crockett et al. 1996; Abbas, Moghaddam et al. 2003).

98. The content of toxic metals present in the bottom ash from municipal waste incinerators is usually 10-100 times larger than in natural soils (Theis and Gardner 1990).

99. As a result of the toxicity associated with the heavy metals and other contaminants several researchers have concluded that bottom ash should be classified as a hazardous waste because of the ecotoxic properties it exhibits.

100. Ferrari et al (Ferrari, Radetski et al. 1999) subjected municipal waste incineration bottom ash to a range of ecotoxicity tests in both the leachate and solid phase.

101. Their results clearly demonstrated "*a significant increase in all antioxidant stress enzyme activity levels across all plant tests even at the lowest test concentrations (solid phase and leachate)*". This was demonstrated to be a good indicator of solid or leachate phase toxicity.

102. As with many other test regimes it is clear from this work that the bottom ash may not prove hazardous in all tests. This indicates that care must be taken with the test regimes and that selective testing could deliver apparently reassuring, and hence misleading, results. For ash to be demonstrated to be hazardous, however, a single failure of an appropriate test is sufficient.

103. Ibáñez et al. (Ibáñez, Andrés et al. 2000) found that all four samples of MSW bottom ash from two incinerators (one in an industrial and the other in a rural area) contained chemicals at or above the hazardous waste range. It should be noted that this study was published even before zinc oxide and chloride had to be considered when assessing the hazardous classification of ash.

104. More recently the work by Lapa et al (Lapa, Barbosa et al. 2002) on the

EC Valomat project concluded:

"all bottom ashes [including sample B1] should be classified as ecotoxic materials."

105. Radetski et al (Radetski, Ferrari et al. 2004) then investigated the genotoxic, mutagenic and oxidant stress potentials of municipal solid waste incinerator bottom ash leachates and reported:

"The MSWIBA leachates were found to be genotoxic with the Vicia root tip micronucleus assay.

106. These findings were confirmed by Feng et al. (Feng, Wang et al. 2007):

In this study, our results clearly demonstrated that MSWIBA leachates had genotoxicity on Vicia faba root cells as other researches did (Radetski, Ferrari et al. 2004). Bekaert et al. (1999[12]) demonstrated that the aqueous leachates from a landfill of MSWI ash had a significant genotoxicity on the amphibian erythrocytes.

107. UNEP (UNEP and Calrecovery Inc 2005) warned in 2005 that whilst ash from incinerators has been reused in civil engineering works:

"in industrialised countries, the most prevalent method of management is disposal of the ash in lined landfills to control the risk of underground pollution by soluble toxic chemicals leached out of the ash.

108. UNEP continued:

"Both fly ash and bottom ash contain chemical constituents that pose potential serious risks to operating personnel and the public. The chemical constituents of concern include heavy metals, dioxins, and furans".

109. Feng expressed surprise about countries that do not include bottom ash on their hazardous waste lists:

However, in many countries and territories (such as USA, some OECD countries, China), Bottom ash is not included in the List of Hazardous Wastes, being dumped into landfills directly or after maturation (Gau and Jeng, 1998; (Ibáñez, Andrés et al. 2000);(Lapa, Barbosa et al. 2002)). Therefore, we suggested that the comprehensive evaluation of the environmental impacts of BA is necessary before decisions can be made on the utilization, treatment or disposal of bottom ash.

110. Ore et al (Ore, Todorovic et al. 2007) examined the leachate from bottom ash that had been stored outside for six months and then used for road construction.

111. They carried out several ecotoxicity tests and found a high initial release of salts and Cu in line with relatively high concentrations in laboratory generated MSWI bottom ash leachates presented in the literature (Meima and Comans 1999; Lapa, Barbosa et al. 2002)

112. A mung bean assay using *Phaseolus aureus* revealed the toxicity of bottom ash leachate - which continued to the final tests three years later, albeit due to different compounds leaching.

113. Leachates with significantly higher concentrations of Al, Cl, Cr, Cu, K, Na, NO_2–N, NH_4–N, total N, TOC and SO_4 were generated in the road-section built on bottom ash when compared to the road-section built with conventional gravel. Compared to the leachate from gravel, the concentrations of Cl, Cu and NH_4–N were three orders of magnitude higher, while those of K, Na and TOC were one order of magnitude

[12] Bekaert, C., Rast, C., Ferrier, V., et al., 1999. Use of in vitro (Ames and Mutatox tests)and in vivo (Amphibian Micronucleus test) assay to assess the genotoxicity of leachates from a contaminated soil. Org. Geochem. 30, 953–962.

higher. After 3 years of observations, while the concentrations of most components had decreased to the level in gravel leachate, the concentrations of Al, Cr and NO_2–N in bottom ash leachates were still two orders of magnitude higher.

114. The authors concluded that high concentrations of chloride emitted from the road can lead to increased toxicity to the recipient, e.g. for plants, and the bottom ash reused in a road construction could thus have a toxicological impact on the surroundings.

115. If the ash had not been weathered (and carbonated) for six months before use then the leaching would have been significantly more damaging.

116. A series of ring tests for ecotoxicity methods have been carried out in Europe (Becker, Donnevert et al. 2007; Moser 2008). These included sampling and testing of incinerator bottom ash from a Dutch incinerator (Cu 6,800 mg/ kg; Zn 2,639 mg/ kg; Pb 1,623 mg/ kg) a high pH (about 10.5). The bottom ash was found to be ecotoxic in these tests even after it had been aged for several months (Römbke, Moser et al.).

117. The Environment Agency has admitted it does not "*have 100% confidence*" in its classification of incinerator bottom ash (IBA) as non-hazardous waste (ENDS 2009).

118. It cannot therefore be assumed that the bottom ash would be suitable for re-use as proposed. Furthermore if there are even slight concerns about the quality of bottom ash then following the regulatory fiasco at Byker where the Environment Agency allowed heavily contaminated bottom ash and fly to be spread on allotments, it is likely that customers will be reluctant to take incinerator ash. There are other alternatives for more homogenous ash locally – at Aberthaw, for example, there is at least 500,000 tpa of power station ash available for recycling.

119. Any recycling of incinerator ash is therefore likely to displace the recycling of this power station ash and this would have no environmental benefit as incinerator bottom ash from mass burn facilities like this proposal contains a wider range and higher concentration of heavy metals whilst being less homogenous than power station ash even if it was not hazardous waste.

120. The WRATE assessment indicates:

> *RPS developed an amended process to ensure a fair representation of anticipated metals recovery. This is particularly important as WRATE results are sensitive to assumptions relating to recovery of non-ferrous metals.*

121. In practice post incineration recovery of non-ferrous material is difficult and unsatisfactory due to heavy alloying of the various metals and the difficulty of subsequent recovery. Even ferrous metals recovered post incineration are badly contaminated and have low scrap value. These practical problems are not reflected in the WRATE assessment and thus the model gives a distorted perspective of the real, low, values of any recovered metals. It is notable, in any case that the application does not secure any recovery of the metals as this is left entirely to others. In practice recovery is likely to be low with high levels of residual landfill for the reasons detailed below.

122. Even when incinerator bottom ash is 'recycled' only part of the ash can be used. In Hampshire, for example, where particular efforts have been made to increase the acceptability of incineration only about 33% of the

ash seems to be utilised according to Project Integra reports[13]. This contrasts sharply with the impression given in the application and in the WRATE modelling assumptions are unclear[14] but appears to assume that 100% recycling would be delivered. In Hampshire, however, only approximately 33% of the ash is recycled:

Currently Portsmouth produces 12,000 tonnes of IBA, which is currently landfilled. Under the new recycling scheme, 12% will be process losses (water etc), 8% will be oversize and landfilled, there will be 8% residue from the process, which will also be landfilled. This will give a remaining 72% for recycling, of this material the contractor predicts that 50% will be sold, with the remainder being used in landfill engineering projects. This means that there will be a diversion of approximately 4,000 tonnes of IBA from landfill to a recycling route.

123. Furthermore I note that the Covanta's consultants, RPS, commented in March 2007 on another proposal in Exeter that:

"*In practice….markets for such material [combustion residues] are difficult to secure and are piecemeal.*"

124. For that application it was assumed that:

"*all residues will be transported and disposed of at the landfill site.*"

125. This would be the appropriate approach to take in this application also. Given the likelihood that at least a significant proportion of the ash would ultimately have to be regulated as hazardous waste for which no site is available in Wales this would be an enormous increase in exports to England – contrary to the policy goals of Planning Policy Wales.

126. **On the basis of the evidence available it is reasonable to conclude that much of the bottom ash should be treated as hazardous waste and would have to be landfilled in England.**

POPs Regulations and 'priority consideration' of alternatives

127. Technical Appendix 7.1 of the application on air quality refers to the European Regulation (No 850/ 2004 on persistent organic pollutants and amending Directive 79/ 117/ EEC as amended) (European Commission 2004).

128. This regulation implements the obligations arising from the Stockholm Convention and the 1979 Convention on Long-Range Transboundary Air Pollution (United Nations Economic Commission for Europe (UNECE) 1979) together with the associated UNECE protocols on Persistent Organic Pollutants (UNECE 1998).

129. The Regulation is "*binding in its entirety and directly applicable in all Member States*".

130. Article 6(3) of the Regulation requires that:

131. *3. Member States shall, when considering proposals to construct new facilities*

[13] Project Integra Sub Strategy (Partner Implementation Plan) – 2006/ 7 to 2012 Portsmouth City Council November 2006 http:/ / www.portsmouth.gov.uk/ media/ et20061219r7app.pdf

[14] Contrary to the Environmental Assessment Regulations which require that the data used to support the application should be provided in order that it may be checked by others. This is particularly important when using 'black box' models such as WRATE with user specified variables. Essentially a consultant can reverse engineer any output they desire by careful selection of a few key variables making it essential that a proper audit trail should be available to the IPC and objectors.

or significantly to modify existing facilities using processes that release chemicals listed in Annex III, without prejudice to Council Directive 1996/61/EC (1), <u>give priority consideration to alternative processes, techniques or practices that have similar usefulness but which avoid the formation and release of substances listed in Annex III</u>. (<u>my emphasis</u>)

132. The substances listed in Annex III are:

Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/ PCDF)

Hexachlorobenzene (HCB) (CAS No: 118-74-1)

Polychlorinated biphenyls (PCB)

Polycyclic aromatic hydrocarbons (PAHs)

133. Incineration of waste, as proposed, clearly results in releases of all these substances - especially in residues but also in emissions to atmosphere (European Commission 2006).

134. Section 4(b) of the Persistent Organic Pollutants Regulations 2007 (HMSO 2007) requires the Environment Agency to comply with Article 6(3) of Council Regulation (EC) 850/ 2004 (as amended) (European Commission 2004) 'the EC POPs Regs'), If it is considering an application for an environmental permit.

135. The Environment Agency cannot, as part of the environmental permitting process, give effect to the requirement to "*give priority consideration to alternative processes, techniques or practices that have similar usefulness*" but which avoid the formation and release of PCDD/ PCDF, HCB, PCB and PAHs. This must inevitably be a planning function and this has been confirmed by the Environment Agency in legal correspondence to the Hull-based anti-incineration campaign group 'HOTI'. The Agency said (2nd December 2009):

"The encouragement of recycling and promotion of alternative waste management solutions within a particular area are matters for local waste planning authorities and the Secretary of State, not for the Agency"

136. This has been acknowledged in a recent public inquiry Decision letter (Grantham 2011) saying:

"IR1239. Uncontested evidence suggests that the proposed ERF would be a net producer of persistent organic pollutants (POPs) and that it is therefore necessary, under European law, to give priority consideration to alternative processes that would not generate and release these substances. This would appear to a matter for the planning regime, rather than the pollution control authority. [1035-1036]

IR1240. The implications of the law are not for me to decide. Nevertheless, this argument lends weight to the suggestion that the application should be refused so that more waste, which would otherwise be incinerated, could be recycled, composted or fed to an anaerobic digester. [1046]"

137. The Applicant suggests that because high temperature incineration can be used to destroy POPs the regulation does not apply to incineration. This is a weak argument which is not consistent with the approach of the Inspector above nor of the Environment Agency. This is not, in any case, a hazardous waste incinerator but a proposal for a municipal waste incinerator which will generate relatively high levels of dioxins and other POPs in the air pollution control residues but for which alternatives which produce no, or lower emissions of POPs, are available.

138. "*Priority consideration*" should therefore be given to alternative technologies such as anaerobic digestion and MBT processes.

Ground 2 – High Environmental Costs

The total environmental costs of the proposal outweigh the benefits of the scheme.

External Costs of Emissions:

139. The assessment in the application and environmental statement only consider the air pollution and health impacts in the immediate vicinity of the proposed incinerator.

140. It is much too simplistic to assume that as long as the air quality standards are achieved at the point of maximum ground level concentrations then emissions from the incinerators would be acceptable and would have no adverse impact on health or the environment, The high level of air pollution related deaths acknowledged by COMEAP and the Government demonstrates this.

141. The inadequacy of the applicants approach particularly in relation to pollutants which have no threshold such as particulates is clear. By 2001 Staessen (Staessen, Nawrot et al. 2001) concluded that "*current environmental standards are insufficient to avoid measurable biological effects*". More recently Kraft et al (Kraft, Eikmann et al. 2005) found that no safe level could be established for oxides of nitrogen and concluded that "*on basis of epidemiological long-term studies a threshold below which no effect on human health is expected could not be specified*". Thus the NOx emissions should be considered in a similar way to other no-threshold emissions such as particulates. It is self-evidently wrong to ignore the impacts from such emissions because the majority of the effects are not in the very tightly defined immediate vicinity of the incinerator.

142. Furthermore the failure to consider the secondary impacts described by above represents a major flaw in the application and is inconsistent with the obligations from the Environmental Assessment Regulations.

143. The statutory requirements for the contents of an environmental statement includes:

'the likely significant effects (including direct, <u>indirect</u>, <u>secondary</u>, cumulative, short, medium and long-term, permanent and temporary, positive and negative) of the proposed development on the environment resulting from:

"The existence of the proposed development

The use of natural resources

The emission of pollutants, the creation of nuisances and the elimination of waste" and a description is required of the forecasting methods used to assess the effects on the environment.' (<u>my emphasis</u>)

144. The EU definition of 'Indirect Impacts' is:

Indirect Impacts: Impacts on the environment, which are not a direct result of the project, often produced away from or as a result of a complex pathway (sometimes referred to as second or third level impacts or secondary impacts).

145. The release of emissions which form secondary particulates have not been addressed at all in this application.

146. The EU "*Clean Air For Europe*" ('CAFE') programme has assessed the secondary impacts of pollutants in detail for each country in the EU25 together with assessments for emissions on the four major seas around

Europe. The overview of the methodology (AEA Technology plc 2005) says, in relation to the assessment of the impacts of air pollution on human health:

The pollutants of most concern here are fine particles and ground level ozone both of which occur naturally in the atmosphere. Fine particle concentration is increased close to ground level by emissions from human activity. This may be through direct emissions of so-called 'primary' particles, or indirectly through the release of gaseous pollutants (especially SO_2, NO_x and NH_3) that react in the atmosphere to form so-called 'secondary' particles. Ozone concentrations close to ground level are increased by anthropogenic emissions, particularly of VOCs and NO_x. (my emphasis)

147. Ozone is clearly a secondary impact associated with the release of VOCs (volatile organic compounds) and NOx, both of which are significant emissions from the facility as demonstrated below. As with the effects of secondary particulates, however, the impacts of secondary ozone appear to have been completely omitted from consideration in the environmental statement.

148. These are serious omissions from any assessment of a major combustion facility.

149. In an effort to establish whether the emissions that have been omitted from consideration in the application have any 'significant' impacts I have applied the UK specific CAFE external costs to the projected emissions from the incinerators.

150. Oxides of nitrogen are responsible for the generation of secondary particulates which are the primary contributors to the health impacts (Howard 2009).

151. No bag filter system can be effective at reducing those particulate levels because they are formed after the filters. The appropriate approach would be to use primary NOx reduction techniques such as selective catalytic reduction (SCR) which is in increasingly common use on incinerators around the world but is not proposed for this incineration plant.

152. The emissions data in the application shows that the incinerator would produce about 825 [15] tonnes per year of oxides of nitrogen if operated at the Waste Incineration Directive Standards:

Emissions	Average Daily Emission Conc. mg/m3	Annual Emissions tonnes
Total Dust	10	41.25[16]
Volatile organic compounds	10	41.25

[15] Emission rates do not appear to be included in the application therefore it has been assumed that the incinerator produces c.5,500 m3/ tonne of flue gas

[16] Corrected to 24.75 in the calculations to allow for PM $_{2.5}$

(VOCs)		
Sulphur Dioxide (SO_2)	50	206
Nitrogen Oxides (as NO_2)	200	825
Ammonia	10	41.25

153. The CAFE Programme assessment of the impacts and associated external costs is detailed extensively (AEA Technology plc 2005; AEA Technology plc 2005; AEA Technology plc 2005) and has been subject to a publically available peer review (Krupnick, Ostro et al. 2005). The CAFE process recommended tighter standards on human health grounds.

154. COMEAP has recently accepted (COMEAP 2008) EU work showing children are more sensitive to air pollutants and can suffer a wide range of ill-health and developmental harm; this is not included in the CAFE estimates.

155. The costs associated with PM are considered by the US reviewers to be higher than used for CAFE; the health coefficient is to be taken to range from 6%-17% per 10ug/ m^3 $PM_{2.5}$, instead of the previous 6%. The more recent COMEAP report on the effect on mortality of long term exposure to air pollution (COMEAP 2009) accepts, in response to the US peer reviewer's critique, that 6% is out-of-date.

156. To calculate the external environmental costs associated with this proposal I have used the (conservative) CAFE costs without updating them for the increased harmfulness now acknowledged.

157. I have applied those costs to the total emission levels derived from the application, as above, and the maximum and minimum country specific external costs. I have then multiplied these costs over a nominal 25 year operating period.

158. Using this approach the minimum external costs associated with emissions of particulates, VOCs, SOx, NOx and ammonia alone is in the range €156 million to €427 million.

159. I have assessed the sensitivity of these externalities to the claimed operating regime where the actual emissions are likely to be lower than the permitted emission levels (though if lower levels are to be relied upon then Covanta offer to guarantee those lower emission levels by incorporating them into their environmental permit).

160. To do this I have taken emission levels of PM, VOCs, SOx as 40% of the WID standards. For NOx, which is a more demanding target for an incinerator with only SNCR I have taken average emissions at 90% and for ammonia slip, largely linked to the achievement of NOx levels, I have taken 80% of the application emissions levels.

161. The outcome is that the total external costs range from € 103 million to € 274 million. These are, in any terms, enormous external costs to satisfy the requirements of the EIA Directive and the implementing Regulations they should be included in the Environmental Statement.

162. The applicant has also clearly failed to properly assess the health and environmental impacts of the emissions from their proposal. The consequence of ignoring these secondary and far field impacts of the emissions means that the public, by accepting damage to their health, would be subsidising the applicant by approximately €8.3 - €22.7 per tonne of waste burned.

163. I note that these external damage costs are very similar to those calculated for direct non-greenhouse gas related emissions by Eunomia (Eunomia Research & Consulting and TOBIN Consulting Engineers 2008) and others:

Table E - 1: Externalities from Landfill, Incineration and MBT

	Landfill	Incineration	MBT
Direct emissions non-GHG related	€ 2.64	€ 23.51	€ 0.49
Direct emissions GHG related	€ 59.13	€ 28.71	€ 15.62
Total Direct Emissions	**€ 61.78**	**€ 52.22**	**€ 16.11**
Offsets GHG related	-€ 1.60	-€ 6.79	-€ 4.72
Offsets non-GHG	-€ 2.95	-€ 9.61	-€ 6.18
Total Offsets	**-€ 4.55**	**-€ 16.40**	**-€ 10.90**
Net Environmental damages	**€ 57.23**	**€ 35.82**	**€ 5.22**
Disamenity	€ 4.25	€ 14.30	€ 9.28[a]
Total External Costs	**€ 61.48**	**€ 50.12**	**€ 14.49**

a) This is an average of the two figures for landfill and incineration (see discussion in main text below).

Note: GHG = greenhouse gases

The Total Costs of Incineration:

164. The capital cost of an EfW plant is very much greater than that of a conventional electricity generating station of the same capacity (AEA for DTI 2005) and this is due to two main factors:

i) the low energy density of MSW compared with other renewable fuels (and even more so compared with conventional fossil hydrocarbon fuels) necessitating physically much larger plant,

ii) the need for advanced pollution control equipment fitted to the plant and the costs of safe disposal of ash and other residues.

165. The European Commission's thematic strategy on waste prevention and recycling notes that "*at low energy efficiencies incineration might not be more favourable than landfill*" (ENDS 2007).

166. This conclusion is supported by a large body of literature showing that the external costs of thermal treatment are actually very similar to those for landfill. Studies finding similar results include, but are not limited to:

Rabl, A., J. V. Spadaro, et al. (2008). "Environmental Impacts and Costs of Solid Waste: A Comparison of Landfill and Incineration." Waste Management & Research **26**(2): 147-162. (Rabl, Spadaro et al. 2008).
Holmgren, K. and S. Amiri (2007). "Internalising external costs of electricity and heat production in a municipal energy system." Energy Policy **35**(10): 5242-5253. (Holmgren and Amiri 2007)
Eshet, T., O. Ayalon, et al. (2006). "Valuation of externalities of selected waste management alternatives: A comparative review and analysis." Resources, Conservation and Recycling **46**(4): 335-364. (Eshet, Ayalon et al. 2006)
HM Customs & Excise (2004). "Combining the Government's Two Health and Environment Studies to Calculate Estimates for the External Costs of Landfill and Incineration, December 2004." (HM Customs & Excise 2004)

Eunomia (2006) A Changing Climate for Energy from Waste? Final report for Friends of the Earth. (Hogg and Eunomia Research & Consulting Ltd 2006)

Eunomia Research & Consulting and TOBIN Consulting Engineers (2008). Meeting Ireland's Waste Targets - the Role of MBT Final report for Greenstar (Eunomia Research & Consulting and TOBIN Consulting Engineers 2008)

Turner, G., (Enviros Consulting), D. Handley, (Enviros Consulting), et al. (2004). Valuation of the external costs and benefits to health and environment of waste management options Final report for DEFRA by Enviros Consulting Limited in association with EFTEC, DEFRA. (Turner, Handley et al. 2004)

167. An independent study by Dijkgraaf (Dijkgraaf and Vollebergh 2004) concluded:

> *"The net private cost of WTE (waste-to-energy) plants is so much higher than for landfilling that it is hard to understand the rational behind the current hierarchical approach towards final waste disposal methods in the EU (European Union). Landfilling with energy recovery is much cheaper, even though its energy efficiency is considerable lower than that of a WTE plant."*

168. This conclusion is similar to that reached by the OECD (Organisation for Economic Co-operation and Development (OECD) 2007) this year following their review of waste Management in the UK and the Netherlands:

> *"In both countries, there is currently a strong preference given to incineration compared to landfilling of waste – as reflected e.g. in the landfill taxes they apply. A similar preference underlies the Landfill Directive of the European Union, which fixes upper limits for the amounts of biodegradable waste member states are allowed to landfill.*
>
> *However, estimates in both countries indicate that the environmental harm caused by a modern landfill and a modern incineration plant are of a similar magnitude, while the costs of building and operating an incinerator are much higher than the similar costs for a landfill. Hence, the total costs to society as a whole of a modern incinerator seem significantly higher than for landfilling - which indicates that some reconsideration of the current preference being given to incineration could be useful."*

169. And:

> *"Analyses of the negative environmental impacts of landfilling and incineration in both countries suggest, however, that the foundation for the present preference for incineration is questionable from the point of view of total social costs".*

170. It should be noted that the "*social costs"* of waste management include the respective *private costs i.e.* the costs to society of building and operating the various management options together with the external environmental costs.

171. **It is concluded that there would be serious health impacts associated with secondary pollutant generation from the proposed incinerator which have not been assessed in the application, contrary to the requirements of the Environmental Assessment Regulations and that the total environmental costs of the proposal outweigh the benefits.**

External Costs Calculations:

Emissions	Average Daily Emission Conc. mg/m3	Annual Emissions tonnes	External Costs Min €	Max €	Annual Costs Min	Annual Costs Max	25 year Costs Min	25 year Costs Max
***Total Dust*[17]**	10	24.8	37,000	110,000	€ 915,750	€ 2,722,500	€ 22,893,750	€ 68,062,500
Volatile organic compounds (VOCs)	10	41.3	1,100	3,200	€ 45,375	€ 132,000	€ 1,134,375	€ 3,300,000
Sulphur Dioxide (SO_2)	50	206.0	6,600	19,000	€ 1,359,600	€ 3,914,000	€ 33,990,000	€ 97,850,000
Nitrogen Oxides (as NO_2)	200	825.0	3,900	10,000	€ 3,217,500	€ 8,250,000	€ 80,437,500	€ 206,250,000
Ammonia	10	41.3	17,000	50,000	€ 701,250	€ 2,062,500	€ 17,531,250	€ 51,562,500
					€ 6,239,475	**€ 17,081,000**	**€ 155,986,875**	**€ 427,025,000**

Emissions	Annual Average Daily Emission Concentration mg/m3	Sensitivity - average emissions as % of WID	25 year Costs at < WID emissions Min	25 year Costs at < WID emissions Max
Total Dust	10	40%	€ 9,157,500.00	€ 27,225,000.00
Volatile organic compounds (VOCs)	10	40%	€ 453,750.00	€ 1,320,000.00
Sulphur Dioxide (SO_2)	50	40%	€ 13,596,000.00	€ 39,140,000.00
Nitrogen Oxides (as NO_2)	200	90%	€ 72,393,750.00	€ 185,625,000.00
Ammonia	10	80%	€ 7,012,500.00	€ 20,625,000.00
			€ 102,613,500	**€ 273,935,000**

[17] Corrected to $PM_{2.5}$

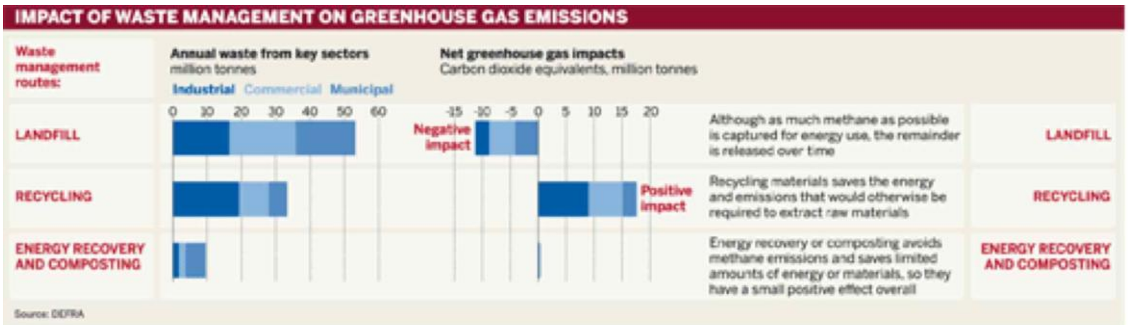
Ground 3 - Carbon Emissions and Climate Change:

The assessments of climate change impacts presented in support of the proposal are flawed and over-state benefits.

Climate Change Issues

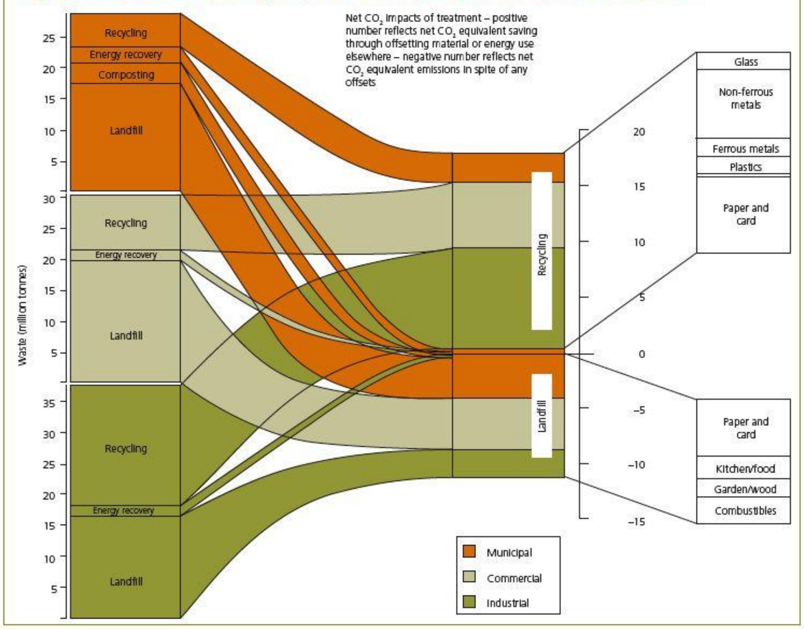
172. Climate change remains the world's greatest environmental challenge. For the past 100 years or so, greenhouse gases have been accumulating in the atmosphere, primarily as a result of burning fossil fuels and changes in land use. Over the same period, global average temperatures have increased by around 0.8°C. The first decade of the twenty-first century was the warmest since instrumental records began. The world is committed to further climate change. Emissions of carbon dioxide from energy use have increased by 30% in the past ten years. Even if emissions peak within the next decade and then reduce year-on-year at 3-4% for the rest of the century, global temperatures still have around a 50:50 chance of rising above 2°C by 2100.

173. Tables in the previous English waste strategy "Waste Strategy 2007" (Department for Environment Food and Rural Affairs 2007) showed that whilst recycling makes a strong positive contribution to reducing climate change impacts, energy from waste is, at best, very slightly positive (ENDS 2007):



174. This can also be seen in figure 1.1 from WS 2007:

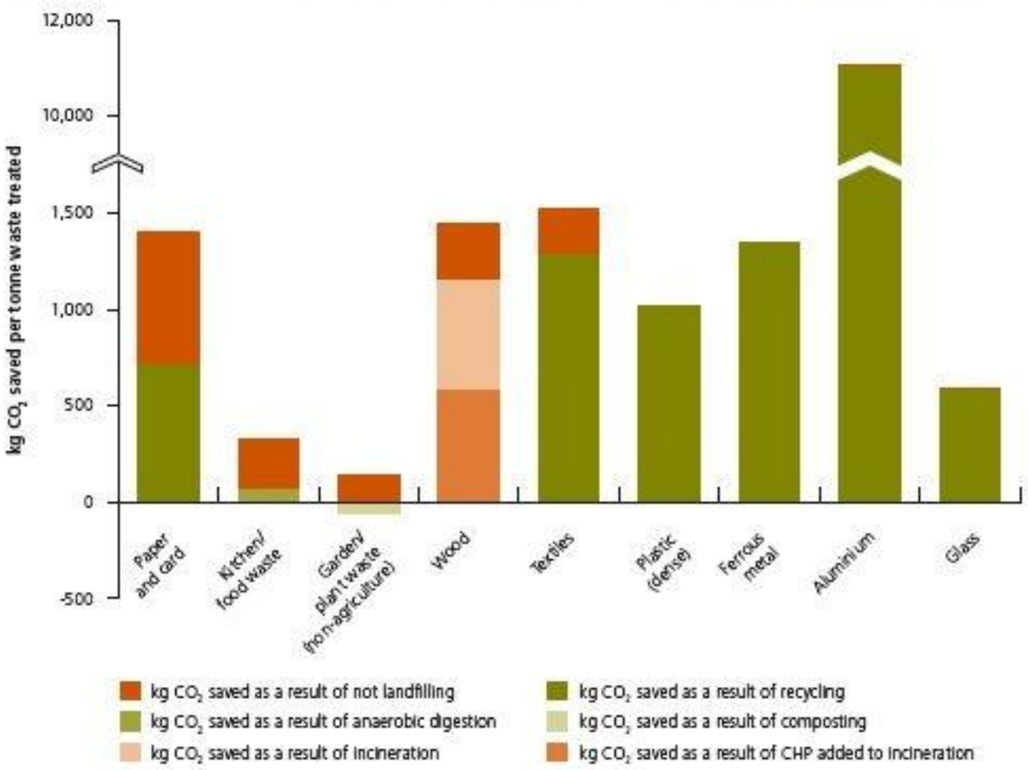
Figure 1.1: Greenhouse gas emissions from the main waste sectors



175. It can be seen that recycling gives positive benefits in terms of greenhouse gases in every case whilst incineration is effectively considered carbon neutral. Clearly the ‘opportunity cost’ of incineration in circumstances where recyclable material is burned would include the lost benefits associated with recycling.

176. Waste Strategy 2007 also included a helpful comparison of the carbon benefits of diverting wastes from landfill. The assumptions made by DEFRA are: paper and card, textiles, plastics, metals and glass are recycled; food waste is anaerobically digested, and garden/ plant waste is composted. Only wood is incinerated with energy recovery – even this assumption is questionable as discussed below.

Chart 4.1: Estimated carbon benefits of diverting different waste materials from landfill

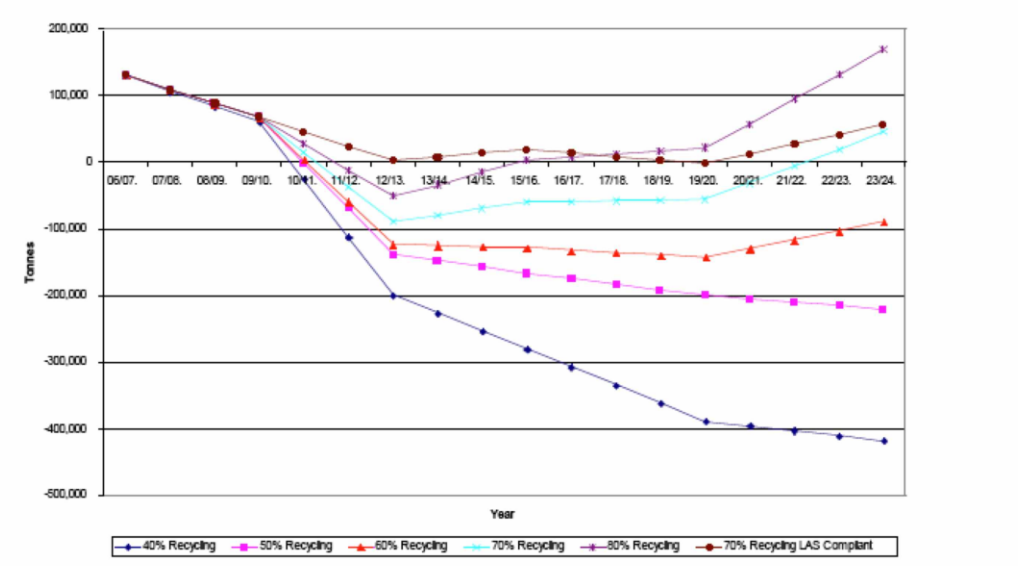


177. Similarly modelling for the Committee on Climate change report 'Building a low-carbon economy – the UK's contribution to tackling climate change' (Committee on Climate Change 2008) indicated that by far the most effective treatment strategy to reduce greenhouse gas emissions from waste was to increase recycling.

178. It is clear from the work that has been carried out and published on the National Waste Strategy (Welsh Assembly Government 2007) that the Landfill Directive targets for diversion of biodegradable municipal waste can be met without incineration.

179. To do so requires a 70% recycling target with 52% recycling/ composting in 2012/ 13, which the consultants say will be cost effective because recycling will be cheaper than the costs of treating the residual wastes in the longer term.

Figure 2: Balance of Landfill Allowances, All Recycling Scenarios (positive means targets exceeded, negative means a shortfall with targets not being met)



Renewable Energy?

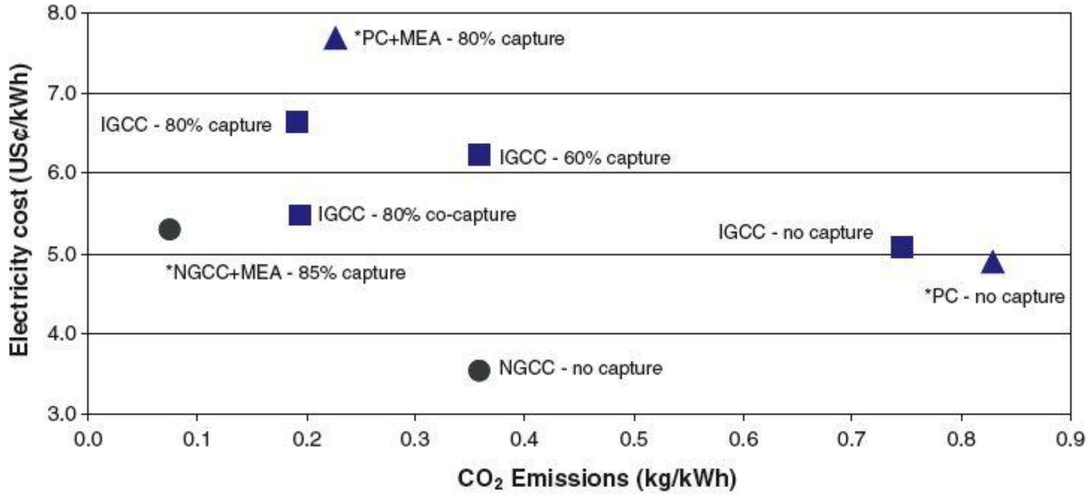
180. It would be self-defeating and inconsistent with the Welsh Government's approach to renewable energy to include options which produce more carbon than conventional fossil fuel power stations as a climate change abatement strategy.

181. Yet incineration, according to a recent parliamentary answer (HC Deb, 17 January 2011, c480W) by the minister from DECC, produces 540 gCO_2/ kWhr, without even taking account of biogenic carbon, whilst the UK 'Average Mix' electricity generation in 2007/ 8 produced 480 gCO_2/ kWhr. The assessments of climate change impacts are therefore flawed and over-state benefits.

Electricity Generator	DECC	BIS Data	FoE Data
Coal fired power stations		910	835
Combined Cycle Gas Turbines (CCGT)		360	382
UK 'Average Mix' electricity generation in 2007/ 8		480	
Waste fired power station (incinerator)	540		1645 total 510 non-biogenic
Renewables		0	

182. The data in the final column is derived from a report by Eunomia for Friends of the Earth (Hogg and Eunomia Research & Consulting Ltd 2006).

183. Whilst Government data shows that incineration already produces significantly higher climate changing emissions than the UK average mix and far higher than combined cycle gas turbines the difference will become substantially greater in the near future as gas fired pant become more efficient and coal fired plant are fitted with carbon capture with lower carbon intensities than incineration (Ordorica-Garcia, Douglas et al. 2006):



CO2 mitigation cost comparison chart (* from Riemer P. The capture of carbon dioxide from fossil fuel fired power stations. IEA Green House Gas Research. Report IEAGHG/SR2, London, UK, 1993.)

184. These data are consistent with those reported by Huang (Huang, Rezvani et al. 2008) who calculates 725-804 g CO_2/kWh for IGCC which reduces to 86-97g CO_2/kWh with carbon capture.

185. The consequence is that incineration produces more fossil based carbon dioxide (and far more total carbon dioxide) than the current average mix of electricity supply, much more fossil carbon dioxide than combined cycle gas turbine (CCGT) power stations and more than future coal fired plant fitted with carbon capture.

186. It is irrational to class such a high carbon emitter as a "*low carbon*" supply of electricity or to pretend that it has a role in climate protection – particularly when considering future emission scenarios.

Would the proposal generate "Renewable Energy"?

187. Only the non-fossil element of waste is renewable energy and this follows the definition of biomass in Article 2 (e) of Directive 2009/28/EC on the promotion of the use of energy from renewable sources (amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC). The definition of biomass in the Directive is consistent with that from the earlier Directives:

> (e) <u>'biomass' means the biodegradable fraction of products, waste and residues from biological origin</u> from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, <u>as well as the biodegradable fraction of industrial and municipal waste</u>; (<u>my emphasis</u>)

188. The then Minister, Malcolm Wicks (Wickes 2008) confirmed that in the UK "*only the biogenic carbon content can be counted as renewable*".

What is the Biogenic Carbon Content of Waste?

189. The balance of the fossil and biogenic carbon in waste is therefore central to the assessment of the carbon dioxide emissions from incineration and any claimed renewable energy generation is dependent on this balance.

190. The Supporting Statement claims (Para 34):

The Brig y Cwm Facility would generate up to 67MW of electricity (with no CHP) to export to the grid of which just over 50% would be classified as renewable energy, contributing to UK and Wales targets.

191. Thus implying that more than 50% of the waste that would be burned would be biogenic. I note that significantly higher assumptions have been made in the WRATE assessment and thus this over-estimates the renewable energy element (and because the carbon emissions from the biogenic element are ignored, it understates the true carbon emissions from the proposal).

192. Even the supporting statement claim for the proportion of renewable energy overestimates the biogenic carbon content of the waste which would be incinerated however.

193. This can be seen from the 2007 DTI consultation (Department of Trade and Industry 2007) on the review of the Renewables obligation.

194. The UK Government response to the submissions to the consultation was published in January 2008 (BERR 2008) and said :

Deeming the biomass fraction of waste: *we will proceed with the introduction of deeming, but will begin with a lower deemed level of 50% fossil fuel energy content that will increase over time to 65% following a trajectory in line with the Government's waste policy*[18].

195. And warns:

5.9 Ofgem will be given powers to withhold ROCs for mixed waste streams where there is reasonable doubt that the biomass energy content reaches the deemed level. This is consistent with the approach currently used under the scheme for issuing Climate Change Levy Exemption Certificates. It should be noted that lowering the deemed level of fossil-fuel energy from 65% to 50% is likely to increase the risk for some stations that a test of reasonable doubt will be met.

196. This consultation and response considers the carbon levels in the waste that would be burned <u>after</u> the removal of the recyclables that the Government clearly considers should be taken out. Thus at present only about 40% of the output from an incinerator would be biogenic carbon and this would be expected to fall to 35% by 2018 as more recycling is undertaken.

[18] The Government propose setting the deemed levels of fossil energy content at: 50% from 2009 to 2013; 60% from 2013 to 2018; 65% from 2018. There is the possibility of producing evidence of different waste analysis but this must be well founded and evidence based: *We will allow operators the opportunity to present Ofgem with evidence that the fossil fuel content is lower than the deemed level and look to make the fuel measurement system more flexible.*

Annex E: Analysis on Biomass Fraction of Waste for Use in Deeming the Fossil Fuel Fraction of Waste

	Biomass %	GCV (MJ/kg)	Unsorted waste % waste	Unsorted waste Total GCV	Unsorted waste Biomass GCV	Scenario A[32] % waste	Scenario A[32] Total GCV	Scenario A[32] Biomass GCV	Scenario B[33] % waste	Scenario B[33] Total GCV	Scenario B[33] Biomass GCV
Paper and card	100	12.6	18.0	2268.0	2268.0	2.7	340.2	340.2	9.0	1134.0	1134.0
Plastic film	0	23.6	2.7	637.2	0.0	9.5	2249.3	0.0	8.6	2039.0	0.0
Dense plastic	0	26.7	3.5	934.5	0.0	1.4	373.8	0.0	2.1	560.7	0.0
Textiles	50	15.9	2.4	381.6	190.8	1.2	190.8	95.4	1.4	229.0	114.5
Absorbent hygiene products	50	8.0	2.2	176.0	88.0	7.8	621.3	310.6	7.0	563.2	281.6
Wood	100	18.3	3.2	585.6	585.6	1.6	292.8	292.8	2.4	439.2	439.2
Other combustibles	50	15.6	1.5	234.0	117.0	5.3	826.0	413.0	4.8	748.8	374.4
Non-combustibles	0	2.8	12.3	344.4	0.0	43.4	1215.7	0.0	39.4	1102.1	0.0
Glass	0	1.5	6.6	99.0	0.0	3.3	49.5	0.0	3.3	49.5	0.0
Ferrous metal	0	0.0	1.6	0.0	0.0	0.8	0.0	0.0	0.8	0.0	0.0
Non-ferrous metal	0	0.0	0.4	0.0	0.0	0.2	0.0	0.0	0.2	0.0	0.0
Kitchen waste	100	5.3	17.2	911.6	911.6	4.3	227.9	227.9	4.3	227.9	227.9
Green waste	100	6.5	19.2	1248.0	1248.0	1.9	124.8	124.8	1.9	124.8	124.8
Fines	50	4.8	4.0	192.0	96.0	14.1	677.8	338.9	12.8	614.4	307.2
WEEE	0	7.6	4.5	342.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hazardous household waste	0	0.0	0.6	0.0	0.0	2.1	0.0	0.0	1.9	0.0	0.0
TOTAL			**99.9**	**8353.9**	**5505.0**	**99.7**	**7189.9**	**2143.6**	**100.0**	**7832.6**	**3003.6**
Biomass GCV					**66%**			**30%**			**38%**

Base data from:
Carbon Balances and Energy Impacts of the Management of UK Wastes: Table 3.2 (GCV); Table 1.24 (municipal waste composition England), Table B1.2 (recycling and recovery upper limits – for Scenario A), Impact of EfW and recycling policy on UK GHG emissions: Table 3.1 (% biodegradability)

32 Scenario A: Removed 85% paper/card, 75% food, 90% green, 50% wood, textiles, glass & metals, 60% dense plastic, WEEE
33 Scenario B: Removed 50% paper/card, 75% food, 90% green, 25% wood, 40% textiles & dense plastic, 50% glass & metals, WEEE

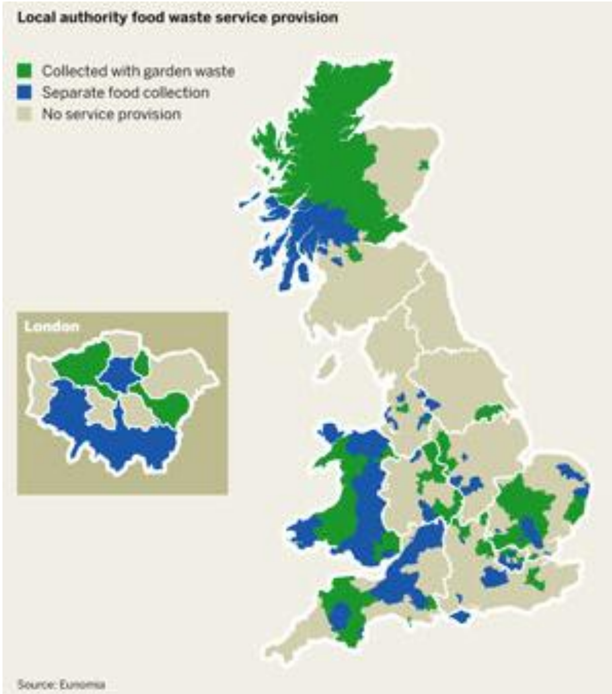
197. The approach taken by RPS in the WRATE modelling in support of the application is misleading because it takes an average of the biogenic/ biodegradable content of the MSW (and C&I) waste streams and makes no allowance for the changes in residual waste composition as recycling increases. The easiest target materials for recycling and paper and card for both MSW and in C&I wastes and these will inevitably be significantly reduced in residual wastes.

198. The levels of food waste collection in Wales are also high with all 22 authorities now operating separate collections. Some authorities such as Cardiff and Conwy, are only just rolling out their schemes and so their collection levels are likely to increase in the next year. Most collect food waste separately from garden waste, but the majority still goes to composting schemes (ENDS 2011).

FOOD WASTE RECYCLING BY COUNCIL IN THE UK

Area	No of boroughs	None	Food recyclers	Pilots
England (except London)	308	200	97	11
London	33	14	18	1
Scotland	32	19	18	1
Wales	22	–	20	2
Northern Ireland	26	12	13	1
UK total	**421**	**245**	**154**	**22**

199. Currently 82% of Welsh households have access to food waste collection and the Welsh government wants this to hit 90% by 2012 (ENDS 2011).



200. As the food waste collection levels in Wales are much higher than in England it is not sensible to use data for the biogenic carbon in the waste based on English levels as RPS does. Furthermore as the collection levels increase due to the continuing expansion of food waste collections the levels of biogenic carbon in residual waste will fall further.

201. This is not reflected in the application modelling data – indeed the WRATE report (Doc 8.5) claims that the biogenic to fossil ratios in the waste which would be incinerated are very high:

2.10 The biogenic to fossil carbon content ratio of the applied MSW composition is 63:37, representing relatively low fossil carbon content as the composition is dominated by paper and card and organics. This ratio is important for GWP results as only fossil carbon emissions contribute to GWP. The GWP performance of thermal treatment options may be limited by the combustion of plastics, as this releases fossil carbon as CO_2.

202. And:

2.12 The biogenic to fossil carbon ratio of the applied C&I waste composition is 66:33. Consistent with the MSW composition C&I waste is relatively low in fossil carbon, the composition being dominated by paper and card and organics with significant further contributions of biogenic carbon from wood and combustibles.

203. The levels claimed for biogenic carbon in the waste by RPS/ Covanta can be seen to be seriously overstated when compared with the likely current levels of c.40% (and would, in any case, assume that the incinerator is planning to burn mainly recyclable paper and digestible food waste!). The overestimation of the renewable output is at least 50% and, as can be seen below, the carbon dioxide emissions are similarly underestimated because RPS has ignored the biogenic emissions.

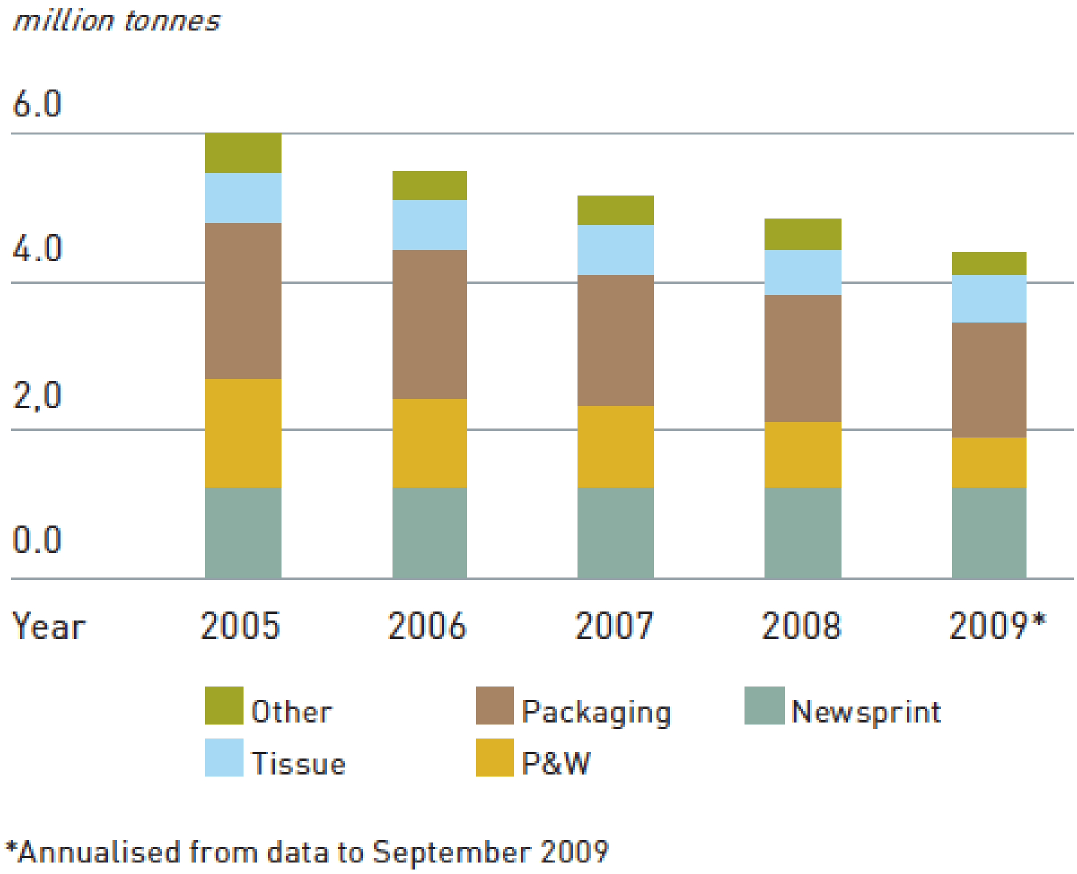
204. Little weight can therefore be placed on the claimed carbon savings attributed to the WRATE modelling.

205. I conclude that it is incorrect to define mass burn incineration/ energy from waste as renewable energy for planning purposes without first assessing whether the waste can be reduced, re-used, recycled (and in the case of food waste treated by the Government's preferred method of anaerobic digestion) and secondly determining the residual unrecyclable

biomass fraction of that waste.

Future Changes in Biogenic Elements of Waste

206. A report published in February 2010 on UK paper production by WRAP (WRAP, 2010) shows that around 5 million tonnes of paper and board was manufactured in the UK in 2008, 3% less than in 2007 and that this continues the steady decline seen over recent years:



207. The pace of decline increased in late 2008 and 2009 as a number of mills closed. Data for the first nine months of 2009 suggested that paper production will be about 15% lower in 2009 than in 2008. A consequence of the fall in demand has been the recent closure of the Bridgewater Paper Company (ENDS, 2010).

208. Furthermore this reduction in domestic production, which precedes any economic downturn, is not being replaced by imported paper and board. Indeed imports are falling as well:

Table 1: UK consumption of paper and board

million tonnes

Paper grade	2007	2008	2009[1]
Newsprint	2.5	2.4	2.1
Printings & writings	4.5	4.2	3.7
Tissue	1.1	1.1	1.1
Packaging	3.4	3.2	3.0
Other paper and board	0.6	0.6	0.5
Apparent consumption of unconverted paper and board[2]	**12.1**	**11.5**	**10.4**
Net imports of converted products[3]	0.8	0.6	..
Net imports of packaging around other goods (estimated)	1.2	1.1	..
Estimated total consumption	**14.1**	**13.2**	**..**

[1] Annualised from data to September 2009.
[2] UK home sales plus imports of unconverted paper and board.
[3] For example, boxes, cartons, books, brochures, catalogues and nappies.

Sources: CPI, HM Revenue and Customs and WRAP estimates

209. About 24 and 33% of the household waste stream is paper and card (Burnley, 2007). As this has been consistently falling nationally over at least the past five years it is not surprising that that household waste arisings are also consistently falling. This fall will also certainly be influenced by the major campaign being run by WRAP "*Love food- Hate waste*"[19] which targets the major component of household waste.

210. WRAP concluded that "*there is likely to be some rebound in paper consumption as the UK emerges from recession, but the long-term trend in consumption is likely to be downward*." (my emphasis)

211. For some paper sectors – such as newsprint – declining consumption and increased production will mean that the UK will be more self-sufficient, meaning that there will be domestic end markets for more of the paper recovered from the UK waste stream.

212. Recent research by Moberg et al. (Moberg, 2010) comparing newsprint with the increasing use of tablet e-papers, for example, shows that printed newspaper in general had a higher energy use, higher emissions of gases contributing to climate change and several other impact categories than the electronic readers. It was concluded that tablet e-paper has the potential to decrease the environmental impact of newspaper consumption. The recent introduction by Apple of the iPad[20] is likely to accelerate the move away from paper. The waste electronics generated instead of paper are quite unsuitable for incineration – not least because they contain high value resources which are increasingly targeted for recovery from the design stage (Kuo, 2010).

213. Increased incineration capacity represents a further threat to the future of remaining UK paper recycling capacity, an issue of particular concern in Wales given the importance of Shotton to the economy, as it is

[19] http://www.lovefoodhatewaste.com/

[20] http://www.apple.com/uk/ipad/

inevitable that incinerators and paper recyclers will increasingly compete for the diminishing tonnage of recyclable paper.

Accounting for Biogenic Carbon

214. The WRATE report (Doc 8.5) confirms, however that the biogenic emissions of carbon have been ignored in the assessment:

In line with "Guidelines for National Greenhouse Gas Inventories Volume 5 Waste" published by the Intergovernmental Panel on Climate Change (IPCC) in 2006, biogenic CO_2 emissions are excluded from WRATE GWP calculations. The carbon in MSW is of both biogenic (short-cycle) and non-biogenic (fossil) origin. IPCC guidance states that CO_2 emissions from combustion of biomass materials (e.g. paper, food and wood) contained in the waste are biogenic emissions and should not be accounted for in emissions estimates.

215. In fact IPCC (IPCC 2006) says:

if incineration of waste is used for energy purposes, both fossil and biogenic CO_2 emissions should be estimated. Only fossil CO_2 should be included in national emissions under Energy Sector while biogenic CO_2 should be reported as an information item also in the Energy Sector.

216. The need for estimates to be provided is acknowledged by RPS at Para 1.33, although they fail to do so as part of the application but IPPC continue:

Moreover, if combustion, or any other factor, is causing long term decline in the total carbon embodied in living biomass (e.g., forests), this net release of carbon should be evident in the calculation of CO_2 emissions described in the Agriculture, Forestry and Other Land Use (AFOLU) Volume of the 2006 Guidelines.

217. No consideration appears to have been given to this by RPS. In this case the useful biogenic carbon is mainly assumed to come from paper (carbon in food contributes practically no energy as almost all the heat is used to boil the water in the food waste).

218. Hogg reports "*Brief discussions with IPCC suggest that they believe that the issue of biogenic carbon is effectively dealt with through the reporting under the Land Use, Land-Use Change and Forestry (LULUCF) sector*"(Hogg and Eunomia Research & Consulting Ltd 2006). He comments "*The approach used here is to use stock changes to estimate emissions. In theory, IPCC has suggested (in a private communication) that this is meant to include not just uptake of CO_2 by crops and forests etc but also, the release of CO_2 after use as food, fuel or from waste disposal. Perhaps unsurprisingly – neither incinerators nor landfills obviously look like something which registers under 'Land-use Change and Forestry' – these do not seem to be reported. We believe this is a potentially significant omission*".

219. It appears, therefore, that the claim made by the applicants in relation to the need to report is incorrect but because of the confusing approach adopted by IPCC under-reporting is widespread.

220. Whether actually accounted by IPCC or not the biogenic carbon should be reported and not ignored as in this application.

221. That this is the appropriate approach has recently been confirmed in a strongly worded editorial by Ari Rabl in the International Journal of Life Cycle Assessment (Rabl, Benoist et al. 2007):

In a part of the LCA community, a special convention has been established according to which CO_2 emissions need not be counted if emitted by biomass. For example, many studies on waste incineration do not take into account CO_2 from *biomass within the incinerated waste, arguing that the creation of biomass has removed as much CO_2 as is emitted during its combustion.*

222. Rabl continues:

"*The logic of such a practice would imply absurd conclusions, e.g. that the CO_2 emitted by burning a tropical forest, if not counted, would equalize the climate impact of burning a forest and preserving it, which is obviously wrong. Likewise, the benefit of adding carbon capture and sequestration (CCS) to a biomass fuelled power plant would not be evaluated because that CO_2 is totally omitted from the analysis.*

223. Amongst the advantages of including biogenic carbon emissions, Rabl says, are those:

By explicitly counting CO_2 at each stage, the analysis is consistent with the 'polluter pays' principle and the Kyoto rules which imply that each greenhouse gas contribution (positive or negative) should be allocated to the causing agent.

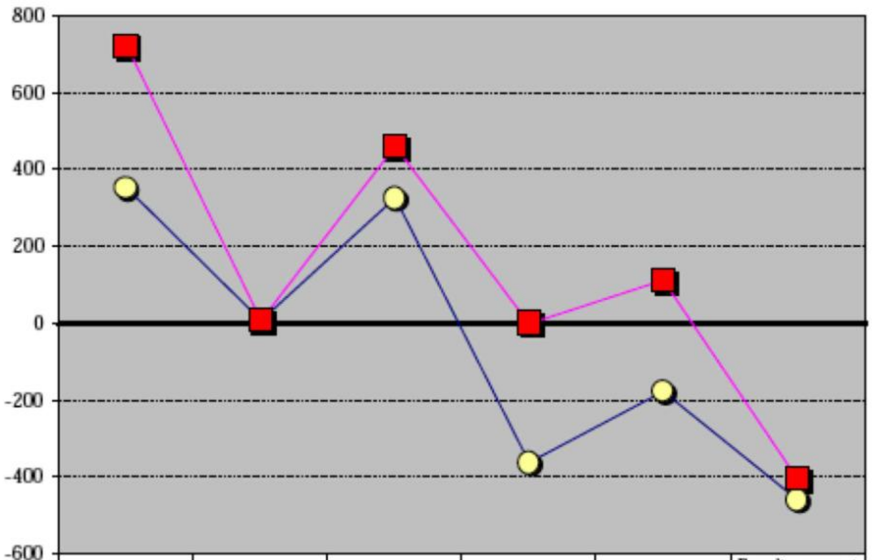
224. The total annual emissions of carbon dioxide from the proposed incinerator would be approximately 188,000 tonnes of carbon[21] (as per figure 2.3 in the WRATE assessment) but RPS has ignored c.121,700 tonnes per annum because they are claimed to be biogenic. Properly corrected for the levels of recycling, as above, the total fossil based carbon dioxide emissions would be at least 113,000 tonnes (compared with the claimed 66,000 tonnes). This represents very large error in the application and the total carbon emissions converted to carbon dioxide from the facility, at close to 700,000 tonnes are enormous so the scope for errors in the claims relating to the biogenic content can be large.

225. The high levels of carbon emissions from incineration, when properly assessed are not surprising and are consistent with the published literature. Lifecycle calculations for real efficiencies of biostabilisation and following the IPCC prescription are included in the Eunomia ATROPOS model, which found (Eunomia Research & Consulting and EnviroCentre 2008) that "*scenarios using incineration were amongst the poorest performing*"[22] while those using MBT were much better. A detailed review by AEAT for the European Commission (AEA Technology, Smith et al. 2001) similarly finds that MBT when sequestration is taken into account performs much better than energy from waste. The graph when the displaced fuel is assumed to be low carbon, as will be increasing the case over the next 40 years and is true when there is competition on price or for subsidy with renewables, as in the UK, shows:

[21] Note that the figures are for carbon rather than carbon dioxide (for which it is necessary to multiply them by 44/ 12)

[22] This report was peer reviewed by EMRC Consulting, who concluded that the report is free from major flaws in terms of the methods and data used. The findings and recommendations of the peer review were incorporated into the final report.

Figure 21: Overall net greenhouse gas fluxes from waste management options – EU-average landfill gas collection and wind electricity replaced kg CO2 eq/tonne MSW.



	Landfill raw waste	Mass burn	RDF-FBC	MBT landfill	MBT incin	Recycling, compost & AD
Net flux	350	8	324	-363	-178	-458
Net flux excluding sequestration	720	8	458	1	111	-403

226. Mass burn, uniquely amongst the scenarios, is unaffected by considerations of sequestration because the carbon is nearly all released immediately. It is therefore favoured by models which do not take any account of sequestration. WRATE[23] is one such model and I comment further on this below.

227. Unlike with waste recycling, which can be implemented rapidly given the political will (and the rapid intensification of recycling in WWII was one example) reductions in carbon intensity targets for electricity generation are more likely to be relatively slow and difficult to achieve. This underlines the importance of ensuring that all new facilities are compatible with and make the maximum possible contribution to the necessary c. 75% reduction in carbon intensity (from greater than 300 to c.80 g CO_2/ kWh) which is necessary between 2020 and 2030.

228. The Environment Agency biomass policy (Environment Agency 2009; Georges and Huyton 2009) says that by 2030, "*biomass electricity will need to be produced using good practice to avoid emitting more GHG emissions per unit than the average for the electricity grid indicated to be necessary by the Committee on Climate Change*".

229. This would require that any incinerator should produce electricity with a carbon intensity of 80 gCO_2/ kWh.

[23] WRATE is Waste and Resources Assessment Tool for the Environment

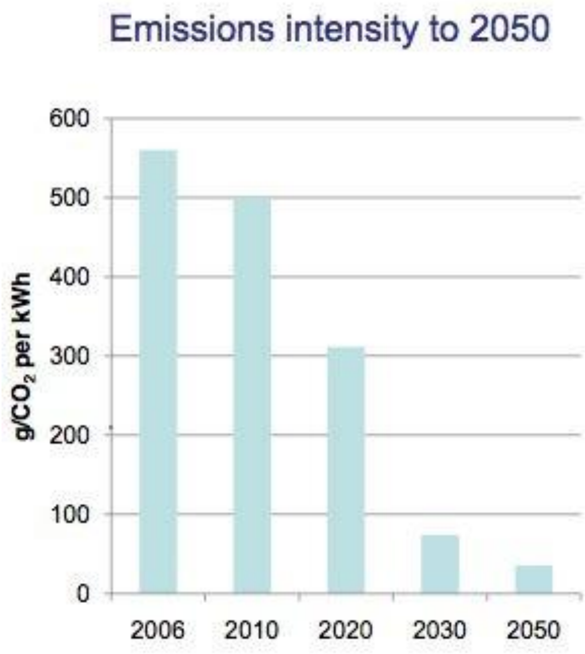
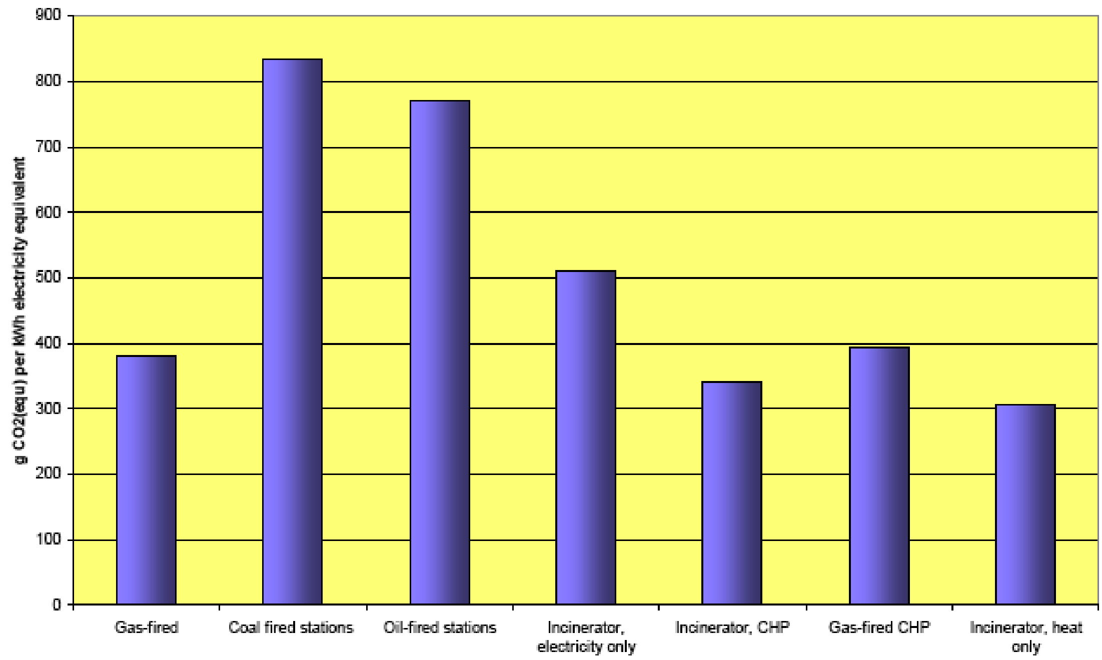


Figure: CO2 intensity per kWh of electricity generated, 2006-2050 (Committee on Climate Change 2008)

230. However the carbon intensity of incineration, even if biogenic carbon is ignored - as shown in the figure below (Hogg and Eunomia Research & Consulting Ltd 2006), is more than 500 g/ kWh. This is clearly inconsistent with the climate change objectives and viewed this way incineration is unarguably, in the words of the Environment Agency (Environment Agency 2009) a "*carbon sinner*" rather than a "*carbon sink*".

Figure 1: Excludes CO_2 from Biogenic Carbon, Heat=0.4 x Electricity

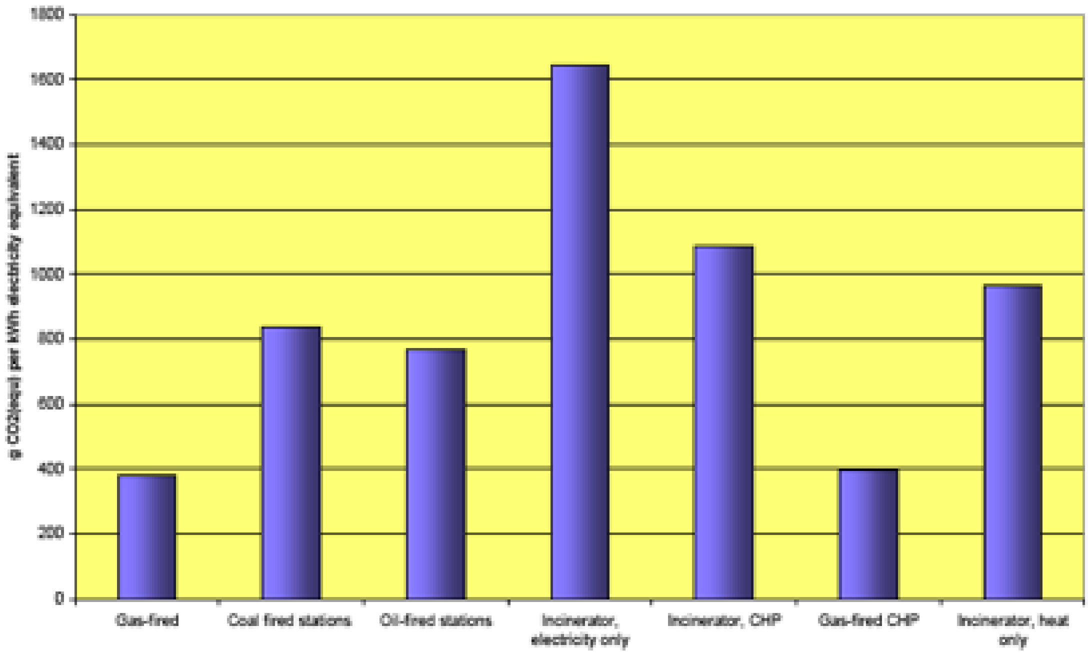


231. With higher levels of recycling the fossil fuel derived impacts are even worse. Data from the DTI (Department of Trade and Industry 2007; BERR 2008), discussed above, showed that the biogenic proportion of residual waste reduces with increased recycling. Whilst unsorted waste was calculated to derive 66% of the calorific value from biomass this falls to 38% when recycling c 45% and then to just 30% biomass when recycling c

60%. This is because the wastes that tend to be pulled out for recycling/ composting are those like paper and kitchen waste with high biogenic proportions. This concentrates the plastics and composite materials in the residual.

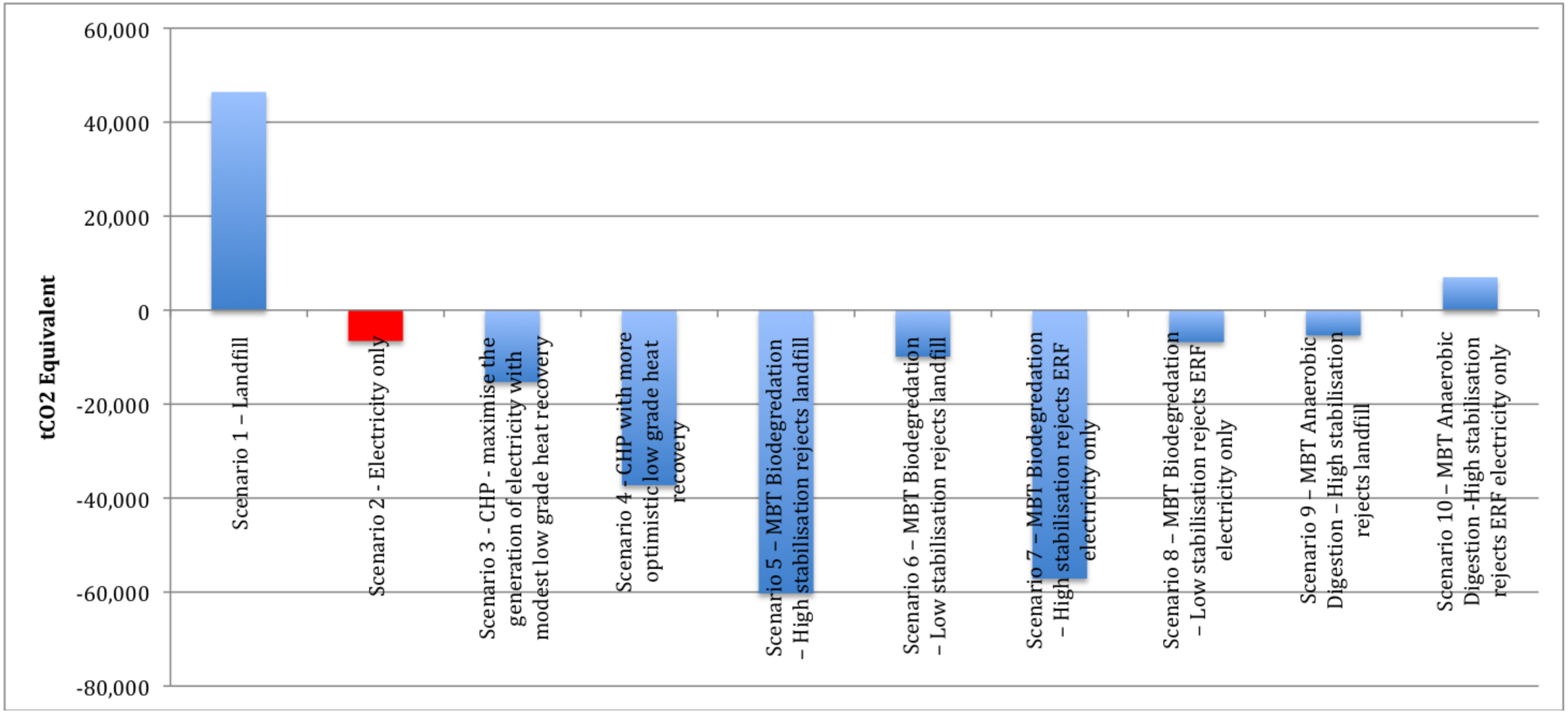
232. If biogenic carbon is included, as shown in the figure below (Hogg and Eunomia Research & Consulting Ltd 2006), then electricity only incinerators are likely to have approximately **20 times** the carbon intensity of the fuel mix required in 2030.

Figure 3: Includes CO_2 from Biogenic Carbon, Heat=0.4 x Electricity



233. Modelling by RPS for another incinerator application, since refused by the Secretary of State, at Rufford in Nottinghamshire, shows very clearly that electricity only incineration is one of the worst options in terms of climate change impacts. This can be seen most clearly when the results are plotted graphically as below. RPS's model also shows that even with the most optimistic scenarios for CHP use, which are very unlikely to be delivered on this site, MBT with high stabilisation and landfill still performs better than incineration:

Climate Change impacts of the Scenarios modelled by RPS – the 'low' scenarios have been plotted :



The proposed option, electricity only incineration, is highlighted in red

234. Incineration is actually one of the worst options in climate change terms and only really does well when compared with poor quality landfill of mixed wastes – an option that must be phased out to meet the requirements of the Landfill Directive in any case[24].

235. The MBT option with high stabilisation and residues to landfill performs more than nine times better in climate change terms than the incinerator. Furthermore if biogenic carbon emissions were counted the electricity only incineration option would be a large net producer of greenhouse gases whilst the better MBT option would be largely unchanged.

236. I should note that the WRATE software used in this application differs from the RPS model used in Nottinghamshire because it does not properly account for the reduction in respirability of treated residues. Almost uniquely amongst modern LCA models WRATE therefore penalises MBT and compost-based options by largely ignoring the biological changes undertaken in the processes and attributing them with high methane emissions – and thus climate change impacts. The consequence is that when the RPS results presented above were compared to those from the Environment Agency using WRATE then the options which included a residual landfill or MBT/ compost element will appeared to perform worse than a mix including higher levels of incineration. The Environment Agency did, however, acknowledge that the RPS model used in that case was more sophisticated in it's capabilities than WRATE. It is unfortunate, therefore, that RPS has reverted to WRATE for the current assessment.

237. In doing so they appear to have used inappropriate displaced electricity mixes for modelling of incineration in the future. Policy requires a progressive and increasingly rapid reduction in the carbon intensity of the future fuel mix. This reduces the benefits associated with incineration – because the displaced electricity is generated with lower carbon emissions.

238. RPS say:

For Project Year 2020 the Wales marginal fuel mix is represented by 100% fossil fuel sources (33.8% coal; 4.2% gas; 62% combined cycle gas turbine CCGT). This fuel mix has a significant GHG burden, so offsetting its use by recovering energy from waste (i.e. a fuel comprising <100% fossil carbon) can lead to significant emissions savings.

239. No details have been given for other project years (but even the 2020 data does not appear to be based on the reductions in carbon intensity required by policy as detailed in the *UK Low Carbon Transition Plan (Department for Energy and Climate Change (DECC) 2009)*. If the actual carbon intensity in the transition plan was used, including an increased contribution from low carbon renewables, then incineration would fare much worse as the benefits from displaced electricity would be very much lower than assessed.

240. I conclude that little weight can be placed on the results from the WRATE modelling.

[24] the MBT/ AD options also perform fairly badly which was anomalous when compared with other similar assessments – that was why PAIN was so keen to obtain the input data but the refusal of RPS to provide it means that I cannot assess what assumptions have been used in those cases.

Displaced Electricity Assumptions

241. The assumptions made about the electricity supply displaced by an incinerator are one of the most critical aspects of modelling (Wallis and Watson 1994; AEA Technology, Smith et al. 2001; Turner, Handley et al. 2004; Hogg and Eunomia Research & Consulting Ltd 2006) – the more 'dirty' in climate change or emission terms the displaced electricity the better the incinerator looks in the comparison.

242. The Government's advice (Department for Environment Food and Rural Affairs 2006) on the displaced electricity to use is that it is appropriate to assume that new build CCGT is displaced.

243. This has been confirmed in a recent parliamentary answer (Hansard 2008):

"For long-term electricity savings the Government assume that new-build combined-cycle gas turbine (CCGT) generation is displaced. It is currently estimated that new-build CCGT plant emits 0.43 kg carbon dioxide per kWh delivered to the point of consumption. This emissions factor includes distribution losses."

244. The assumptions made by RPS is that the displaced electricity is equivalent to the emissions from the marginal mix which includes emission intensive "*peak lopping*". This is entirely inappropriate for a facility which will be operating in base load configuration. A more appropriate comparator is with the alternative low carbon base load generation that would be displaced by the incinerator in the transition to a low carbon grid over the period to 2030. Using a high carbon generator as a base load plant represents a large opportunity cost and makes decarbonisation targets much more difficult to achieve.

Future Carbon Emissions

245. The Climate Change Act 2008 requires that greenhouse gas emission reductions through action in the UK and abroad of at least 80% by 2050, and reductions in CO_2 emissions of at least 26% by 2020, against a 1990 baseline (ENDS 2008). The 2020 target will now be reviewed to reflect the move to all greenhouse gases and the increase in the 2050 target to 80%. A carbon budgeting system which caps emissions over five year periods, with three budgets set at a time, will set out the trajectory to 2050. The first three carbon budgets will run from 2008-12, 2013-17 and 2018-22, and must be set by 1 June 2009. The Government must report to Parliament its policies and proposals to meet the budgets as soon as practical after that (DEFRA 2008).

246. Implementation of the Act will mean that energy and particularly electricity generation needs to be very significantly 'decarbonised' over the coming decades. As this happens the benefit from energy generation from waste, in climate change terms, even if biogenic carbon is ignored will rapidly turn negative. In the meantime, the marginal new sources will have to have a carbon intensity which, on the average, declines rapidly over time. Therefore practically the worst thing that could be done with waste – looking to 2050 and the Government's targets – is to burn waste containing plastics, or any other fossil carbon, at the low efficiencies of the proposed incinerator. Whilst the current climate performance of energy from waste is poor the technology will become an increasing liability over the coming years.

Combined Heat and Power

247. Incinerators are particularly inefficient generators of electricity. This can be improved by operation as combined heat and power ("CHP") plants but, if this is to be meaningful and effective, this requires a large heat load. Only in those circumstances, as can be seen below, is incineration likely to be notably better than landfill.

248. In a 2005 report for DEFRA on extending the Renewable Obligation to include energy from waste with CHP ILEX consulting wrote:

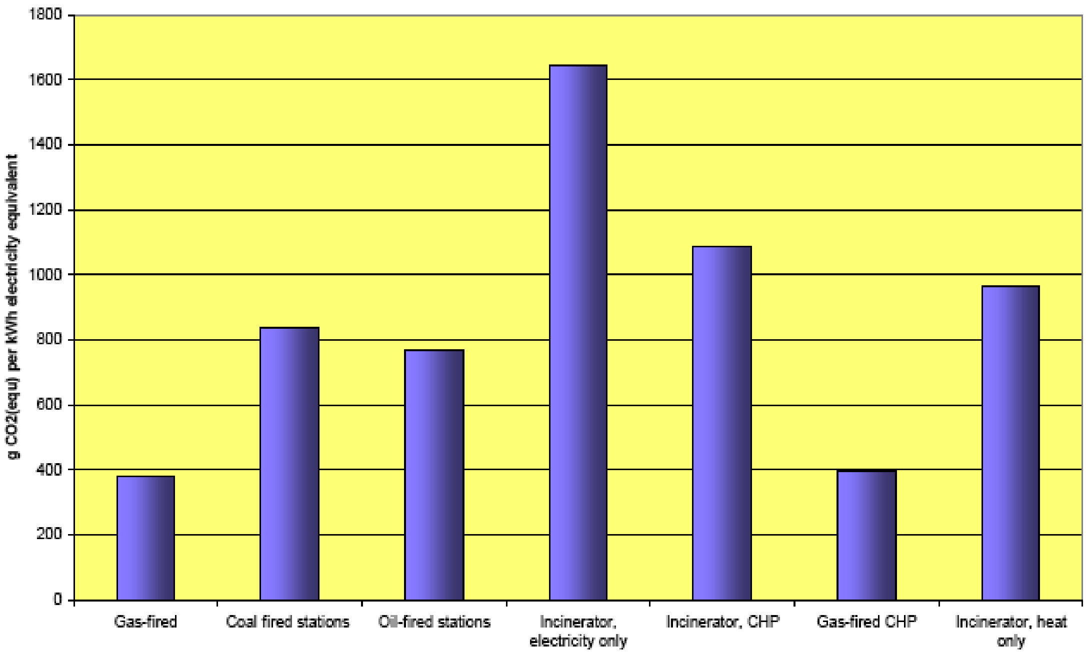
> *We estimate that EfW with CHP will produce a net environmental gain, producing additional carbon savings beyond that from electricity-only EfW plant – of between 120 kgCO_2 and 380kgCO_2 for each MWh$_{th}$ of heat produced.*

249. They thus estimated that:

> *" a 400kt/yr EfW with CHP facility would create additional carbon savings of between 0.7 and 1.0 million tonnes[25] of carbon dioxide (CO2) in total over a 20-year lifetime, over and above those achieved by a conventional EfW facility without CHP."*

250. The graph below, from research by Eunomia (Hogg and Eunomia Research & Consulting Ltd 2006) for Friends of the Earth shows how electricity only incinerators produce about twice as much carbon dioxide per kWh as coal fired power stations.

Figure 3: Includes CO_2 from Biogenic Carbon, Heat=0.4 x Electricity



251. For completeness it should be noted that this graph includes biogenic carbon. This is the appropriate approach to adopt when accounting for incinerator emissions. The applicants have ignored this element of the emissions claiming that it is 'climate neutral' but that would only be valid in an incineration life cycle assessment if the climate change impacts of a

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[25] Additional net carbon savings assumed for the upper bound a plant operating at 20 MWth capacity producing 125 GWhth per annum, at a net saving of 380kgCO_2/ MWhth. For the lower bound ILEX assumed a plant operating at 45MWth capacity producing 280 GWhth per annum at a net carbon saving of 120 kgCO_2/ MWhth.

biogenic carbon dioxide molecule was different from any other carbon dioxide molecule.

252. The Waste Incineration Directive (European Commission 2000) says:

Article 4 (2)(b):

(b) the heat generated during the incineration and co-incineration process is recovered as far as practicable e.g. through combined heat and power, the generating of process steam or district heating;

Article 6 (6):

6. Any heat generated by the incineration or the co-incineration process shall be recovered as far as practicable.

253. Whilst the Environment Agency is the body normally responsible for implementing the "*Waste Incineration (England and Wales) Regulations 2002*" (HMSO 2002) the locational requirements for CHP can only be secured at the planning stage and should be addressed as part of this application.

254. The Environment Agency has confirmed this in their submission:

"Location is a matter for the DCO and not something that can be reviewed during the determination of the Environmental Permit. In light of the above and the importance given to CHP within the draft National Policy Statement (NPS) on Energy, we highlight the effect of location on the potential for CHP as an important issue.
We note that the draft Energy NPS states that if the operator is not proposing CHP they should "explain why CHP is not economically or practically feasible". We suggest in light of this that their proposal to link CHP with future developments in the area should be fully investigated to ensure adequacy at the planning stage. Based on our understanding of Department of Energy and Climate Change heat maps, we would suggest that the options for developing heat user capability could be limited at this time. There is always potential for future development which could utilise the heat, but the likelihood of their availability in the foreseeable future should be assessed fully as part of the application. Should these developments not proceed it would appear unlikely, based on our experiences on similar sites in the UK, that CHP would actually be developed. We are therefore, based on the information seen thus far, unlikely to be able to require anything more than CHP readiness in the Environmental Permit.".

The concerns about the deliverability of CHP in this location are well made. The proposals for CHP are vague and are extremely unlikely to deliver a year round heat load of the scale which would be required to significantly increase the efficiency of the facility. Operators invariably promise future potential CHP loads as part of their applications but there are no large scale examples of this being delivered after construction. The mis-named SELCHP (South East London Combined Heat and Power Plant) remains CHP less after nearly two decades of efforts to find heat loads in an mixed urban area. The prospects for a facility of the size of this proposal finding a large CHP load when sited in the middle of open moorland are much less attractive.

Ground 4 – Visually Intrusive Development on a Greenfield Site

The visual impacts of the proposal on this greenfield[26] site would be large and unacceptable.

A Greenfield Site

255. The Planning Statement supporting the application says at Para 5.21 that the proposed development:

"Would be on previously developed land (pdl) even though it forms part of a site for which there is an approved restoration strategy. Whilst it would not strictly meet the definition of 'pdl' in Planning Policy Wales (Edition 3), therefore, it is plain that the site cannot reasonably be described as a 'greenfield' site".

256. This is a surprising interpretation by Consultants who had just fought, and lost, another incinerator public inquiry at Rufford in Nottinghamshire on grounds including their mistaken identification of a Greenfield site as brownfield/ Previously developed land[27].

257. Planning Policy Wales defines 'Previously developed land' in Figure 4.1 on Page 56 as land:

"which is or was occupied by a permanent structure (excluding agricultural or forestry buildings) and associated fixed surface infrastructure... and land used for mineral extraction and waste disposal ... <u>where provision for restoration has not been made through development control procedures</u>" (<u>our emphasis</u>)

258. In this case provision has been made for restoration through the development control procedure as part of the current permission and thus the land is NOT defined as previously developed for planning purposes and it is wrong for the applicant to say that the development "*would be on previously developed land"* in a planning context, as here.

259. The situation is very clear - a site can be either Greenfield or Brownfield depending on its specific characteristics. It cannot be both. In this case the proposal is on Greenfield land but the consultant has made considerable efforts to avoid the implications of this conclusion and has apparently invented a new category which has been accorded a lower status than a greenfield site.

260. The applicant accepts that "*There is a strong preference for the re-use of land in PPW with paragraph 4.8.1 confirming that previously developed land should, wherever possible, be used in preference to greenfield sites*".

261. Thus this erroneous approach brings into question the selection of this

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[26] The site is not, in planning terms, previously developed land due to the restoration conditions on the current planning permission.

[27] In that case the Inspector Mr Rupert Grantham wrote Grantham, R. (2011). Planning Inspectors's Report to the Secretaru of State for Communities and Local Government re Application by Veolia ES Nottinghamshire Limited Land at former Rufford Colliery, Rainworth, Nottinghamshire NG21 OET. Application Ref: 3/ 07/ 01793/ CMW SOS Ref: APP/ L3055/ V/ 09/ 2102006 Dated 17th March 2011, Planning Inspectorate.: -IR1232: "...the site selection process failed to prioritise previously developed land, over the Rufford site. Furthermore, it has not been demonstrated that the sustainability credentials of developing brownfield sites, which were identified in the process, are worse than those of developing Rufford"

site as the most suitable location for the facility or whether it represents the BPEO – not least because there are scores of brownfield sites in Wales. There is no need to use a Greenfield site for a waste development like this one and if this Greenfield site was to be favoured above an alternative brownfield location then there is an opportunity cost in terms of the lost potential for remediation and the returning the rejected brownfield sites to beneficial use.

262. For completeness I note that the approach suggested above in relation to this site being greenfield is consistent with the decision of the Secretary of State in relation to an appeal relating to the Sandyforth opencast coal site (Secretary of State for Communities and Local Government 2006).

263. In that case the SoS said:

The definition of previously developed land in Annex C to PPG 3 Housing states: "The definition includes defence buildings and land used for mineral extraction and waste disposal where provision for restoration has not been made through development control procedures."

264. And concluded:

Inquiry Document 52 (Report to Planning and Development Committee of 30 April 1996) includes a list of recommended conditions, including those to cover the restoration of the site. <u>As such, the Secretary of State concludes that the appeal site does not constitute previously developed land, and should be considered a greenfield site, in line with the extracts from PPG3 above</u>. (<u>my emphasis</u>)

265. Similarly the successful Judicial Review by Capel Parish Council and the decision of Collins J in *Capel Parish Council v Surrey County Council* [2009] EWHC 350 (Admin) (5th March 2009) (England and Wales High Court (Administrative Court) 2009) has highlighted the importance of the correct designation of sites – particularly in relation to the comparisons with alternatives (see, for example (ENDS 2009)).

266. The Court considered the question of the greenfield nature of the Capel site and the judgement says (Para 30)…"*That permission had, as I have indicated, expired in December 2004 and there was a condition of restoration of the land. Thus it has properly to be regarded as a greenfield site*".

267. The judge commented (Para 32) that "*An error in identifying the nature of a site, in particular whether it was greenfield or previously developed, is of considerable importance*".

268. That case related to a development plan but the same principle can be applied in relation to the inappropriate weighting in the site selection process by RPS as the Judge continued "*SCC's errors could have undermined the whole process of identification of suitable sites and certainly it was necessary in my view for the inspectors to look at the whole process afresh*".

269. The alternative sites should therefore be revisited in the light of the weighting given by RPS following their comment "*it is plain that the site cannot reasonably be described as a 'greenfield' site*" there should be "*a rigorous examination*" of the site selection procedure and the merits of "*any …… alternative sites*" compared with the Brig y Cwm site.

Visual Impact

270. Whilst the applicant attempts to hide the major visual impacts of the scheme by reference to and comparison with the Ffos-y-fran Opencast Scheme the proposal is undoubtedly a massive development in an exposed area of open countryside with major, and damaging, visual

impacts both during the day and at night from nearly all perspectives.

271. The full impacts of the scheme have not been properly assessed, including, for example, the extent of the visibility of the plume from the 115m high stack.

272. The site lies within the Merthyr Tydfil Landscape of Outstanding Historic Interest and the restoration of the land at Ffos-y-fran aims to re-establish a natural landform and features which would contribute to the open character of the area.

273. The harm associated with the visual impact of the proposal will therefore gradually increase and even the applicant admits that the impact from near to the site will have long term adverse effects from Major/ Moderate in the day, which are significant in terms of the EIA Regulations. These impacts cannot be effectively mitigated by the design solution due to the open character of the landscape and it is difficult to understand how the applicant can claim that this does not conflict with policy in terms of the visual impacts.

Ground 5 – Public Participation

The failure of the process to facilitate meaningful public participation.

274. The application and accompanying environmental statement are voluminous documents and accessibility is vital to enable effective public scrutiny and participation in the decision making process. Whilst copies are available in local venues including libraries the amount of paperwork involved means that in practical terms personal copies of the reports are needed to allow careful review. It is disappointing, therefore, to find that the cost of the documents is at least £400 –a price beyond the means even of national NGOs and certainly not affordable for local residents. It is not substitute to say that documents are available on the web – some of the figures are only available as files larger than 460MB and are not practical downloads except on the highest speed connections.

275. Participation has been further hindered by the proposed changes to the application which generated another mountain of documents to review and the reliance on 'black box' models for much of the justification without providing full details of the input parameters and assumptions. These models often cost thousands of pounds and it is not possible for local residents and the wider public to access them to test the results upon which the application is founded.

Ground 6 - Prematurity

The proposal is premature in relation to the emerging waste policy framework for commercial and industrial wastes in Wales.

276. The Welsh Government is currently developing[28] a number of sectoral waste plans for consultation in 2011 including:

- Construction and demolition;
- Food Manufacture and Retail Sector Plan;
- Collection, Infrastructure and markets;
- Remaining Industrial and Commercial waste; and
- Public Sector.

277. The Covanta application is for an extremely large facility which over the potential operating lifetime would require more residual waste than each of these sectors produced. To consent such a large operation at this time would have significant impacts in relation to Strategy and make future policy development largely academic. This would not be an acceptable outcome at a time of such rapid change in waste streams and associated policy development.

278. The pending sectoral plan on Industrial and Commercial waste is particularly important given the lack of good recent data on this waste stream and the reliance of the facility on this waste as the MSW waste reduces.

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28 http://wales.gov.uk/topics/environmentcountryside/epq/waste_recycling/bysector/?lang=en

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September 2011

Briefing Note

Pylons and Power

Cyfeillion y Ddaear Cymru
Friends of the Earth Cymru

Friends of the Earth Cymru has commissioned research demonstrating that underground electricity connections can be made to mid Wales wind farms far more cheaply than suggested by National Grid. There would be very little change in performance from overhead lines. This means that Friends of the Earth Cymru supports the principle of placing underground much or all of the electricity transmission works to proposed wind farms in rural Wales.

Pylons and Power in rural Wales

Rural parts of Wales have long had more than their fair share of electricity transmission infrastructure. Until 2010, Snowdonia National Park, for example, had the unenviable status of hosting more high-voltage overhead power lines than every other National Park put together. Most of this infrastructure has been in place since the 1950s, when the Central Electricity Generating Board had a carte blanche to install intrusive infrastructure in almost any location in order to transmit electricity as cheaply as possible.

Although times have changed and there is far greater institutional awareness of the importance of landscape to people and communities, National Grid has demonstrated a dogged reluctance to move away from its inherited practice of using large, highly visible infrastructure. The landscape impact of transmission infrastructure relates particularly to the transverse nature of overhead lines: they run in long sections across the landscape and are supported by large metal pylons at irregular intervals.

But there is an alternative: placing transmission lines underground. Friends of the Earth Cymru has commissioned research that shows that National Grid typically over-specifies the transmission links that connect electricity generating infrastructure to the grid. This in turn raises the cost of placing these links underground and renders them much less attractive in a traditional cost-benefit analysis.

Friends of the Earth Cymru supports the principle of placing underground much or all of the electricity transmission works to proposed wind farms in rural Wales.

In relation to the current wind farm proposals in mid Wales, the capital and life-time costs of an underground link could be reduced from around the £600 million estimated by National Grid in their initial consultation to £300-390 million.

The technical detail

Examining data from a group of wind farms in southern Scotland, we have shown that the link to mid Wales wind farms proposed by National Grid is an over-specification that would result in several hundred million pounds of unnecessary expenditure. Given the relatively high costs for the under-grounding of transmission links Friends of the Earth Cymru suggests that cost reductions of the order estimated could facilitate a decision to place underground much or all of the transmission links. National Grid should conduct a thorough reappraisal of both the options for placing transmission lines underground and energy storage.

National Grid propose two circuits, both exceeding the installed capacity of the wind farms, which results in very high link costs - particularly for the underground options. The high-voltage, direct current (HVDC) option is specified at 2 GW (2 x 1 GW circuits). Yet this 2 GW link, estimated to cost in excess of £600 million, would connect about 700-870 MW of schemes at most whose output would average about 240MW over a typical year. So the 2 GW HVDC link capacity option specified by National Grid would be at least seven times greater than the average output of the wind farms. A relatively small percentage of energy produced by wind farms annually is generated at high outputs (it may be that less than 10 per cent of annual production would be generated at more than 66 per cent of installed capacity, or above what one circuit might carry).

Similarly, the costs for installing alternating current (AC) underground cables (e.g. 2 x 1 GW circuits) would also be high and presumably even pylon capacity may be over-specified to a degree that significantly changes the scale, height, cost and visual impact of overhead lines.

Our research indicates that a 1 GW HVDC link (2 x 500 MW circuits) could transmit all of the power generated by 870 MW of wind turbines. Failure of one circuit in this two-circuit 'link' (of combined capacity just exceeding the installed capacity of the wind farms) may not result in a significant reduction in power transmission, depending on the reliability of the technology and duration of the outage. An outage would not directly affect the electricity supply to consumers as the link affected would be to the grid. If one of the circuits were to fail for a period of four weeks, we have estimated the value of ‘lost’ production for an 870 MW wind generation supply to be about £1.2 million, or £30 million over 25 years. The overall cash saving during this time period over the option suggested by National Grid is £220 million.

Integrating an electricity storage facility into the transmission link could help reduce lost production during circuit outages. Even if the storage facility cost as much or more than the value of the lost production (£30m over 25 years) the benefits to the system such as demand-responsive power and supply smoothing could help justify the investment. Some commercial storage technologies are available for wind energy storage, and several storage schemes are in operation at wind farms globally.

In this instance the storage facility would require a very large capacity to capture more than a few hours’ worth of electricity at any one period of stronger winds in an outage period which may last days, and it would therefore be expensive. However, the benefits of having a very large facility available to the national grid would then also be great, in terms of technical aspects and hence potentially valuable.

We have also considered the possibility of a triple 250 MW link. This may be a more cost-effective option because even if two of the circuits were to fail, one link would be sufficient to transmit nearly the average output of the wind turbines in the proposed developments.

The above-ground HVDC sub-stations are highly compact and visually less intrusive than AC equivalents. With some innovative design the facilities could be made to look for the most part like farm sheds with a road access.

Friends of the Earth Cymru

Cyfeillion y Ddaear Cymru

Welsh Assembly Government Consultation
Draft Technical Advice Note 8: Renewable Energy
July 2004

Response by Friends of the Earth Cymru

November 2004

Friends of the Earth Cymru

Friends of the Earth Cymru inspires solutions to environmental problems, which make life better for people.

Friends of the Earth Cymru:

- is dedicated to protecting the environment and promoting a sustainable future for Wales
- is part of the UK's most influential environmental campaigning organisation
- is part of the most extensive environmental network in the world, with over 60 national organisations across five continents
- supports a unique network of campaigning local groups working in communities across Wales
- is dependent upon individuals for over 90% of its income

Friends of the Earth Cymru
33 Castle Arcade Balcony
Cardiff
CF10 1BY

Tel: 029 20229577
Email: cymru@foe.co.uk

www.foecymru.co.uk
www.cyddcymru.co.uk

PLANNING POLICY WALES

DRAFT TECHNICAL ADVICE NOTE 8: RENEWABLE ENERGY (July 2004)

Consultation Response from Friends of the Earth Cymru

Introduction

We welcome the opportunity to comment on this draft Technical Advice Note on renewable energy.

We are strong supporters of renewable forms of energy in order to both combat the threat of global climate change and reduce the other harmful effects of burning fossil fuels, such as acid rain, ill health and premature death. In a recent presentation to Welsh Assembly Members, one of the World's leading experts on climate change, Sir John Houghton, warned of the catastrophic consequences of a changing climate and stressed the urgent need to develop renewable energy systems.

It should also be noted that official estimates show that two thirds of the surface area of Wales is acidified (1) and that up to 24,000 people die prematurely each year in the UK as a result of air pollution (2). We maintain our long held opposition to nuclear power as an energy source and point out that the dangers of nuclear power are actually increasing as acts of terrorism reach new heights. Also as the UK and Wales have a stated aim or duty of playing a leading role globally in action on climate change and sustainable development we believe that renewables should be progressed strongly to encourage other countries to follow the same path and avoid the dangers of nuclear proliferation.

We were supportive of the Government's vision for a sustainable low carbon energy system, as set out in the Energy White Paper (February 2003), and of the recommendations, in the Review of Renewable Energy Policy in Wales (January 2003) undertaken by the National Assembly for Wales' Economic Development Committee, that over the next twenty to fifty years it will be necessary to move to a zero carbon electricity system and that the Welsh Assembly Government should set a benchmark for the production of electricity from renewable sources of 4TWh per year by 2010, amounting to just over 20% of annual Welsh electricity demand in Wales (figure based on 2002 UK per capita electricity consumption). Although the overriding purpose of developing renewable energy must be to deliver a very significant reduction in emissions of carbon dioxide, we also believe that the development of a new sustainable industry will have considerable economic and social benefits for Wales.

Planning

Planning has an important role to play in helping us to move from a highly centralised, fossil fuel and nuclear-based energy system towards a more distributed and sustainable renewable energy system. The consequences of this are that local authorities, local communities, environmental organisations, government agencies and developers, who might never have previously had much involvement in the consideration of energy projects, will now be more likely to be involved in shaping policies and assessing applications. It is, therefore, important that they receive clear and unequivocal guidance from the Welsh Assembly Government.

The key policy dilemma for TAN 8 is to balance the imperative for the development of renewable energy with respect for important statutory designations and other considerations relating to biodiversity, built heritage and landscape quality. In our view, renewable energy development, which is of a scale and form that does not damage the features of interest underpinning such designations, should be encouraged. TAN 8 should provide strong general encouragement for the development of renewable energy technology and we welcome the statement in Section 12.8.5 of the Draft Ministerial Interim Planning Policy Statement on Renewable Energy (June 2004) that “renewable energy projects should generally be supported by local planning authorities providing environmental impacts are avoided or managed, and nationally and internationally designated areas are not compromised”.

Specific Comments

Energy Benchmarks and Proposed Capacity for Wind Turbines

We welcome the Welsh Assembly Government’s 'benchmark' or minimum commitment of generating 4 TerraWatt hours (TWh) per year of energy (mainly electricity but also some heat) from renewable resources by 2010 as part of its policy of reducing the emission of the gases and pollutants that are causing climate change. The 4TWh would amount to approximately 20% of Welsh electricity demand. We also broadly welcome the Assembly Government’s aim of securing most of this output by means of wind energy (800MW of onshore wind along with 200MW of offshore wind and other renewables) as this is the most economically attractive and technologically applicable renewable energy resource currently available.

The cost of generating electricity from onshore wind energy (currently around 3p per kilowatt hour depending on site) has fallen significantly in recent years and wind is now competitive with new clean coal generation (3.0-3.5p per kilowatt hour - PIU 2020 Forecast) and cheaper than from new generation nuclear reactors (3-4p per kilowatt hour - PIU 2020 Forecast). The Energy Review, produced by the Performance and Innovation Unit (PIU) in the Cabinet Office in February 2002, estimated that, by 2020, onshore wind would provide the cheapest form of electricity (1.5-2.5p per kilowatt hour) in the UK. Wales particularly has relatively high wind speeds so generation costs towards the lower end of this range may be attained on many sites. For example, the Moel Moelogan windfarm in north Wales has been operating at an annual load factor of about 37%, the nominal value being 30% for onshore sites in the UK.

Wind energy has a positive energy balance, recovering all of the energy used in its manufacture, operation and decommissioning within approximately three months thereby recovering about 80 times its energy input over an operating life of around 20 years. In terms of carbon emissions, a number of life cycle analysis studies (3) indicate that wind produces the least amount of carbon throughout the processes of manufacture, use and decommissioning of all electricity generating systems.

Map-Based Planning

We appreciate the intention behind the Assembly Government's map-based approach to wind energy planning. Such mapping has the potential to identify the least sensitive and most appropriate sites with regard to a given benchmark capacity. However, we have reservations about the degree of reliance on a map-based as distinct from a criteria-based approach. While it is entirely reasonable to use available knowledge and data about Wales to identify the best locations for windfarms, the usefulness of the sieve-mapping approach is very dependent on assumptions and the quality of the data and could result in inappropriate guidance.

In order to reduce unnecessary cumulative visual or other impacts impacts, we agree that, generally speaking, developments should consist of fewer large windfarms rather than a larger number of smaller windfarms. This approach also has benefits in terms of road access, grid connection and environmental disturbance. So, the idea of designating strategic search areas (SSAs) has much to commend it in terms of identifying the most appropriate and least sensitive areas in Wales. However, we think that the current SSAs in the draft TAN may be placing excessive pressure and potentially unreasonable expectations within certain SSAs while excluding suitable sites outside the SSAs.

The implied presumption that much, most or possibly all of the 800MW capacity benchmark could or should be achieved within certain Strategic Search Areas (SSAs) identified by the study is questionable, if indeed that is the presumption implied. More detailed site surveys may identify further constraints and the estimated capacity for a given SSA may not actually be achievable in practice. We understand that Welsh-based wind energy developers have already come to the conclusion that the SSAs would not support the capacity estimated in TAN 8 once detailed site constraints are taken into account. Also, the SSAs may well include some unsuitable locations, whereas suitable areas outside of the SSAs are potentially being excluded not least because of the arbitrary cap of 25MW capacity. The proposals as they stand also beg the question about the policy for windfarm proposals outside the SSAs if the nearest SSA is not deemed fully developed.

For the same cumulative impact reasons the 25 MW capacity cap on schemes in areas outside the SSAs is too restrictive. There may be a few good sites for schemes between 25MW and the 100MW minimum designated for the SSAs. For example a 75MW scheme would likely have less cumulative impact that three 25MW schemes. Presumably if the mapping data is up to the job then such sites should be capable of being identified. Consequently, we recommend that the 25 MW cap on proposals outside the SSAs is deleted and criteria-based policy would apply across Wales, with less stringent cumulative impact criteria within the SSAs.

To sum up, we believe that planning guidance would be better if the best aspects of the mapping and a criteria approach were integrated. This would build on the criteria based guidance followed in England and Scotland which assesses each individual application on its merits. The merits of the SSA idea could be integrated into ‘criteria-plus’ guidance that would retain a criteria based system but would include the positive benefits of mapping exercises and SSAs to identify the most appropriate way of achieving the specified capacity.

Updating the Maps

We recommend that the TAN should also include provision for revision of the maps as and when constraints change over time. Indeed, the constraints and opportunities could change potentially very significantly (eg. TTAs, radar exclusion zones, sensitive areas for birds, ecology, etc). Also the data-sets which generate the maps may well improve over time and the maps should quickly be updated and refined accordingly.

In particular, if the MoD's Tactical Training Area (TTA) in mid Wales is reduced in part or whole, or moved in exchange, then whole new areas of low sensitivity may suddenly become available. The proposed Camddwr windfarm at 300MW+ (40% of the 2010 benchmark capacity) may become a very attractive proposition for all concerned in achieving the 2010 benchmark if the TTA constraint changed. We recommend that the Assembly Government should specifically assess the Camddwr Trust's proposals and approach the MoD to do what it can to realise the possible benefits of a scheme in this area (see Annex 1 for details of the Camddwr Trust windfarm proposals).

The assumptions made about Grid access for the mapping are simplistic at the moment (the constraint used appears to be for schemes within 10km from existing Grid lines). Grid connection costs are a function of transformer and the nearby network Grid capacity, not just distance. Furthermore, some sites at greater distances but with higher wind speeds may still be commercially viable even with higher connection costs. More accurate data-sets should be incorporated as soon as they become available.

The current maps also do not clearly indicate that the SSAs are subject to Grid and road access considerations, if not constraints, when they may actually exist. A map indicating road and track access would be useful. Road access is particularly relevant in the case of SSArea D, Nant y Moch in Pumlumon where Grid and road access is poor. Also, this area also appears to be of greater landscape sensitivity than the other SSAs, and some areas outside the current SSAs, and there are already several existing windfarms operating in the vicinity. Consequently we recommend that the Nant y Moch area should not be designated as an SSA and criteria-based policy only should apply. We do however recommend that the Nant y Moch area should be considered for designation as a TTA in exchange for that part of the existing TTA area which currently precludes the building of the Camddwr Trust's windfarm proposal.

Sensitive Areas

Considering the 2010 benchmark we agree that windfarms should not be considered within the National Parks and AONBs and a 4 km buffer around such areas would seem reasonable and would probably not preclude much capacity anyway. Smaller community-scale and domestic turbines should be allowed.

Community and Consumer Involvement

We welcome the recognition in TAN 8 of the need for the active involvement of the local community in windfarm developments (large and small) and would like to see greater emphasis placed on this important issue. Section 43 should read, "Developers are obliged [rather than encouraged] to consider ways in which their proposals may include the active involvement of the local community". That said, some windfarm proposals have already been proposed where the public can invest in the scheme. Also some windfarm developers already offer significant annual funds for biodiversity, community and energy efficiency projects.

We would also suggest that planning guidance, and the distinction between building regulations, for small windturbines (0.2kW- 25kW) in domestic, commercial and industrial locations (roofs, elevations, gardens etc) needs to be clearly stated. There could be significant potential for community and consumer involvement and investment in shared or privately purchased devices (similarly, there also needs to be clear guidance or regulations for solar panels both thermal and PV).

Interim Policy

Planning policy for scheme proposals already well advanced or submitted should not be undermined by the significant change the new TAN represents. The TAN may take some months before coming into effect and a positive interim policy should be adopted in the meantime.

Onshore Renewables other than Windfarms

While it is inevitable that much of the TAN has focussed on planning for onshore wind energy we are pleased that various other onshore renewables have been highlighted. However, we are concerned that insufficient consideration has been given to the potential contribution and planning implications of both heat energy and other forms of renewable energy in TAN 8. This is particularly the case with regard to wood fuel and we believe that the TAN 8 estimate of this fuel resource, at just 10MW, is an underestimate. Wood heating schemes, such as at Preseli School and Leisure Centre in Crymych and the refurbished Pembrokeshire Coast National Park offices at Llanion Park, Pembroke Dock, provide good examples that could be replicated on a large scale throughout Wales in the near future.

We believe that the potential for the use of methane from coalmines as a source of fuel (although not strictly a renewable source) has also not been fully explored. We would also like to see greater emphasis being placed on the use of combined heat and power (CHP) technologies to maximise the efficiency of energy generation. Section 79 recognises that CHP is “a particularly efficient way of generating electricity whilst using the waste heat for productive purposes” and that this results in “significant carbon savings”. Yet, the implementation of CHP in recent years has been extremely disappointing and is likely to remain so unless measures are introduced to specifically improve the take up of CHP.

Whilst accepting that time is of the essence and that wind energy is the best available option for achieving the required contribution from renewable energy by 2010, we believe that greater consideration has to be given to these other options if we are to meet the 200MW target for offshore and other renewable sources. There will likely be planning implications especially if any technologies become more commercially attractive and are deployed sooner than anticipated. For example, increasing farm-scale biomass capacity may stress or de-stress the network capacity of the nearby Grid which may have knock on implications for other renewable developers and visa-versa.

As there is little specific guidance on the various non wind renewables perhaps the guidance could incorporate some of the relevant technical annexes from PPS22.

Recommendations

Onshore wind energy planning:

1) The 800MW by 2010 onshore wind energy capacity benchmark is retained

2) The sieve-mapping planning approach should be better integrated with criteria planning to create a ‘criteria-plus’ approach

3) The 25MW capacity cap for windfarms outside the SSAs should be removed

4) Great clarity is needed as to the acceptability and relationship of developing windfarm capacity outside the SSAs with that inside the SSAs

5) The maps should be updated as and when constraints change and when more detailed data-sets become available. Consideration should be made for the creation of new SSAs in the event of constraints being removed.

6) WAG should identify the merits of and put the case for the Camddwr Trust windfarm proposal to the M.O.D as the current Tactical Training Area restrictions are having a very significant effect on the strategic planning of wind energy in Wales

7) The Nant y Moch SSA (Area D) should be deleted and possibly offered to the MoD as an exchange area for a TTA in the Camddwr area

Other onshore renewables:

8) Greater consideration should be given to the planning implications of a more rapid grow of other forms of renewable energy schemes and devices (eg: biomass schemes, small hydro schemes, CHP schemes, small wind turbines)

Notes

1) ‘A Living Environment for Wales’ by The Countryside Council for Wales (Fig. 11.2)
2) The Commission on the Medical Effects of Air Pollution
3) Open University publication RENEW edition 133 Sept/Oct 2001. The Energy Technology Support Unit (ETSU) 1999. ‘Power in Balance: Energy Challenges for the 21st Century by Friends of the Earth (p97).

Annex 1

Camddwr Trust Windfarm Proposal

One suggested large site outside of the SSAs is the 300MW (which would supply 5% of Wales’ electricity demand) Camddwr site near Tregaron. This area is arguably less landscape sensitive than areas within the proposed SSAs as it is on a less intrusive upland and forested plateau. Whereas a number of the SSA sites have poor road access, the Camddwr area is already well provided with forestry tracks. The scheme would also have a significant community benefit, via the Cymuned Camddwr Trust, that would invest 5% of the project’s revenues (around £2m per annum) into local community and regeneration activities. There would likely be a major biodiversity enhancement as it is intended to undertake environmental enhancement work on the site replacing the Sitka plantations with a far more habitat rich open broadleaf woodland.

The Camddwr area is currently designated an absolute constraint in the mapping process, yet would almost certainly show up as major SSA if the MoD’s tactical training area designation was removed (with the potential of over 300MW of capacity). The MoD only uses the area occasionally (about 30hrs per year) for low flying by large slow moving Hercules transport aircraft (as distinct from fast jets). The Welsh Assembly Government could negotiate with the MoD about this restriction and offer another appropriate area, such as the Nant y Moch area.

Renewable Wales 2050

Headline recommendations

1. The Welsh Government should focus its policies and attention to supporting and facilitating the building of an energy system and infrastructure which would be 100% renewably powered by around 2050.

2. In order to move towards a fully renewable Wales by 2050, the Welsh Government must consistently press for full devolution of powers over energy. The absence of these powers leaves the Welsh Government hamstrung in its efforts to achieve its energy and climate change targets. Cross-party agreement on this stance would be a useful democratic tool to facilitate 'Renewable Wales 2050'.

3. In the interim, support under the current devolution settlement would be for the construction of offshore and onshore wind farms, facilitating the deployment of combined heat and power (CHP), solar (both heating and photvoltaics (PV)), heat pumps, fuel cells, tidal and other renewable and fuel efficient technologies, and fuel-flexible carbon capture and storage (CCS) infrastructure which could progressively be used for carbon-negative energy generation or biofuel production (assuming sustainable biofuels become available).

4. The Welsh Government should continue to press the UK government for a complete moratorium on nuclear new build in Wales on the grounds of :
   - expense (and particularly the subsidies involved)
   - lack of need in terms of energy security or climate considerations
   - the avoidance of the production and use of health-damaging nuclear fuels and wastes
   - the avoidance of major radioactive releases due to accident or malicious intent
   - the use of civil nuclear as cover for nuclear weapons programmes

Executive summary

1. The potential for Wales to become fully renewably powered by 2050 is partly dependent on the speed with which the renewable resources available can be built into a cost-effective, demand-responsive energy system using existing, new and emerging energy technologies and existing infrastructure assets where possible. This means that this aim will be dependent on Welsh and – until energy consents are devolved – UK government commitment to a fully renewable Wales by 2050.

2. We estimate that energy demand in Wales in 2050 will be around 72 TWh per year or 53 kWh per day per person. This future demand is just 23% lower than current energy demand because a forecast 19% rise in population by 2050 partially counteracts efficiency improvements and technological advancements. This demand is what a 2050 energy system has to aim to supply with the renewable resources and energy technologies available. We estimate that the renewable resources available to Wales lie within the range of 60 to 80 TWh per year.

3. The potential renewable energy resource in Wales plus imported shows that the likely level of 2050 demand falls in the range of renewable resources. Consequently, demands could

potentially be fully met by a renewable energy system by 2050 but rapid progress on numerous fronts would be necessary.

4. A fully renewable powered Wales would require extensive deployments of offshore wind farms and solar PV roofing as the future cost of these technologies is estimated to become about the lowest cost except for onshore wind energy. About half of the future energy for Wales and the rest of the British Isles could come from just these two resources, though other technologies may emerge.

5. Offshore wind alone may contribute 12 TWh per year by 2030 around and 30 TWh per year by 2050 – 40% of Wales's energy needs. At UK level, thousands of giant turbines, many on floating structures over extensive sea areas, would need to be built in any likely scenario. An offshore wind deployment occupying an area slightly greater than the ‘size of Wales’ would become the engine room of the Welsh and British economy and industry, generating electricity and hydrogen in possibly equal measure.

6. The concept of solar PV panels delivering possibly 8 TWh per year (more than 10% of 2050 Welsh energy demand) is a more novel and possibly surprising prospect given the stereotype of the Welsh climate. Yet the solar resource is very favourable, particularly in south western Wales. Solar PV is continuing to develop and beyond 2020, new materials and manufacturing techniques, coupled with building-integrated designs, are forecast to lead to major cost reductions. We will see solar PV reaching grid parity in Wales by the end of this decade.

7. Extracting heat from the local environment to heat buildings may at some point become as cost-effective as measures to stop heat leaking back into the environment from buildings. In a fossil fueled world heat pumps have been of dubious value but powered with renewable electricity they come into their own. A deployment of heat pumps in about half the buildings in Wales could contribute 7.5 TWh per year or more (10% of 2050 demand). If heat pumps prove very consumer-friendly and cost-effective then possibly a saturation deployment may occur with devices in most buildings or larger pumps in CHP schemes. Heat pumps need to be matched to building heat needs. Better standards of insulation across the existing building stock would reduce building heat needs by 4.5 TWh per year, a 17% reduction despite significant new build.

8. Onshore wind farms could contribute around 5 TWh per year (7% of 2050 demand) or more depending on landscape considerations. Onshore wind is and will likely remain more cost-effective than most other if not all larger-scale renewable energy technologies. Future replacement turbines built on existing foundations would be cheaper still. Most, if not all, of a 5 TWh per year deployment could be built by 2020 bringing much needed early emission reductions.

9. A visionary plan and concerted drive to reforest Wales and harness its other bio-energy potential could provide another significant contribution. Farm-scale anaerobic digestion schemes producing bio-gas would also be a useful rural source of bio-methane or hydrogen. Indigenous bio-fuel production, assuming 75% efficiency in converting various bio-energy feedstocks to useful bio-fuels, could contribute around 4 TWh per year (around 5% of demand).

10. Several other indigenous renewable resources, such as hydro, solar thermal and possibly wave would make smaller contributions due to cost, resource constraints or better alternatives. In the Reference Scenario solar PV predominates over solar thermal schemes for roof space in most areas as heat would be available from other sources, and PV would provide electricity for cooling systems. The contribution from wave technologies is very much dependent on the reduction in costs, especially in comparison with offshore wind energy.

11. Tidal range and marine current resources could make sizeable contributions. Several large tidal schemes, including offshore or land-attached lagoons, on the Welsh side of the the Severn Estuary could be possible. Innovative designs, sustainable structures and low-cost construction techniques would determine how much capacity may get built. A major barrage across the Severn Estuary is not included in the resource potential due to its ecological impacts and high capital cost. There is also tidal current generation potential around northern Anglesey, Penrhyn Llyn and Pembrokeshire.

12. Even with all the above indigenous resources, Wales would still need some imports of renewable energy, particularly liquid biofuels for aviation and shipping.

13. Overall, the indigenous and imported renewable energy resources potentially available to Wales amounts to 80 TWh per year, with imports comprising around 10%. This level of resource would be 11% greater than the 2050 energy demand of 72 TWh per year. On the other hand a shortfall of 12 TWh per year could be possible if there was slow deployment on every front especially if offshore wind schemes, solar PV and heat pumps were not deployed at considerable scale and sustainable bio-energy sources did not materialise at scale.

14. One of the principal design requirements of the energy generating system is to reliably deliver the electricity and heat demand during a severe and prolonged cold snap caused by a windless winter anticyclone. The sleeping energy giant which comes to the rescue at such vulnerable times does not so much comprise large lumbering power stations and the national grid but millions of small gas boilers in buildings fed by the gas networks. Gas infrastructure, largely hidden in buildings and below ground, provides over three times more energy than electricity infrastructure when it is really needed. Reports of its demise due to a move to electric heating and electric transport are premature.

15. Most of the potential renewable energy resources identified around Wales would provide intermittent electricity as most if not all bio-energy would be needed in the transport sector. Yet a cost-effective, demand-responsive energy system which is also reliable, robust and secure can be built from such intermittent resources. The latest developments in hydrogen technologies including fuel cells, micro-CHP boilers and electrolysers, can turn intermittency into demand-response. Such technologies would also enable the existing gas distribution network, a transmission asset which would cost billions of pounds to construct or replace, to continue to be used. Hydrogen, be it mixed with bio-methane or pure, could give the gas network a new lease of life in a low-carbon future. The forty year hiatus since hydrogen was last distributed extensively by the nations gas network could be reversed over the next forty years.

16. The 2050 Reference Scenario describes an energy system in which very large scale intermittent renewable energy sources provide hydrogen which the gas network could distribute. Heat pumps backed up by fuel cell domestic boilers and CHP schemes supplied by

hydrogen from offshore windfarms could provide electricity and heat when and where it is needed.

17. Another factor to consider in the design of a future Welsh energy system is carbon dioxide emissions. The next few decades are critical. The energy system chosen for the Reference Scenario would have considerable carbon-negative potential, rather than just being carbon-neutral or low-carbon. Liquid bio-fuels, bio-methane and bio-hydrogen produced in bio-refineries fitted with CCS plant would be ‘carbon-negative’ to some degree. Most of the bio-carbon dioxide released in bio-refineries around Wales would subsequently be stored in depleted gas wells and other geological formations deep under the Irish seabed.

18. This report clearly indicates that there are sufficient renewable energy and CCS alternatives without accepting, and been locked into, new nuclear power programmes which may in any case become obsolete within just over a decade.

Background

This report examines the potential for Wales to move away from fossil fuels and nuclear power to become a fully renewably powered country by 2050. The report also examines the potential of Wales to become 'carbon-negative' by using bio-energy in conjunction with carbon capture and storage technology (BECCS), and shows how renewables and carbon capture and storage (CCS) can address energy security and climate concerns well beyond that which even a large scale new-build nuclear programme could. The possibility of synthetic liquid bio-fuels, made using carbon dioxide captured directly from air and renewable energy, is also considered.

The report makes projections of the country's surface transport, building stock, industrial, aviation, shipping and other sector energy demands in 2030 and 2050. Using official and other forecasts, including significant population increase, and assessing the effect of possible and likely technology developments, a picture of future demands is described. The prospects for harnessing renewable energy from around Wales are then assessed including onshore, offshore resources and also imported energy sources. How these sources, most of which are variable or intermittent, can be integrated into a demand-responsive and resilient energy system is considered in some detail.

The report finds that it will be challenging but quite possible for Wales to acquire all its energy needs by 2050 or soon thereafter from renewable sources. The projected increase in the Welsh population of 10% by 2030 and 19% by 2050 may require an extra decade or so beyond 2050 to complete construction of the additional offshore wind farms, heat pump systems and other infrastructure to meet demand. Even though Wales is relatively renewable energy resource rich it will, as now, need some energy imports. That said, the percentage of demand supplied by imports would decline from 46% currently to probably between 10-20%, and these imports would comprise mainly raw bio-energy feedstocks for aviation and shipping. The declining use of coal with CCS, or gas if available, may extend for a time beyond 2050 to help smooth the transition.

Some of the technology possibilities and findings in this report go well beyond what most public and politicians are even vaguely aware of. Some interesting choices have emerged in the iterative analysis which provide context and present opportunities but may also challenge commonly-held concepts, views and received wisdom.

The analysis generates some big questions: should Wales import bio-fuels and feedstocks; should the Welsh or entire UK gas network switch from natural gas to hydrogen and if so when and how; should any coal use be ruled out; at what point should policies incentivise heat pumps and fuel cell boilers over insulation schemes; should bio-kerosene aviation fuel be produced in a highly carbon-negative process at greater cost to account for high-altitude emissions; should thorium reactors which would consume legacy radioactive waste be consented if proven; could solar synthetic bio-fuels become cheaper than conventional crop equivalents; should Wales become the first country with a 'carbon-negative' commitment within its sustainability policy to show global technical and ethical leadership?

This report highlights these and other interesting and crucial questions, which may offer directions to energy pathways the people of Wales will make on their journey through the twenty-first Century.

Introduction

Rising energy bills at home and concerns about dangerous global climatic changes caused by burning coal, oil and gas are two big issues facing the public and politicians in Wales and around the world today. There are also concerns about oil resources declining globally leading to higher fuel prices or newly discovered 'shale gas' resources which could bring down gas bills. Added to such issues is an on-going public debate about the benefits and drawbacks of various low-carbon energy technologies.

In May 2011, the Government's climate advisory group, the Climate Change Committee (CCC), advised that to keep energy prices down the construction of new nuclear power stations and onshore wind farms should be prioritised while offshore wind farm construction should be slowed before 2020. The CCC suggests that nuclear capacity should be increased by a factor of two to three across the UK by 2030. It acknowledges that adverse events, particularly the multiple reactor meltdown disaster at Fukushima, may turn the UK public and politicians to non-nuclear pathways as has happened in Germany, Italy and other countries. Such advice has major implications for Wales' pathway to a low-carbon future. Wylfa, on Anglesey, would be the location for a new truly leviathan 3.2 GW nuclear power station, more than three times the size of the existing station. Two other proposed sites for multiple reactors are very close to Wales, at Oldbury in Gloucestershire (3.3 GW), and Hinkley Point in Somerset (3.2 GW).

The balance between onshore and offshore wind farm construction in and around Wales may also be affected, as could the prospects of building a world-leading offshore wind industry.

While wind farms and nuclear power attract the media spotlight this report shows how the range of possible new energy technologies and existing infrastructure may fit together to build a sustainable, secure, resilient and potentially carbon-negative energy system for Wales.

This report puts detail to the broad energy choices or pathways for Wales which excludes the proposed new nuclear power station at Wylfa. It aims to show how the potentially major technologies particularly offshore wind, solar PV, heat pumps, sustainable biomass, energy efficiency and CCS could be integrated into an increasingly low-carbon and sustainable Welsh energy pathway to 2050.

The report also sets in context the wide range of other technologies and resources including tidal, wave, hydro and indigenous biomass which would have a smaller role. It also highlights the critically important role of the gas network in Wales despite the wide focus on electricity over many years. Finally it also shows how Wales could go beyond being a 'low-carbon' country to become 'carbon-negative' by mid-century.

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1 Current energy demand and energy infrastructure

1.1 Much of the energy infrastructure in Wales, be it grid links, gas pipelines, power stations, domestic central heating boilers, or LNG terminals are closely interconnected with infrastructure in the rest of the UK. This shared larger infrastructure enables a more efficient, cost-effective, resilient and responsive energy supply and delivery system. This report assumes that energy consumption in Wales will continue to share a similar profile with that of the UK, even accounting for such differences as housing stock, manufacturing base, gas network coverage, annual car mileage and earnings.

1.2 Over the last few years consumption of energy (mainly as electricity, natural gas and transport and heating fuels) has been an average of about 1,850 TWh/year (82 kWh/day per person). Energy consumption in Wales has averaged about 93 TWh/y in recent years though the closure of Anglesey Aluminium Metal Ltd in 2010 resulted in an abrupt 2 TWh/y reduction in electricity demand (nearly 10% of electricity demand in Wales). This energy demand is referred to as 'final' or inland' as it is a measure of demand for 'produced fuels' used.

1.3 Note that due to the large quantity of electricity used in the smelting process aluminium has been called 'congealed electricity' and most of the aluminium produced on Anglesey, like many other manufactured products, would have been used throughout the UK or abroad. Similarly many imported goods will contain large amounts of embodied energy. Such energy exports and imports are not assessed in detail in official statistics and are beyond the scope of this study.

International aviation and shipping

1.4 Carbon dioxide emissions and some energy consumed by UK residents during international air travel and demand for goods imported on international shipping have to date been accounted for separately in official publications. This international energy consumption by UK including Welsh residents has been rising steadily over the years and is significant despite moderating influences (including terrorism and economic recession). International energy consumption amounted to an additional 10.5% (195 TWh/y) on top of UK consumption by 2009. International aviation demand reached 150 TWh/y for the UK in 2009 and shipping was 45 TWh/y. Disaggregated information on international energy consumption by the four countries of the UK is not available.

1.5 A more accurate picture of energy consumption by any country should include international aviation and shipping. Final energy demand statistics include aviation fuels delivered to UK airports, though this fuel will be used transporting air passengers of many nations, just as fuel supplied at foreign airports will be used transporting UK and Welsh residents. Adding in the *net* international aviation consumption (estimated to be 120 TWh/y), overall UK energy demand would have been just over 2,000 TWh/y during recent years. Assuming a proportionate per capita share of aviation (5%), Welsh gross energy demand has been about 100 TWh/y over recent years.

Fuels used in energy generation

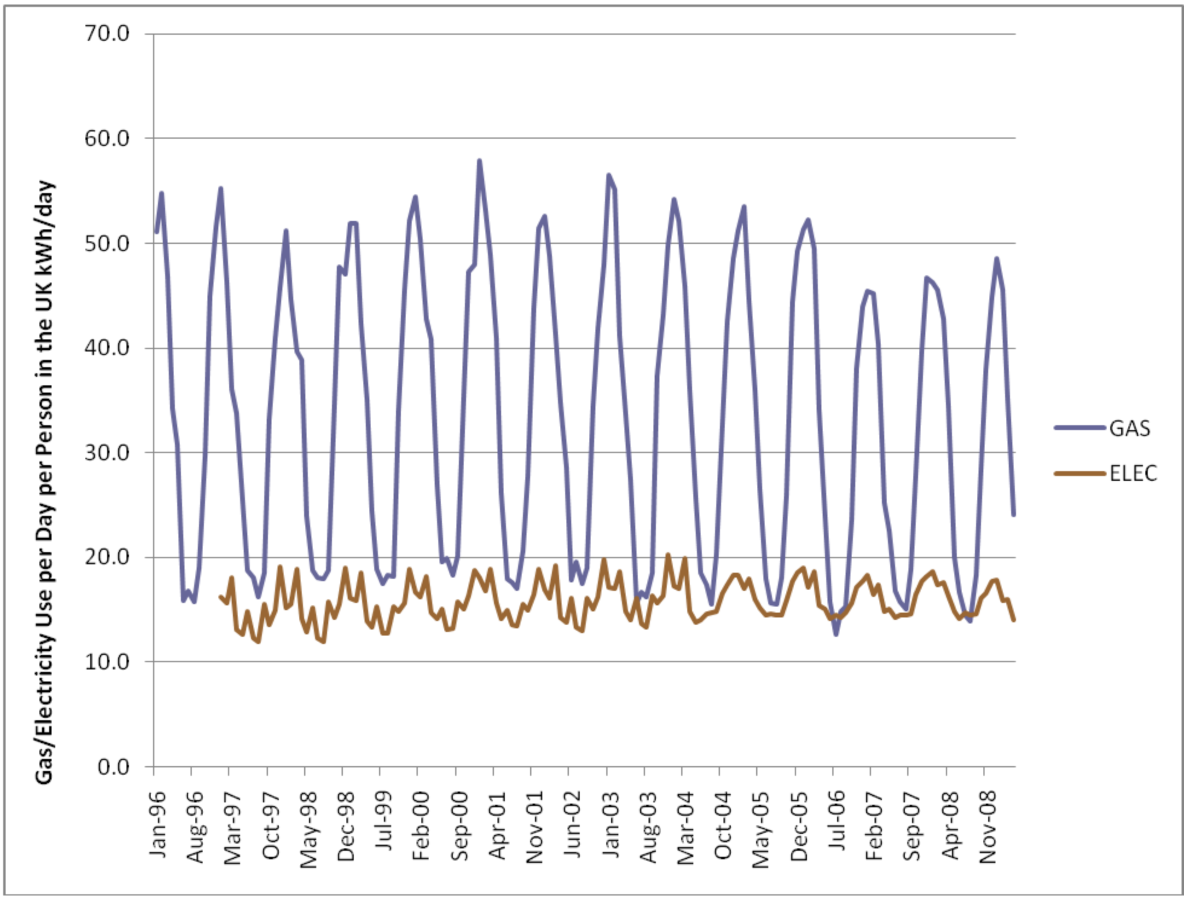
1.6 In 2008 (the most recent year for which Wales figures are available), more than 95% of energy consumption was fossil fuels with 2.7% being supplied by nuclear and 1.8% by renewables. When international aviation and shipping energy consumption is included the nuclear and renewables percentages fall further.

1.7 Nuclear power stations supplied an average of 62 TWh/y of electricity to the grid in Great Britain between 2005 and 2009. Renewable technologies reached 50 TWh/y in 2009 and are continuing to rise as new capacity is built.

1.8 About 25% of total Welsh energy demand (excluding international aviation and shipping) is for transport, mostly petrol and diesel fuels for vehicles and trains.

1.9 Peak winter UK energy demands over the most recent years has averaged 65 kWh/day per person. During the very severe cold spells in the winters of 2009/10 and 2010/11, each lasting more than a week, the energy demand on some days peaked at about 100 kWh/day per person. Daily gas demand, predominantly for heating buildings, varies much more every year than daily electricity use (Figure 1). Figure 1 also shows that UK gas and electricity demand in recent summers has typically been about 40% of typical winter demand and a third of severe winter peak demand.

Figure 1 Daily Gas and Electricity Demand since 1996



Energy infrastructure

1.10 In 2009 losses of electricity from the system amounted to about 7% of the electricity generated. About 22% of these losses occur at the high voltage transmission level, 74% from distribution of electricity to customers, and 4% through theft or meter fraud. Distribution losses in the gas network comprise about 2% of the total throughput.

1.11 The UK's gas network carries three times more energy than the electricity grid does. About two-thirds of the UK gas network's strategic pipelines are offshore under the North Sea. These pipelines link twenty or so gas fields in the North Sea to more than 20 million consumer appliances.

1.12 The UK imports natural gas by pipelines from Norway (72% in 2009), the Netherlands (23%) and Belgium, and Liquefied Natural Gas (LNG) by ship. In 2009, the UK was a net importer of gas (as it has been since 2004) with 319 TWh net imports of gas.

1.13 The UK has considerable capacity to import LNG. The two new LNG terminals in Milford Haven have a capacity to unload the equivalent to about 30% of current UK gas demand. LNG terminals in other parts of the UK are being expanded.

Primary Energy Supply and Final Energy Demand

1.14 Across the world 'primary sources' of energy (mainly coal, crude oils and 'dirty' natural gas), are converted in power stations and refineries to fuels which are usable by consumers, mainly electricity, transport fuels and clean natural gas. The energy lost in converting the primary energy supply to 'produced fuels' to meet consumers' energy needs can be considerable. Existing coal and nuclear power station are about 38% efficient at best, though new coal technologies are achieving conversion efficiencies around 45%. New gas-fired power stations are achieving nearly 60% conversion efficiency in optimal conditions.

1.15 In 2009 the UK's primary energy supply was 2,560 TWh/y. After conversion losses (mainly wasted heat in large power stations) the final energy produced and consumed was 1,776 TWh/y. This 'final demand' excludes 'distribution losses' of 47 TWh/y but includes 'non-energy' uses of 106 TWh/y which accounts for oil and gas being converted to numerous chemical products (e.g. paints, fertilizers) and plastic materials.

1.16 Final energy consumption comprised 18% of electricity, 30.5% of natural gas, 47.5% of oil (mainly road fuels), and 4% of other fuels (eg coal, biomass, derived fuels).

1.17 Of this 2009 final energy demand 17.5% was consumed in the industrial sector, 28.7% in the transport sector and 47.8% in the residential/non-residential and other sectors. Non-energy uses (eg chemicals, oils, paints, plastics) accounted for the remaining 6%.

UK energy imports

1.18 The UK currently imports about 46% of the primary energy used to produce fuels used in the UK. Imports comprise mostly coal, oil, gas and uranium. Biomass imports are currently small (less than 1%) but as traditional sources decline for various reasons, bio-energy sources (i.e. raw biomass feedstock or produced fuels mainly as bio-kerosene, bio-diesel and bio-methane) could increase significantly.

2 Future energy demand in Wales in buildings and industry

This section puts forward estimates for energy demand from residential and non residential buildings and industry in 2030 and 2050.

2.1 Most of the existing Welsh housing and other building stock was designed and built without adequate insulation. Most Welsh buildings could be better insulated and various area-wide retro-fit insulation programmes, albeit under-funded, have made some progress over the years. From 2012 the Green Deal policy Investment Bank will fund a two decade programme of building insulation. Efficiency improvements will include insulation of lofts, flat roofs, cavity walls and external walls, plus glazing, pipe-lagging and draught-proofing. Gradual improvements to the existing building stock will take place to 2050 and beyond as major structural maintenance and changes such as re-roofing and extensions provide opportunities to improve insulation and passive heating and cooling. Demolition of poorly insulated stock will also make way for new-build housing which will be built to much higher energy efficiency standards.

2.2 The efficiency of heating water is likely to improve as direct electric and more efficient condensing and fuel cell boilers progressively replace the existing less efficient products. New boilers are now about 90% efficient and this could increase to 95% or more with the 'passive flue gas heat recovery' technology that uses the exhaust air from boilers and fuel cells to pre-heat incoming water.

2.3 Accurately determining the actual heating needs of the current residential and non-residential stock is difficult. Boiler and central heating system efficiency vary, different fuels and direct electric heating are all used (sometimes in the same property), and inefficient electrical appliances and incandescent lighting also indirectly contribute to heating needs for many months of the year, and also to cooling demands in some buildings.

2.4 In future decades it may be that considerably more electric heating is used, possibly in combination with air or ground source heat pumps. If so, energy losses from gas or oil boiler systems, which are becoming very efficient anyway, would reduce even further. Where gas boilers are used they will probably be smart, highly efficient, electricity-generating, micro-Combined Heat and Power (mCHP) boilers, probably incorporating fuel cells. The high electricity output of fuel cells may be as much as 45-50% of the gas consumed, much higher than the 10% or so of the mCHP boilers on the market today. Micro-CHP boilers could power the buildings' heat pump at times when grid electricity is more expensive due to the intermittent availability of electricity from renewable energy sources. Such de-centralised electricity generation, in domestic boilers and local CHP schemes, could become the principal way in which the intermittency of renewable sources is managed.

New homes and other new buildings

2.5 While more efficient heating technologies and better insulation will reduce residential and non-residential heating demand in Wales, a 19% increase in population and thousands of new buildings will create considerable new demand.

2.6 In Wales there are 1.3 million Welsh households and the current population of just over 3 million is forecast to rise to 3.3 million, living in 1.6 million households, by 2030. These figures indicate a fall to 2 persons per household. The Reference Scenarios in this report assumes 1.65 million homes by 2050, with around 2.27 persons per dwelling.

2010 residential and non-residential heat need and heat demand

2.7 To assess future heating needs, the actual heat needs of the existing building stock need to be estimated. This heat 'need' is distinct from the energy demand by buildings for supplying the heat need, because of heat losses in inefficient boilers and heating systems, and indirect heating gains from inefficient electrical appliances.

2.8 Residential and non-residential sector energy demand for heating amounted to 535 TWh/y in 2007 of which 78% was residential and 22% non-residential. Assuming boiler and central heating system losses averaged 20% across the national stock and such systems supply 90% of heat needs, (10% is via direct electric heating) then heating losses comprised about 105 TWh/y. So actual heat supplied would have been about 430 TWh/y in 2007. These figures indicate that overall energy supply to provide heating demand is 1.28 times the residential demand (to account for non-residential demand).

2.9 Residential energy consumption of all fuels amounted to 531 TWh/y in 2008. This residential demand was supplied by gas (68%), electricity (for all purposes) (22%), and other fuels (heating oil, coal, wood, wastes etc) 10%. Direct electric domestic space and water-heating accounted for 26% of electricity supplied to the residential sector in 2008. So the energy used directly in residential heat provision was 444 TWh/y in 2008. Assuming boiler and other heating system losses of 20% suggests that actual residential heating supplied by these fuels was 355 TWh/y with 89 TWh/y heat losses.

Indirect electric heating by appliances and lighting

2.10 Although electricity is used for all purposes in buildings the heat generated by appliances, lighting and cooking indirectly contributes to heat within the buildings. This indirect heating is probably beneficial for much of the year in the cool climate of the UK. So, of the 117 TWh/y of electricity consumed by the residential sector in 2009, 30 TWh/y was used directly in space and water heating and some or much of the remaining 87 TWh/y released in to the building would also have usefully contributed heat for much of the year, particularly as most appliances and lighting will be more heavily used during the winter months. As increasingly efficient appliances and lighting are introduced, such as LED lighting, other forms of heating may be required especially in winter, and concomitantly less cooling in summer. For example, replacing ten 50 W down-lights in a kitchen with ten 4 W LEDs would reduce the electricity demand by a considerable 0.46 kW.

2.11 This indirect heat provision in winter and the avoidance of active cooling, such as fans and air-conditioning, in summer could be significant. Its affects need to be quantified to accurately assess the building stocks actual heat needs (as distinct from the energy demand for direct heating and cooling) to determine heat pump and micro-CHP boiler potental. For example, if about 50% of the residential electricity used for appliances and lighting (i.e. 45 TWh/y) usefully contributed indirectly to space heating then a more accurate heating need of the residential stock may be significantly higher than the 355 TWh/y estimated above using offical data above, in this example 400 TWh/y (12.5% greater).

2.12 The actual heating need of non-residential stock is also likely to be subject to similar heating benefits and cooling disbenefits and could also include significant quantities of indirect electric heating. Applying the scaling factor of 1.28 to the 444 TWh/y of heating energy supplied to the residential sector in 2008 indicates that the energy supplied would be about 124 TWh/y of which 20% could be boiler and other heating system losses. So the heat actually supplied directly would be 99 TWh/y.

Applying a similar indirect heating benefit as assumed for residential buildings (12.5%) from appliances and lighting suggest an actual heat need of 110 TWh/y.

2.13 So, if the indirect heating benefit was about half of the electrical energy used in the building, the actual heating needs of residential buildings could be about 400 TWh/y, and non-residential buildings 110 TWh/y bringing the total heat need to about 510 TWh/y in 2008. Overall boiler and heating system losses woud be 114 TWh/y (assuming average losses of the stock are 20%) and the overall indirect electric heating benefit could be around 56 TWh/y or more.

Future energy demand in existing and new residential and non-residential buildings

2.14 This report assumes that insulation standards of the built environment (ie all types of buildings) steadily improve and reduce heating need (both space and hot water) by about 20% by 2050. Such reductions in heat demand follow reasonable insulation improvements not entailing major non cost-effective changes to existing housing stock or 'super-insulation' standards.

2.15 However, this reduced energy demand is mostly cancelled out by the additional hot water and space heating needs of new-build housing and other buildings, and the forecast 19% population increase by 2050. This is estimated for the UK as a whole to be 40 TWh/y for residential buildings and 12 TWh/y for non-residential buildings.

2.16 Due to climate change, air-conditioning and cooling are also likely to increase energy demand in this sector. Outside air temperatures are expected to rise by 2 to 2.5 Centigrade by 2050. However, warmer temperatures will slightly moderate energy demand for heating for much of the year.

2.17 Boiler losses, which are likely to be 15-20% or more in existing gas and oil heated households, are accounted for separately in this future heat need assessment because they are not strictly heat needs and future losses will depend significantly on what contribution of direct electric heating, fuel cell boilers and heat pumps each make.

2.18 Consequently, the 2050 residential heat demand (excluding boiler losses) is estimated to fall from 400 TWh/y in 2009 to 320 TWh/y in 2050 due to insulation improvements but 40 TWh/y of new demand is added, bringing the 2050 total to 360 TWh/y (Table 1).

2.19 Non-residential buildings such as schools, offices and light industrial premises are assumed to be insulated to similar standards (a 20% improvement as compared to existing stock). The heat need of the non-residential stock falls from 110 TWh/y to 88 TWh/y (excluding boiler losses) but new build adds 12 TWh/y, bringing the total to 100 TWh/y.

2.20 In summary, the overall heat needs of residential and non-residential stock in the UK falls from an estimated 510 TWh/y currently to 460 TWh/y in 2050, including the 52 TWh/y of new demand created by 13 million more people and millions of new buildings. The overall reduction is about 30% bearing in mind new additions, or more if the current and future indirect heating benefit of lighting and appliances are included. Greater reductions are possible, but may not be the most cost-effective, practical or preferred pathway. This is discussed in the report's conclusions. These heat need estimates are summarised by area (urban, sub-urban, rural, new) in Table 1 below.

Table 1: 2050 Building Stock Heating Need (residential and non-residential sector buildings)

2050 UK Heating Need (residential + non residential)	TWh/y
7 m gas-connected urban homes falls to 11 MWh/y and other buildings	77 + 21
4.2 m gas-connected flats falls to 8 MWh/y and other buildings	34 + 10
9.3 m gas-connected sub-urban homes falls to 13.5 MWh/y and other buildings	124 + 34
6.3 m rural homes not gas-connected falls to 13.5 MWh/y and other buildings	85 + 23
6.2+ m new-build with heat need of 6.5 MWh/y and other new buildings	40 + 12
Total Final Energy Demand 460 TWh/y in 2050	360 + 100
Primary Energy Supply	560 - 590

Future indirect electric heating benefit

2.21 Indirect electric heating is assumed to be about 72% of the 112 TWh/y of electricity supplied to residential and non-residential stock for appliances and lighting in 2009. The overall figure for appliances and lighting in 2009 is estimated at 174 TWh/y, so the heating benefit was about 45% of this. However, due to the forecast warmer climate in 2030 and 2050 it is assumed here that the heating benefit falls to 40% by 2030 and 30% by 2050.

2.22 The estimated appliance and lighting demand in 2030 is 140 TWh/y so at 40% the benefit would be about 55 TWh/y, and in 2050 the demand is 120 TWh/y so a 30% benefit would be about 35 TWh/y. The indirect heating disbenefit in summer is assumed to be much smaller in comparison and cancelled out by the estimates above which are conservative. Significant cooling demand has also be separately assessed and included in final demand.

2030 heat demand and heating system losses

2.23 By 2030 all boilers are assumed to be condensing boilers or micro-CHP with efficiencies averaging 90%. Direct electric heat and increasing use of heat pumps is assumed to provide 33% (144 TWh/y) of the remaining heat demand, up from 22% currently. So, boilers would be providing the remaining 293 TWh/y and incur losses of 32 TWh/y in the process, down from losses of around 105 TWh/y currently. Consequently, energy demand for heating in 2030 amounts to 469 TWh/y comprising 437 TWh/y of supplied heat with 32 TWh/y of losses. It is assumed the gas network would be supplying some bio-methane and possibly some areas and branches could have switched to hydrogen supply.

2050 Heat demand and heating system losses

2.24 By 2050 efficiency improvements to existing building stock and demolition of old inefficient stock result in a heat need of 460 TWh/y when new heat need is included. This is 50 TWh/y below the current heat need of about 510 TWh/y. Indirect electric heating benefit meets 35 TWh/y of the need and the remaining 425 TWh/y has to be supplied. How this need is supplied depends on what combination of technologies and fuels are available at that time (eg bio-methane in mCHP boilers, number and types of heat pumps, hydrogen for CHP schemes, direct electric heating).

Cooling demand

2.25 The energy demand for cooling in residential and non-residential stock is assumed to rise from 30 TWh/y currently to 40 TWh/y by 2030 and 50 TWh/y by 2050.

Electricity demands for appliances

2.26 Electricity and appliances are estimated to be 95 TWh/y domestic and 82 TWh/y non-domestic in 2009 (totaling 177 TWh/y). These electricity demands are assumed to fall to 120 TWh/y by 2050 (a fall of 30%) in the Reference Scenarios.

Industry sector

2.27 Current energy use by the main industrial groups was 311 TWh/y in 2010. Of this, 70 TWh/y was process heat and electricity generated by on-site CHP schemes (referred to as 'auto-generation'). CHP schemes provided industry with 28 TWh/y of electricity and 42 TWh/y of heat in 2009.

2.28 A detailed analysis of the industry sector in order to provide 2030 and 2050 forecast of energy demand is beyond the scope of this report. However, much as in other sectors, fuel cells and their high temperature heat provision offer potentially large efficiency gains. Solid oxide cells in particular could produce high temperature steam required in many chemical processes.

2.29 Taking into account the projected population increase, this report assumes energy demand by industry falls by 30% overall by 2050 to 260 TWh/y. Non energy uses are assumed to fall by 10% from 106 TWh/y currently to 90 TWh/y by 2050.

2.37 Future industry energy demand is assumed to be mostly electric, with some bio-feedstock and bio-carbon dioxide inputs, and possibly some coal. Hydrogen is made on demand in electrolysers and heat may be distributed via heat networks to the locality. Peaking electricity on the Grid could be stored in molten salts stores at high temperature for subsequent use in process heat provision or electricity generation, and is used for additional grid management as required. High temperature electrolysers and solid oxide fuel cells delivering process heat on demand are assumed to achieve high efficiency.

3 Transport sector

3.1 The transport sector will require liquid hydrocarbon fuels for some time to come and their carbon dioxide emissions are beyond capture. The aircraft being built in the next decade will have an operational life of up to forty years. Vehicle fleets turn over more quickly and the introduction of electric vehicles now will enable the industry to scale up by 2030 to reap the benefits of re-charging using low-carbon electricity from the grid. HGV's can make quick fuel and emission savings by converting to compressed methane now and could move to hydrogen fuel and fuel cell motors in the coming decades. Much will depend on the global availability of sustainable biomass resources.

Aviation fuel demand

3.2 The priority for global sustainable bio-energy resources in future decades will probably be the need to produce liquid bio-fuels for aviation and possibly shipping.

3.3 As regards aviation there is no quick or effective substitute to the refined high energy-density liquid hydrocarbon fuels used in established aircraft technology. However, if sufficient bio-energy sources were to become available then aviation could become carbon-neutral as bio-aviation fuel is substituted for fossil-derived aviation fuels.

3.4 In 2009, 134 TWh/y of aviation turbine fuel (kerosene) was consumed in the UK, most of it supplied to UK airports and some military bases and test locations. Of the fuel supplied 6% was for domestic consumption. UK military aviation fuel demand is not specified and so is assumed to be 6 TWh/y for accounting purposes. Consequently, about 120 TWh/y would be for international civilian aviation from UK airports and so is counted towards the UK's share of international aviation estimates. Large quantities of aviation fuel would still be required in future decades for supplying demand at UK airports, some of which are 'hubs' for international flights. So there would need to be sufficient bio-refineries in the UK or large scale bio-kerosene imports in any event.

3.6 Due to the longevity of aircraft and slow turnover to more efficient models, together with climate policies and increasing costs, aviation fuel demand is assumed to increase in this report by 4% by 2030. Internal flights and military aviation demand are also assumed to increase marginally by 2030. So, this rise accounts for the projected increase in population outweighing the gradual improvement in passenger-miles fuel efficiency (eg engines, passenger loadings and larger more efficient aircraft) plus the demands of internal and military aviation (between 5-10 TWh/y). Continuing aircraft fuel efficiency improvements between 2030 and 2050 reduce overall fuel demand by 5% despite the increase in population during this period.

3.7 Hydrogen powered aircraft may be developed and become commercially available at some point in the future. This will depend on perceived need, successful designs and the establishment of a successful safety record. However, if large scale bio-energy sources become available it is likely that bio-kerosene will be used for carbon-neutral aviation in the foreseeable future. This would depend on future climate protection imperatives, aviation growth globally and the availability of sustainable bio-energy to meet future demand.

3.8 Aviation fuel use at UK airports, including internal and military use and not solely by UK residents, amounted to 138 TWh/y in 2009.

3.9 To assess what level of bio-energy resources would be required by the aviation sector in 2050 it is proposed here that a similar level of annual fuel demand is maintained in the period to 2050 (i.e. 150 TWh/y by 2050).

3.10 The Reference Scenarios assume 150 TWh/y of bio-kerosene is required in 2050 and a further 14 TWh/y is needed for UK aviation . The conversion efficiency in turning biomass feedstocks via the Fischer-Tropsch process to bio-kerosene is about 75% if additional energy is used to power auxiliary processes at the refineries. So to produce 164 TWh/y of bio-kerosene would require about 220 TWh/y with 56 TWh/y bio conversion losses. A contingency of an additional 13 TWh/y of bio-fuel is included for aviation and shipping to cover for un-forecast demand.

Shipping

3.11 The UK shipping industry currently consumes about 29 TWh/y equivalent of heavy diesel oil or marine bunker fuels. This report assumes that an increase to 50 TWh/y by 2030 occurs by 2030 and that demand falls again to 45 TWh/y by 2050 as a result of motive and logistic efficiency improvements (more efficient engines, much larger ships, etc) and reduced imports and exports of heavy and bulky consumer goods due to lifestyle changes. In terms of motive power there are fuel cell technologies which could offer the prospect of hydrogen electric propulsion and consequently carbon neutral and carbon-negative operation.

3.14 The conversion efficiency in turning biomass feedstocks via the Fischer-Tropsch process to bio-diesel is about 75%. Producing 57 TWh/y of bio-diesel in 2050 (for shipping and rail) would require 76 TWh/y of bio-feedstocks.

Bio-fuel contingency

3.15 A contingency of an additional 5% (13 TWh/y) of estimated Reference Scenario liquid bio-fuel demand is included for aviation, shipping and rural rail to cover for un-forecasted increased demand or an underestimation of conversion losses, particularly in the hydrogenation process to increase yield. If this contingency were not required in the aviation, shipping or (diesel) rail sectors then there would be 13 TWh/y of bio-fuel extra available for CHP schemes, industry, or the gas network for carbon-negative energy generation, or reduced demand.

Road Freight

3.16 Heavy road freight in the UK currently consumes about 83 TWh per year. Apart from aviation and shipping, heavy goods vehicle (HGV) haulage is the other transport sub-sector that could also require large quantities of liquid or gaseous bio-fuels, from potentially limited supplies, to achieve low-carbon operation.

3.17 Heavy road freight haulage and some public transport vehicles over a few tonnes (buses, long-distance coaches and non-electrified train services), could not practically be powered over useful distances by currently available battery technologies. However, hydrogen-powered fuel cell trucks and buses are already being demonstrated and, if successful, offer the prospect of carbon neutral and carbon-negative road freight. More fuel-efficient diesel engines and other design features, together with compressed methane gas and hydrogen could significantly reduce fuel consumption, carbon dioxide emissions and local air pollution.

3.18 Advances in automotive fuel cell technologies, on-board hydrogen storage, and on-site hydrogen fuel production technologies are being made. Fuel depot and forecourt electrolysers and 'cold plasma' units, both of which use electricity to convert water or bio-methane respectively to hydrogen gas offer a flexible transition to low-carbon transport refueling. Plasma hydrogen refueling facilities would need a reliable methane supply so would be mostly located in areas served by the gas network. Electrolyser hydrogen refueling facilities could be located in any area served by sufficient electrical supplies which include most rural areas.

3.19 Conversion losses in electrolysers at fuel depots and forecourt units could be minimised by supplying electrolyser heat to local CHP schemes. Every 10 TWh/y of on-site electrolytic hydrogen production would produce 2.5 TWh/y of heat and valuable oxygen. Much if not all of the heat could be distributed to local industry and other buildings. Oxygen could be used at gasifier, refineries or other industrial sites.

3.20 Plasma units convert methane or bio-methane to hydrogen using electricity. For every 10 TWh/y of hydrogen produced about 1.2 TWh/y of electricity would be used to 'crack' about 10 TWh/y methane to hydrogen and carbon black. The carbon black powder would be a feedstock for carbon-fibre manufactured products including vehicle and aircraft structural components (ie a non-energy use) so that energy is not lost. Heat from the units could also be supplied to local CHP schemes.

3.21 Such technologies could enable a cost-effective and speedy roll-out of infrastructure supplying hydrogen-powered freight vehicles with either fossil or bio-hydrogen. Using electricity and natural gas, to produce hydrogen would enable a transition towards carbon-neutral road haulage. A further transition to carbon-negative road haulage could be made as bio-hydrogen or other renewable hydrogen sources became available in quantity. For what road haulage remained it would be relatively straightforward to switch to bio-diesel / bio-methane fuels, which could also be produced in carbon-negative CCS refineries.

3.22 This report proposes that energy consumption by rigid and articulated HGV's falls from 3.0-3.5 TWh per billion km in 2010 to 1.8-2.0 TWh by 2050.

3.23 HGV vehicle distance in 2010 was 26.4 billion km. At an average energy consumption of 3.2 TWh per billion km HGV energy consumption was 84 TWh/y in 2010.

3.24 UK freight in 2008 was transported by road (67%), water (20%), by rail (9%) and by pipelines (4%). Energy demand by rail, waterways and coastal shipping is assumed to be one third of that for road and one fifth for pipelines. On this basis 2010 energy demand is estimated at approximately 4 TWh/y for rail freight, 9 TWh/y for waterway freight and 1 TWh/y for pipelines.

3.25 Road freight as a share of overall tonne miles in 2050 falls to 62% as modal shift to electrified rail and waterways takes place. The share of rail and waterways rises to 34% of tonne miles and pipelines remain at 4%. Efficiency and logistic improvements and lifestyle changes are assumed in this briefing to reduce freight by 10% by 2050.

3.26 Other factors are also at play. Increasing population, improved logistics to reduce 'empty running', and increased motive efficiency combine with modal shift to reduce UK road freight energy demand from 84 TWh/y in 2010 to 47 TWh/y in 2050. In the Reference Scenarios it assumed that sufficient bio-feedstocks are not available to produce much bio-diesel and that a complete switch to hydrogen fuel produced by electrolysers occurs.

Coastal shipping and railfreight

3.27 The share of UK freight delivered by rail, waterway and coastal shipping rises from 29% in 2008 to 34% by 2050 as modal shift from road occurs (pipelines remain at 4%).

3.28 Rail freight increases by about 50% and overall freight by 20%. Electric freight train and marine fuel demand rise proportionately less due to improved motive efficiency. In the Reference Scenarios it is assumed that sufficient bio-feedstocks are available to produce bio-diesel for coastal shipping.

3.29 This briefing assumes that the energy consumed per tonne km moved by rail is three times less than by road.

3.30 Energy demand from rail freight was 3.6 TWh/y and water 8.6 TWh/y in 2008 with 1 TWh/y required for pipelines.

3.31 By 2050 rail freight energy demand is 3.5 TWh/y and freight by water remains at about 7 TWh/y. In summary, energy demand from rail, waterways, coastal shipping and pipelines falls slightly from 13 TWh/y in 2008 to 12 TWh/y in 2050.

Public Transport

3.32 Buses and coaches currently consume another 18 TWh/y equivalent as diesel fuel. As with HGV's there is the potential for hydrogen-powered fuel cell buses, coaches and even branch line train services. In terms of future demand for public transport, combining increased population with modal shift from cars increases bus and coach vehicle miles by 33% by 2050.

3.33 Fuel-efficiency gains due to engine technologies, particularly hybrid and fuel cells, could reduce energy demand significantly from 3.9 TWh per billion bus km in 2010. The fuel efficiency figures used in this report for buses and coaches are 1.75 TWh/y per billion bus km by 2050. Bus and coach traffic is assumed in the Reference Scenarios to rise to 6.85 billion km by 2050 (a 33 % increase on 2010).

3.34 Consequently, energy demand by buses and coaches falls from 20 TWh/y in 2010 to 12 TWh/y by 2050. Hydrogen for bus and coach refueling, like HGV refueling, is produced at depot-based electrolysers or via the gas network from electrolysers or gasifiers on larger industrial sites or refineries.

Car, light van and motor cycles energy consumption

3.35 In 2009 the energy demand from cars, vans and motor-cycles was 363 TWh/y. Biofuels comprised 2.9% of all road fuels.

3.36 It is assumed in this briefing that hybrid and electric vehicles increase their share of the UK car and that traffic reduction policies and lifestyle changes moderate additional traffic generated by the increased population to a 4% increase by 2050.

3.37 By 2050, energy consumption falls to 0.125 TWh per billion vehicle km by which time essentially all vehicles are electric/fuel cell and hybrid. Consequently, for a marginal rise in traffic overall, this report estimates energy demand by light vehicles falls to 140 TWh/y by 2030 and 60 TWh/y by 2050.

3.38 All the 2030 and 2050 transport energy demand forecasts estimated or assumed for the reasons stated are summarised in Table 2 below. The transport demand in Wales would be about 5% of these UK-wide estimates.

Table 2 UK transport energy demand estimates for 2030 and 2050

UK Transport Energy Forecast TWh/y	2010	2030	2050
Freight - HGVs	84	52	47
Freight - coastal shipping, waterways	7	7	7
Buses & coaches	20	13	12
Cars, vans & motorcycles	356	140	60
Rail (diesel + electric) + pipelines	8 + 9 +1	8 + 12 +1	5 + 15 + 1
domestic civil aviation, military aviation	14	14	14
UK transport demand (national)	499	247	161
International aviation	150	155	150
International shipping	45	50	45
UK Transport Demand (inc international share)	694	452	356

4 Potential renewable energy sources for Wales

4.1 In this chapter the potential for renewable energy resources around Wales is assessed. Renewable energy sources which could be imported to Wales are also similarly assessed.

4.2 The main indigenous resources assessed are wind energy (on and offshore), solar technologies, heat pumps, biomass, marine currents (tidal stream), tidal range, wave, hydro and geothermal resources. Imports sources assessed are biomass feedstocks, produced biofuels (bio-methane, bio-oils), Saharan solar CSP and wind electricity and manufactured or synthetic fuels (eg synthetic methane, synthetic aviation fuel).

Solar PV

4.3 The electricity output and hence annual resource of electricity generating solar PV panels depends on the amount of sunlight that shines on the PV modules or solar collector. Wales has relatively good solar resources compared to other parts of the British Isles, particularly south west Wales. The map (right) shows the incident solar radiation in Wales over the course of one year. A solar PV system in south west Wales will generate over 20% more than one in Northern Scotland.

4.4 The prospects for solar thermal panels are less clear. This report looks at infrastructure scenarios in which potentially sufficient hot water is generated in micro-CHP boilers and CHP schemes (primarily in load-following mode) to meet hot water demands. If this is the case then any roof or other suitable space for solar installations would be better used by PV panels. PV panels are also a good fit with summer cooling needs.

4.5 In view of the above resource and cost estimates this report assumes solar PV across the UK could generate up to 140 TWh/y by 2050 and requires most southerly facing roofs and facades. Solar thermal systems would probably be mostly fitted to buildings in rural areas off the gas network where there would be no fuel cell heat available and 20-40 TWh/y may be optimal. Consequently, Wales has good potential to harness about 6-7 TWh/y of PV and 1-2 TWh/y of solar thermal amounting to 7-9 TWh/y of combined solar resource by 2050.

Onshore Wind Resource

4.6 Onshore wind capacity is estimated in this report to increase to about 2 GW of capacity by 2020 and level off at about capacity as offshore wind and other technologies begin to fall in price and availability. The average capacity factor of the turbines, considering the higher output of the larger more modern turbines being installed, and the re-powering of early schemes, is estimated here to be 30% in 2020. Some early multi-megawatt turbines are achieving annual capacity factors well above 30% currently in the uplands of Wales (Moel Malogen has reported factors around the 35% mark for some years, noting that 2010 was a low wind year).

4.7 Consequently, this report estimates that onshore wind deployment in Wales would produce about 5 TWh/y from about 2 GW of capacity by 2020 and the output is maintained through to 2050.

Offshore Wind Resource

4.10 Wales already has two of the earliest offshore wind farms built globally sited a few miles off the north Wales coast in relatively waters: the North Hoyle scheme (60 MW) and the Rhyl Flats scheme (105 MW). A larger 575 MW scheme (Gwynt y Môr) has been consented and is about to start construction. Other areas proposed by the Crown Estate for several gigawatts of developments include further out in the Eastern Irish Sea and in the Bristol Channel.

4.11 The offshore wind resource around the UK is probably up to 400 TWh/y for fixed structures, and including floating designs, up to around 1,270 TWh/y out to 100 miles. Given current technology and probable development, offshore wind is clearly a potentially leading UK energy resource, with significant capacity in waters off the coast of Wales.

4.12 In terms of the marine renewable resources around the British Isles offshore wind far exceeds that of tidal stream and wave. The UK's tidal and wave resource is 70 TWh/y (21 TWh/y tidal stream and 50 TWh/y wave).

4.13 So the cost of electricity (and possibly hydrogen) from offshore wind farms is likely to be a major determinant of the scale of deployment. Currently, costs are high due to the sheer global demand causing bottlenecks in manufacturing and deployment equipment such as jack-up barges. Beyond 2020, costs are forecast to fall to become one of the cheapest large-scale technologies alongside solar PV by 2040. Large, vertical axis floating devices, possibly 10-20 MW scale could open up large sea areas for deployment at very competitive cost.

4.14 In view of the very large scale resource and relatively low cost estimates the 2050 Reference Scenario assumes that offshore wind will be one of the major renewable energy technologies which can power Wales in the future. Considering the estimated future energy demand and the potential of other renewables the Reference Scenario includes a '+' to denote that offshore wind could provide some or much of the balance of demand to achieve a renewably powered Wales by mid-century.

4.15 A resource estimate of 30 TWh/y offshore wind for Wales is included in the 2050 Reference Scenario.

4.16 Visual impact from coasts, depending particularly on the success of floating turbine designs, and set in context with onshore power generation of any kind, could be relatively marginal.

4.17 As the output from this major resource is intermittent including spikes in output for short periods, and little for much of the duration of a severe winter anti-cyclone centered over north western Europe, the management of the output and system integration is considered in this report.

4.18 One management technique would be to convert some of the electrical output to hydrogen. Electrolysers could be used to deliver the peakier output as hydrogen (peak-lopping above about 50-60%). Based on UK offshore generation of 600 TWh/y by 2050, at about 33% peak-lopping hydrogen produced would be about 160 TWh/y plus electrolyser conversion losses of about 35 TWh/y (at 82% conversion efficiency). Conversion to hydrogen for strategic storage and use in the gas network is assessed in this report but not included in the Reference Scenario as hot water from electrolysers are utilised onshore. Hydrogen could be used to produce synthetic methane by synthesis with captured carbon dioxide. This potentially could be done offshore if bio-carbon dioxide was available (either piped or directly captured).

Larger offshore wind energy deployments

4.19 Depending on other major future factors (sustainable biomass availability, future population, heat pump deployment, aviation demand, CCS coal gasification) it may be necessary to extend offshore wind energy deployment to address 2050 demand. Generating 750 TWh/y (assuming 90 % availability of turbines ie 36 % capacity factor) would require 240 GW of capacity. A 240 GW deployment could comprise around 15,000-22,000 turbines, many floating, and a mix of turbine sizes mostly between 10-20 MW. The Welsh share of this resource would be about 37 TWh/y. This is not included in the 2050 Reference Scenario.

4.24 Assuming peak lopping about 36 % of annual output (270 TWh/y) and electrolysis (at 82 % HHV efficiency) such a massive deployment would produce 210 TWh/y of hydrogen with 60 TWh/y losses (see Annex 1). The heat losses are potentially largely recoverable as heat in CHP schemes if electrolysers are shore-side (eg at refinery site, industrial CHP schemes). In the 2050 Reference Scenario about 220 TWh/y of hydrogen would be needed (160 TWh/y via gas network for Grid back-up, plus 59 TWh/y for fuel cell HGVs and buses via gas network or on-site production in CHP electrolyser refueling schemes).

4.25 The major alternative to such a massive offshore wind deployment (and hydrogen production) would be co-fired coal gasification in CCS gasifier schemes. For example, generating 250 TWh/y of carbon-neutral hydrogen (ie one third of the energy of the 240 GW wind deployment) would require the gasification of 390 TWh/y of coal with 40 TWh/y of woody biomass (at a conversion efficiency of 58 % with CCS, excluding any CHP heat recovery). The amount of coal required would be 58.5 million tonnes per year (equivalent to UK coal consumption in 2008 - DUKES 2010 Chart 2.4 page 45) and the sequestration of 20 million tonnes per year of carbon dioxide.

Tidal Stream

4.26 Of the total practical tidal stream resource around the UK of 21 TWh/y there are four sites around Wales with a potential totaling up to about 3 TWh/y. The largest site is just off Carmel Head on the north coast of Anglesey with a potential of 1.5-2 TWh/y. The other sites, each of less than 0.5 TWh/y potential, are Ramsey Sound, off the coast of Barry, and around the tip of Penllŷn.

4.27 The cost of electricity output during commercial deployment would be 16 p/kWh. This report estimates that 2.5 TWh/y of resource is harnessed, all by 2030. Further exploitation of tidal stream and marine currents would be dependent on innovative new low-cost technologies.

Tidal Range

4.28 Tidal energy in the Severn Estuary was the subject of a major study between 2007 and 2009. Numerous schemes were proposed including the large 10 mile Cardiff-Weston barrage, a smaller Shoots barrage, various lagoon designs and several tidal fence, reef or bar type proposals. No schemes emerged unscathed by uncertainty in terms of capital cost estimates, environmental effects and technical feasibility and uncertainties in all these aspects. The study included assessments of a Shoots barrage and land-attached lagoon on the Welsh Grounds adjacent the Gwent Levels. The annual outputs were assessed at 2.7 TWh/y and 2.6 TWh/y respectively.

4.29 This report envisages some exploitation of the resource on the Welsh side of the Severn possibly harnessing 3 TWh/y by 2030 and 4 TWh/y by 2050. This may include a 50% share in an innovative barrage/stream/lagoon scheme in the Shoots area, possibly part justified on providing a fast rail link to replace or augment the Severn Tunnel.

4.30 A lagoon type scheme in the Welsh Grounds area which uses geo-textile tube technology could also feature, as geo-textile foundations may overcome the unstable sea-bed conditions that would preclude other types of wall structure. A small number of other offshore or land-attached lagoons, possibly integrated with tidal stream devices, may also feature, in the Severn Estuary or off the north Wales coast.

4.31 Costs for traditional barrage structures are estimated as £50 to £200+ per MWh of electricity, so a mid-range electricity output cost for a more conventional project would be at the higher end of the cost/technology range, and a more innovative project may be somewhat less.

Biomass resources

4.32 The availability of land for the production of biofuel is a contentious issue. The IEA and UN estimate a significant global resource of biofuel whereas some observers claim that most if not all available land globally will be needed to feed the forecast 9 billion population in 2050.

4.33 An international review in 2008 recommended that the introduction of biofuels should be slowed until numerous factors were achieved in terms of sustainable production.

4.34 However, the potential global availability of sustainable bio-energy sources is considerable. According to the IEA, 40,000 TWh/y of raw (primary) sustainable biomass would be available in 2050. From this resource about 25,000-30,000 TWh/y of produced bio-fuels could be produced. The 100 million hectares of land required (1 million km^2) is an area equivalent to 10% of the Sahara desert or Europe, or 48 times the size of Wales. Fuel produced from this area would amount to 12-18% of 2050 global energy demand.

4.35 The IPCC has estimated that between 27,700 TWh/y and 83,000 TWh/y of primary biomass could be available for bio-energy uses and the upper bound may be 139,000 TWh/y.

4.36 A fair Welsh share of sustainable biomass, should producer countries wish to export their production, would be about 0.04% as a proportion of Welsh to global population (just over 3 million out of 9 billion in 2050). So, according to this IPCC estimate the sustainable biomass available to Wales on a fair-shares basis would be about 11-35 TWh/y in 2050. This would include indigenous and imported sources.

4.37 Various pathway analyses indicate that Wales could generate an annual indigenous production of 3-6.5 TWh/y if sufficiently suitable land exists and is available.

4.38 Wales is one of the least wooded countries in Europe, with about 14% coverage (332,000 hectares). Of this, 38% is owned by the Welsh Government.

4.39 If about 100,000 hectares of this estate were given over to biofuel production, and assuming 4 MWh per tonne, the yield would be 1.6 TWh per year of woody biomass. Planting new woodland across Wales where possible would be commendable for various reasons.

4.40 Other studies have indicated that higher yields (up to 2 TWh/y more) could be available without radical land-use policy changes. So potentially Wales may be able to produce several TWh/y of woody biomass in future decades.

4.41 This report assumes that 4-6.5 TWh/y of sustainable raw biomass feedstocks from indigenous biomass sources is achievable by 2050. Conversion in AD schemes and gasification plants and bio-refineries, at a conversion efficiency of 75% yields 3-5 TWh/y of indigenous bio-fuels.

Biomass Imports

4.42 In terms of global per-capita fair-share access to sustainable biomass resources, Wales could have access 16 TWh/y of raw biomass feedstock, of which 6.5 TWh/y would be indigenous with the remaining 9.5 TWh/y imported. Conventional, and probably advanced biofuels would likely be cost-competitive with oil at $120 per barrel.

4.43 Importing aviation and shipping bio-fuels from bio-refineries which have used as much electricity, hydrogen and or heat from non-bio sources as possible in the refining process would maximise the bio-fuel output from the raw feedstock.

4.44 The ‘bio-conversion’ efficiency of converting primary bio-energy sources via the Fischer-Tropsch synthesis to aviation fuel (bio-kerosene) and bio-diesel is estimated at 64% for dry raw sources and 44% for wet raw sources.

4.45 However, to produce the UK share of global aviation fuel demand (150 TWh/y) and internal aviation demand (14 TWh/y) at a conversion rate of 64% would require about 256 TWh/y of bio-feedstocks. Meeting aviation bio-fuel demand this way would not leave sufficient bio-feedstock to produce 52 TWh/y in 2050 of marine bio-diesel and 5 TWh/y of rail bio-diesel or leave room for any contingencies. Allowing for a contingency of about 5% (13 TWh/y) would raise liquid bio-fuel demand a further 70 TWh/y bringing the total to 234 TWh/y. At a 64% conversion rate it would require 365 TWh/y of bio-feedstocks which is 14% more than the assumed global fair-share estimated in the report.

4.46 To increase bio-fuel production per unit amount of bio-feedstock, external sources of energy could be used to power some or as many yield-increasing processes at the bio-refinery as possible. The first technique would be to avoid any bio-syngas produced in the gasifier being diverted to power the refineries’ auxiliary processes or the CCS plant if fitted. Grid electricity could be used to power the gasifier air separation units (ASU), pumps, the fuel preparation processes, and a CCS plant if fitted. On-site electrolysers, whose main function would be provide hydrogen for the gas network from intermittent renewable electricity sources, could provide additional oxygen, hydrogen and heat.

4.47 Significant heat recovery around the refinery site would probably be possible and would improve site efficiency, supplying hot water to local industry and homes in addition to bio-feedstock drying. Co-electrolysis is a second yield-increasing technique using external energy that could be used. Co-electrolysis converts some of the bio-carbon dioxide in the bio-syngas (which can comprise about one third bio-CO2) to additional fuel.

4.48 Using external energy sources in this way may improve feedstock-to-liquids conversion efficiency to a useful degree. This report assumes a rate of 75% is achieved but some additional energy losses would be incurred, approximating to over 5 TWh per 10 TWh of enhanced conversion above 64% conversion.

4.49 Heat recovery from around the refinery site for use in adjacent industrial processes or via heat grids for district heating, may recoup for example between 25-33% of the bio-conversion losses though again this would need to be demonstrated. For the purposes of this report a 27% heat recovery rate is assumed. Producing 234 TWh/y of liquid bio-fuels in 2050 from 312 TWh/y of bio-feedstock would incur bio-conversion losses of 78 TWh/y. So heat recovery is assumed to achieve 21 TWh/y or 10.5 TWh/y for the half of bio-fuels refined in the UK.

2050 Reference Scenarios

4.50 Based on the estimates and rationale above, this report assumes that the liquid bio-fuel demand in 2050 amounts to 234 TWh/y at UK level. This demand comprises aviation bio-kerosene demand (164 TWh/y), shipping bio-diesel demand (52 TWh/y), bio-diesel for rail (5 TWh/y), and a liquid bio-fuels contingency of 5% (13 TWh/y). The Reference Scenarios assume that 120 TWh/y of liquid bio-fuels are produced in refineries overseas and 114 TWh/y in UK based refineries at 75% bio-conversion efficiency (65% overall refinery efficiency) using 312 TWh/y of bio-feedstock (indigenous and imported), 48 TWh/y of externally sourced energy to power refinery site processes, and an optional 23 TWh/y for CCS plant to achieve 46 million tonnes per year carbon-negative bio-fuel credits.

4.51 Considering the above (including 4-6.5 TWh/y of indigenous feedstock cultivation), this report assumes that 9.5-12 TWh/y of sustainable raw biomass feedstock is available for global fair-share import to Wales or refineries abroad and 7-9 TWh/y after conversion at 75% to liquid bio-fuels (using external energy sources to drive most of the refining processes).

4.52 That is not to say that more than fair-share amounts of bio-feedstock or refined bio-fuels could not be imported. Many countries, particularly desert countries, could have a surplus of solar energy for their own needs, and with which to process bio-fuels, to maximise bio-fuel production, and sequestrate most of the remaining refinery emissions. Importing carbon-neutral or carbon-negative bio-fuels from bio-refineries abroad (possibly powered by renewable sources and potentially CCS-fitted) would be an indirect way of importing additional renewable energy, or purchasing carbon-negative credits. It would avoid energy demand in the UK to cover conversion losses and CCS energy demand at bio-refineries in the UK.

Modes of importing bio-energy

4.53 The possibility of importing very large quantities of raw bio-feedstocks to UK bio-refineries, or importing pre-refined bio-fuels is worth some consideration in terms of infrastructure, trade and security issues. About 120 TWh/y of aviation fuel is currently distributed at UK airports, some of which are globally international ‘hubs’. Similarly, about 30 TWh/y of marine fuel oils are distributed at UK ports to coastal and international shipping. The scale and location of these liquid fuel demands may not change significantly in the next decades.

4.54 To date these liquid fuel demands have been supplied from mainly UK refineries supplied by crude oils typically by tanker from oil-producing countries or pipeline from the North Sea. However, importing up to 240 TWh/y of relatively bulky, mainly woody, bio-feedstocks to UK ports could require considerable shipping movements to, and handling infrastructure at, UK bio-refineries. Very large scale imports may present some planning problems for fossil based refineries to convert to bio-refining.

4.55 Importing pre-refined liquid bio-fuels, which are essentially identical in transport and handling terms to their fossil counterparts, would be much easier in transportation terms, albeit with some danger of major oil spillage. The long-distance transport of oil and other liquid fuels by pipeline or large ocean-going tankers is established technology and routine global activity. The Reference Scenarios assume that 120 TWh/y of liquid bio-fuels are produced in refineries abroad of which 70 TWh/y is distributed to air and sea ports abroad to supply UK based demand and 50 TWh/y is imported by tanker for distribution to UK air and sea ports.

4.56 The transportation of methane by large LNG carriers and by long-distance pipelines is also an established routine activity and a switch to bio-methane would incur little cost. The UK is connected to the European mainland by three gas inter-connectors including the Bacton-Zeebrugge pipeline capable of supplying 280 TWh/y of gas to the UK. This is more than sufficient to meet the 160-220 TWh/y of gas demand required in the Reference Scenarios.

4.57 Gas pipeline capacity to North Africa, where sustainable bio-methane may possibly be produced, is currently more limited. About 500 TWh/y of natural gas was imported to Europe via sub-sea pipelines under the Mediterranean Sea from Morocco, Algeria and Libya in 2008. A future UK share of that pipeline capacity would be 75 TWh/y of bio-methane.

4.58 Consequently, the existing gas pipeline capacity from Saharan countries to southern Europe is sufficient to supply the UK with about one third to one half of 2050 Reference Scenario gas demand. Given possible security and dependency concerns this may be ample. There is also an excess import capacity at LNG terminals in Wales and England to import some or all the Reference Scenario gas demand from North Africa or other geographical regions.

4.59 In summary there are various options for importing bio-energy at global fair-share quantities into the UK if required. Importing bio-feedstocks at very large scale would require restructuring around UK refinery sites and could cause some planning issues as well as job opportunities. There is ample infrastructure to import refined liquid bio-fuels and bio-methane, and this is helpful in terms of energy security and competitive energy trading.

4.60 Such import capability is highly relevant to the consideration of synthetic bio-fuels (see below) which may possibly become commercially attractive in future decades, especially if global bio-feedstocks are highly constrained. Owing to the high energy intensity of their production it is likely that syn-fuels would be imported from regions with high solar energy potential such as North Africa.

Synthetic bio-fuels produced using direct air captured carbon dioxide

4.61 So-called ‘synthetic’ fuel or bio-fuel, including bio-kerosene, bio-diesel and bio-methane could potentially become commercially viable if research and development into direct air capture of carbon dioxide from atmospheric air and co-electrolysis is successful. The availability of commercially viable synthetic bio-fuels at large scale would have major beneficial global implications. However, it is not included as part of the future Reference Scenarios as it is more a possible rather than a probable technology.

4.62 In the complete absence of bio-feedstocks to supply the any aviation and shipping fuel demand then it may be possible to produce 234 TWh/y of synthetic liquid bio-fuels via co-electrolysis and Fischer-Tropsch processes, using 411 TWh/y of electricity and heat. Production losses would be 177 TWh/y if all the syn-fuel was produced from indigenous sources and assuming the provision of bio-carbon dioxide did not incur additional energy.

Synthetic bio-fuels and biomass-based bio-fuels

4.63 In the absence of a biomass-to-liquids (BtL) production route due to a very highly constrained bio-feedstock availability or cheaper synthetic bio-fuels, the synthesis process could require 411 TWh/y or more of electricity from renewable including intermittent sources.

4.64 To provide such high levels of renewable energy would require a considerable jump in the scale of deployment around the British Isles and might only be achieved using offshore wind. For example, additional offshore wind farms covering a sea area of 18,000 km^2 could be deployed. Alternatively, given that significant amounts of electricity and high-temperature heat could be used to increase the efficiency of the co-electrolysis and direct air-capture processes, synthetic liquid bio-fuels may be most cost-effectively produced using concentrated solar power (CSP) schemes in Earth’s deserts.

4.65 For Wales, minimal overseas bio-feedstock availability could result in the unavailability of 12 TWh/y of bio-feedstock (refined to 9 TWh/y of bio-fuel). For example, in a highly constrained scenario just 4 TWh/y of indigenous bio-feedstock resources may be available to Wales. This amount would produce 3 TWh/y of liquid bio-fuel at 75% efficiency (out of a demand for 11.7 TWh/y). However, importing or purchasing 8.7 TWh/y of synthetic liquid bio-fuels produced abroad would meet Welsh demand and the refinery conversion losses would occur in the energy-rich exporting country. So importing synthetic liquid bio-fuels and their use at air and sea ports overseas, if they become commercially viable, could reduce any mis-match between renewable energy supply and demand in the 2050 Reference Scenario by several TWh/y. Indeed, synthetic liquid bio-fuels produced in very renewable energy-rich countries could become a long-term sustainable energy import with which to make up any indigenous shortfall and achieve a 100% renewable energy supply by 2050 or before.

4.66 Consequently synthetic bio-fuels, depending on cost and availability, could either reduce or obviate any significant demand for global bio-feedstocks and could provide liquid bio-fuels and bio-methane by ship or pipeline in the quantities required to achieve Welsh climate and energy supply policies. Supplies would be relatively secure as desert based synfuel refineries may be widely distributed globally including North Africa and Australia.

4.67 Synthetic bio-fuels are not included in the Reference Scenarios as the technologies are not technically proven, cost-effective or commercially available, let alone understood by the public and politicians. Yet they are an important possibility to consider rather than a reasonable prospect on which to form policy.

Heat Pumps

4.68 The potential for heat pumps to extract renewable heat energy from the Welsh environment is potentially significant.

4.69 Heat pumps work like fridges but are designed to extract heat from the air or ground rather than from inside a closed box. For every 1 kWh of electricity supplied to the heat pump the heat output would generally be between 2 and 4 kWh. Such a heat pump installation would have what is called a Coefficient of Performance (CoP) of 2 to 4. The average efficiency of the unit over a typical year, the average annual CoP, is probably the most useful guide to performance.

4.70 Ground source heat pumps work better than air-source heat pumps in very cold temperatures as heat is retained in the ground whereas there is little heat to extract from air in sub-zero temperatures. This report assumes heat pumps have an average annual system COP of 3.

4.71 The widespread deployment of ground-source heat pumps, which require large undeveloped space (such as gardens) or at least sufficient space for deep boreholes to be drilled, may be a limiting factor in urban areas and many suburban areas.

4.72 The future overall space heating need of buildings in Wales, following better insulation, would be about 16 TWh/y plus a water heating demand of 5 TWh/y. A full heat pump deployment might usefully extract up to two thirds of these demands (i.e. 10-14 TWh/y) from local air, ground or water. This would reduce substantially the demand for gas and direct electric heating.

4.73 Heat pumps need a reliable source of electricity and most of the renewable electricity generating capacity identified around Wales would provide intermittent supplies. So, the potential deployment of heat pumps is partially dependent on electricity provision by other technologies including domestic fuel cell boilers.

4.74 In view of the 2050 infrastructure assessments in the following chapters this report assumes that that the likely level of renewable energy that heat pump technologies could provide in Wales would be around 7.5 TWh/y, though it could potentially be more, possibly as much as 12.5 TWh/y if air-source heat pumps are a success or if radical or novel ground-source installation methods are developed for urban areas.

Other renewable resources potentials around Wales

4.75 There is some potential for small and larger scale hydro, wave, solar thermal, geothermal and possibly other renewable technologies across or around Wales to extract useful energy from the environment. However, this report assumes that such technologies have limited potential or are forecast to be more costly, or do not contribute significantly to additional renewable energy provision or system optimisation.

4.76 This report assumes the wave energy resource harnessed by 2050 would be no greater than 1 TWh and that other technologies collectively contribute 1.5-3.5 TWh/y by 2050. In the Reference Scenarios solar PV features strongly at the expense of solar thermal systems. This is because hot water demand in summer would be available in ample quantity from fuel cells (mCHP boilers and CHP schemes) during routine grid balancing operations. So, roof area and other southerly-facing facades available across the building stock would be better used for electricity generation rather than additional hot water generation. If extensive deployments of ground source heat pumps with inter-seasonal heat storage loops occurred then solar thermal installations would potentially feature more prominently.

Saharan solar and wind resources

4.77 For several years the idea of constructing a European electricity Supergrid, potentially linked to vast resources of solar and onshore wind energy resources in Saharan Africa, has been gathering momentum. A plan called DESERTEC is now in its early stages of planning and development. In view of the DESERTEC plans this report assumes that up to about 100 TWh/y of electricity by 2050 may be exported to the UK of which a Welsh share would be about 5 TWh/y.

New nuclear power programmes

4.78 For comparative purposes nuclear power is denoted as a Welsh per capita share of the existing, possible and speculative future nuclear programmes at UK level (120 TWh/y by 2030, 240 TWh/y by 2050). Wylfa B would be sited in Anglesey and could comprise up to three reactors generating 25 TWh/y but it would be part of a UK wide programme.

4.79 A UK-share is used because if the station tripped out, suffered a major incident or had to be closed due to an intractable fault design or safety issue, the implication is that Wales would be instantly plunged into a major energy crisis (25 TWh/y lost from 75 TWh/y), which would probably not be the case. There would be various back-ups (for example millions of mCHP boilers and CHP schemes fed by a reliable gas supply) in this report's Reference Scenarios at least.

4.80 A sizeable energy crisis could result if there was a major UK nuclear deployment (eg 30 GW by 2050) and if more than one nuclear power station were affected by a common design or other fault. This has happened in the USA in the 1980s when the David Besse reactor and others of the same design had to quickly switch off on safety grounds following the chance discovery of an imminent reactor breach. The Generation III reactors proposed for the UK are of just two designs so faults at one reactor which could have implications for about half the programme.

Table 3 Potential 2050 Renewable Energy Resources for Wales

Resource potential	2009	2030 TWh/y	2050 TWh/y
offshore wind (UK share)	0.18	12	30+
onshore wind	1.0	4.5 - 5.5	4.5 - 5.5
solar (mainly PV, thermal)	-	2 - 3	6 - 8
bio-fuels * (raw resource)	0.17	1.5 - 2.5	3 - 5 (4 - 6.5)
tidal stream	-	1 - 2.5	1 - 3.5
tidal range	-	1 - 3	1 - 4
heat pumps	-	1 - 6	3 - 7.5+
wave	-	0.5	0.5 - 2
other indigenous (hydro, geo, etc)	0.2	1 - 2.5	1 - 2.5
Total indigenous renewables	1.5	24.5 - 37.5	50 - 68
Biomass (fair-share) allocation (75%*)	2 ?	4.5 - 3.5	9 - 7 (12 - 9.5)
Saharan solar & wind imports	-	0 - 0.5	0 - 5
Total renewables including imports		29 - 41.5	59 - 80
gas /coal / CCS + oil (UK share)	balance	36.5 - 49	13 - 0 (with CCS)
Welsh energy demand (RES target)	93.5	78 (target ?)	72 (target 72)
nuclear (UK share) IF built	3.2 until 2012	6 Wylfa B	12 Wylfa B + other
Synthetic bio-fuels (direct air-capture)	-	7+	15+

5 Energy systems

5.1 The next two chapters consider how to use the renewable energy resources available to meet the energy demands required. As can be seen in Chapter 4, most of the potential renewable energy resources would provide intermittent electricity. Bio-energy, the main storable renewable resource, is potentially highly constrained at indigenous and global level and the aviation sector would have first call on the bio-energy which is available.

5.2 To construct a cost-effective, demand-responsive energy system which is also reliable, robust and secure requires consideration the means by which renewable energy sources available could be used by existing and emerging energy generating technologies and distribution infrastructure. Another factor is carbon dioxide emissions as the next few decades are critical. So energy systems which have carbon-negative potential, rather than just being carbon-neutral or low-carbon are also considered as they add another dimension to the puzzle.

Severe winter cold periods

5.3 One of the principal design requirements of the energy generating system is to reliably deliver the electricity and heat demand during a severe and prolonged cold snap caused by a windless winter anticyclone. The sleeping energy giant which comes to the rescue at such vulnerable times does not so much comprise large lumbering power stations and the national grid but millions of small gas boilers in buildings fed by the gas networks. Gas infrastructure, largely hidden in buildings and below ground, provides over three times more energy than electricity infrastructure when it is really needed. Reports of its demise due to a move to electric heating and electric transport are premature.

5.4 Cold snaps usually occur due to windless anti-cyclones moving slowly over the British Isles and north western Europe in winter. These conditions are not uncommon and can last several days to a week or more. At such times there would be little if any output from wind farms, on or offshore, and the short winter days would mean little electricity let alone heat from solar PV and thermal panels. Air source heat pumps would be struggling to extract any heat from the sub-zero air.

5.5 There have been two severe cold snaps in the last two years. In the most recent event daily demand reached over 6 TWh per day (1.2 TWh per day of electricity and 5 TWh per day of gas). Other heating fuels would also have been used in many properties (e.g. coal and wood), so the heat demand would have been around 5.5 TWh per day.

5.6 In future decades the additional energy demand caused by population growth is likely to limit heating demand reduction by insulation and efficiency improvements to the building stock to 80-90% of current levels. The transport sector would also be consuming increasing amounts of electricity and hydrogen (about 0.65 TWh per day by 2050 excluding aviation) as petrol and diesel prices rise due to global oil depletion. So the daily energy demand in a severe cold snap may still reach about 6 to 7 TWh per day in future of which the heating demand could be about 5 TWh per day.

5.7 The total reliable energy-generating capacity from power stations and CHP schemes to domestic boilers and heat pumps required to deliver 6 to 7 TWh per day would be 250 to 290 GW (290 GW x 24 hours = 6,960 GWh = 6.96 TWh per day).

5.8 Anything like 250-290 GW of reliable energy generating power, albeit mainly heat, suggests that the current system of gas supplying boilers in a large proportion in Welsh buildings is a system that would be difficult to beat. An extensive deployment of ground-source heat pumps providing several TWh per day, if practicable, could reduce heat demand by other means significantly. However, the heat pumps would still draw 1.5 TWh per day of electricity, requiring 62 GW of electrical generating capacity. There would be in addition 1.5 TWh/y or more of electricity demand for other electrical demands, requiring another 62 GW or more of power generation. Fortunately, a relatively new technology which could provide the reliable electricity and heat required is reaching the market, namely electricity generating and heat generating gas boilers, referred to as micro-CHP boilers.

Electricity-generating micro-CHP boilers and fuel cell CHP schemes

5.9 Micro-CHP boilers in homes and offices and larger CHP schemes (at community or district scale) could provide electricity and heat from a gas supply at high fuel efficiency (probably 90% or more). At times of low wind and low solar conditions over the British Isles when less grid electricity would be available the micro-CHP boilers and CHP schemes could start up and supply the required electricity and heat demand.

5.10 Some of the latest micro-CHP boilers and CHP schemes are now being fitted with fuel cells which have very good electrical performance. Systems are likely to be at least 45% electrically efficient and 90% overall efficient. Fuel cells require hydrogen which can either be supplied directly or converted on-site within the device from a natural gas supply. If methane is used then carbon dioxide emissions are released and bio-methane would be required to achieve low-carbon performance.

5.11 Micro-CHP has been said to have the greatest mass market potential of any emerging low carbon domestic micro-generation solution. Studies have shown that micro-CHP could displace as much as 90% of existing boiler sales. By 2020 the technical potential is sales of 900,000 units per annum with as many as 4 million actually installed in UK homes. There are about 21 million gas boilers in homes and each year about 1.5 million boilers are replaced. So, by 2030 all of Wales' boilers could be replaced with micro-CHP boilers.

Heat pumps and fuel cell micro-CHP boilers and CHP systems

5.12 The combination of heat pumps and fuel cell boilers and CHP schemes would appear to be highly complementary in creating a robust, fuel efficient, demand-responsive energy system which could back-up intermittent renewable electricity from the grid.

5.13 In the absence of heat pumps, or CHP schemes or significant direct electric heating, the gas demand for heating urban and sub-urban buildings (including new-build) connected to the gas network in the Wales could rise to 15 TWh/y or more in 2050. Including boiler losses the actual gas demand could rise to 17 TWh/y. Yet, particularly when scaled at the UK level, such quantities of fossil or bio-methane may not be available. Heating just by direct electric heating would require 350 TWh/y of electricity being supplied on demand to the gas-connected areas as well as 110 TWh/y of electricity for heating rural areas. This would require many power stations being built at high cost.

5.14 If the UK's electricity grid is also supplied by a significant capacity of intermittent renewable technologies, particularly wind and solar power, then electricity from the grid may not be available at the times of greatest heating demand, particularly in winter. Back-up electricity capacity needs to be available when output from the intermittent sources is low.

5.15 If there were a full roll-out of heat pumps and CHP schemes then back-up electricity would be available and much of the heat demand would then reliably be supplied by the heat pumps. This in turn reduces the need for additional gas and electric heating capacity.

5.16 The system would operate in the following manner. Grid electricity from intermittent sources, when available, would power the heat pumps. When electricity from intermittent sources is not available then millions of micro-CHP boiler and local CHP schemes start up and their electricity continues to power the heat pumps. The hot water produced when the fuel cells are generating electricity augments the heat supply to the building.

Infrastructure Scenarios

5.17 As grid electricity is progressively 'de-carbonised' towards 2030 then it will be increasingly a case of 1 kWh of low-carbon or green electricity replacing 3 kWh of low-carbon or green heat. A roll-out of heat pumps starting now will take some time to scale-up and would coincide with the progressive de-carbonisation of the UK electricity grid.

5.18 This report forecast s1.2 million installations by 2020 mainly in off-gas network areas if an annual installation rate of 200,000 systems a year is achieved by 2016. If heat pump systems become more cost-effective and desirable then installation rates could rise substantially beyond 2020. For example, a rate of 1.1 million per year would potentially achieve a full nationwide 'saturated' deployment to most buildings by 2050.

5.19 However, deploying heat pumps – particularly in urban areas – could prove too disruptive, not cost-effective or consumer-friendly. Consequently, three 2050 Infrastructure Scenarios are assessed in detail below: a partial roll-out of heat pumps across the UK mainly in rural and sub-urban areas; a full UK/Wales deployment; and a virtual zero deployment of heat pumps.

5.20 These infrastructure scenarios assume that grid electricity is used for a period amounting to half the year in total, essentially when offshore wind farms and other intermittent renewables are operating at sufficiently high output. When output from intermittent renewables is low, electricity generated in micro-CHP boilers and local CHP schemes provide reliable power.

5.21 Fuel cell systems would likely produce nearly equal amounts of energy in the form of hot water and electricity from the gas fuel. The hot water from the cell would also be used in the heating system or stored in domestic or community scale accumulators (large insulated tanks). In summer when the mCHP boiler or CHP scheme is being mainly used for electricity generation, the hot water co-produced could be stored or pumped through a ground-source heat pump 're-charge' loop to store the heat underground for winter.

5.22 The scenarios show the effect heat pump deployment has on the demand for gas and electricity.

5.23 The scenarios are based on building stock and area heat needs estimated in Chapter 2 including an indirect heating benefit estimate of 36 TWh/y in 2050. Excluding any indirect heating benefit the gas, electricity and renewable energy extracted by the heat pumps would be about 12% higher.

Infrastructure scenario 1

5.24 Infrastructure scenario 1 assesses a mid-level deployment of heat pumps with rural and suburban areas deploying most systems, be they air-source or ground-source, with mainly air-source in urban areas. It is assumed in this scenario that ground source heat pumps do not become widespread in urban areas (because of, for example, lack of outdoor or indoor space, or cost) and that air-source systems are only partially deployed (for example, because of fan or compressor noise as systems become older or less well maintained, or cost). New-build might not connect to the gas network due to connection costs and lower heat demands.

5.25 The heat need in the buildings served by heat pumps, including heat generated in the fuel cell mCHP boilers and CHP schemes, amounts to 58% (244 TWh/y) of the 2050 building stock's heat need of 425 TWh/y (including the indirect electric heat benefit of 35 TWh/y).

5.26 To simplify the calculations heat pumps serving suburban and rural heat needs (244 TWh/y) only are assessed but any combination of buildings comprising a heat need of 244 TWh/y would be covered in this scenario.

Table 4 Infrastructure Scenario 1

2050 Infrastructure Scenario 1 : mid-level	**Heating system CoP 3.0**	**Time : 50 % Grid / 50 % CHP**
Heat need TWh/y		**Grid + (HP) + (mCHP e + th) + loss**
Urban 142 (132)	mCHP, CHP, few HPs	66 + 0 + (33 + 33) + 7
Suburban 158 (144)	mCHP, CHP, HPs	24 + (48 + 36)+ (18 + 18) + 4
Rural 108 (100)	HPs, little CHP	33 + 67
New 52 (48)	mostly mCHP	24 + 0 + (12 + 12) + 2
Total 460 (424)		147 + 151 + 63 + 63 plus 13 losses
Heat pumps 151 TWh/y	Grid 147 TWh/y	Gas demand 139 TWh/y

5.27 At UK level the heat pumps would harness about 150 TWh/y in 2050 in a mid-level deployment. For Wales, such a mid-level deployment could see heat pumps harnessing about 7.5 TWh/y by 2050. Suburban and urban areas could potentially harness around 4.2 TWh/y and rural areas could potentially harness 3.3 TWh/y of low-grade renewable heat from the local environment.

5.28 The grid and gas network distribution losses in this scenario are additional and would be 12.25 TWh/y along the grid and 2.78 TWh/y gas network, totaling 15 TWh/y.

5.29 If the efficiency of heat pumps rose to CoP 3.5 there would be an increase of 12 TWh/y in heat capture, gas demand would fall by 5 TWh/y and grid electricity demand would fall by 8 TWh/y.

Infrastructure scenario 2

5.30 Infrastructure scenario 2 assesses an extensive nation-wide deployment of heat pumps with most rural and suburban and urban buildings deploying air-source or ground-source heat pump systems. It is assumed in this scenario that heat pumps become widespread in all areas due to relatively low cost, reasonably un-disruptive installation and quiet, reliable operation.

Table 5 Infrastructure Scenario 2

2050 Infrastructure Scenario 2 : high level	Heating system CoP 3.0	Time : 50 % Grid / 50 % CHP
Heat need TWh/y		**Grid + HP + (mCHP e +th) + loss**
Urban 142 (132)	mCHP, CHP, HPs	22 + (44 + 33) + (16.5 + 16.5)+ 4
Suburban 158 (144)	mCHP, CHP, HPs	24 + (48 + 36) + (18 + 18) + 4
Rural 108 (100)	HPs, no CHP	33 + 67
New 52 (48)	mCHP, CHP, HPs	8 + (16 + 12) + (6 + 6)+ 1
Total 460 (424)		87 + 256 + 40.5 + 40.5 plus 9 losses
Heat pumps 256 TWh/y	Grid 87 TWh/y	Gas demand 90 TWh/y

5.31 In this scenario a nation-wide deployment across Wales could potentially harness an impressive 13 TWh/y of low-grade renewable heat from the local environment by 2050 (nearly 2 GW of nuclear capacity).

Infrastructure scenario 3

5.32 Infrastructure scenario 3 assesses a low level deployment of heat pumps with most areas and buildings not deploying systems.

5.33 This scenario assumes that grid electricity is used for about half the year in total, essentially when offshore wind farms and other intermittent renewables are operating at high output. When output from intermittent renewables is low then the heat need is provided by electricity and heat generated in micro-CHP boilers and local CHP schemes. Fuel cell systems would likely produce equal amounts of energy and hot water which could be used in the heating system immediately, or stored in domestic or community scale accumulators if the fuel cell was operating to primarily to provide electricity (eg on a cloudy summer evening with low winds).

Table 6 Infrastructure Scenario 3

2050 Infrastructure Scenario 3 : low level	Heating system CoP 3.0	Time : 50 % Grid / 50 % mCHP
Heat need TWh/y		**Grid + HP + (mCHP e +th) + loss**
Urban 142 (132)	mCHP, CHP	66 + (33 + 33) + 7.5

2050 Infrastructure Scenario 3 : low level	Heating system CoP 3.0	Time : 50 % Grid / 50 % mCHP
Heat need TWh/y		**Grid + HP + (mCHP e +th) + loss**
Suburban 158 (144)	mCHP / CHP	72 + (36 + 36) + 8
Rural 108 (100)	electric / bio-fuel	80+ (10 + 10) + 2.2
New 52 (48)	mostly mCHP	28 + (10 + 10)+ 2.2
Total 460 (424)		246 + (89 +89) plus 20 losses
mCHP el 83 TWh/y	Grid 246 TWh/y	Gas demand 198 TWh/y

5.34 At nearly 200 TWh/y the gas demand in this scenario is significantly higher than in scenarios 1 (139 TWh/y) and scenario 2 (90 TWh/y). The electricity demand in this scenario (246 TWh/y) is also significantly higher than in scenarios 1 (147 TWh/y) and scenario 2 (87 TWh/y).

5.35 Were there to be relatively little consumer take-up of heat pumps then the UK heat demand (424-460 TWh/y in 2050) would be more reliant on direct electric heating, bio-methane or hydrogen via the gas network and biomass-fired or CCS-fossil fired district and city-wide CHP heating schemes.

5.36 In terms of assessing the implications of higher bio-methane demand it is useful to remember that much of any global share of sustainable biomass feedstock would be prioritised for producing bio-aviation fuel. Supplying a 2050 aviation demand of 164 TWh/y of bio-kerosene would require at least 220 TWh/y of feedstock even if bio-fuel production is maximised at the refinery.

5.37 Only 100 TWh/y of raw fair share resource may be available for producing marine bio-diesel let alone significant quantities of bio-methane for the gas network. Even if all shipping switched to hydrogen or ammonia fuels the 100 TWh/y of feedstock would only produce 75-80 TWh/y of bio-methane (after conversion losses of 20-25% for bio-methane). Bio-methane demand in the gas network could be minimised by maximising the deployment of heat pumps and using bio-hythane (mixtures of bio-methane and hydrogen) or converting parts or all of the gas network to hydrogen.

Full deployment of heat pumps to minimise bio-methane demand

5.38 By 2050 the building stock in gas-connected areas including about half of new build would have a heat demand of about 300 TWh/y if the indirect heating benefit is included (see Infrastructure Scenario 2 above). Assuming intermittent grid electricity were available for a period amounting to half the year then grid electricity and heat pumps would supply 150 TWh/y. Electricity and heat generated by micro-CHP boilers and CHP schemes and heat pumps would supply the other 150 TWh/y.

5.39 To provide this 150 TWh/y of space heating and hot water would require 50 TWh/y of electricity from the grid to drive the heat pumps to extract 100 TWh/y of heat from the local environment. When grid electricity is not available then the micro-CHP boilers and CHP schemes start up, generating heat and electricity in almost equal amounts. The electricity powers the heat pumps and the heat is fed directly to the central heating system. So to provide 150 TWh/y of heat, the fuel cell would generate 37.5 TWh/y of electricity to drive the heat pumps which harness 75 TWh/y. The boiler heat adds another 37.5 TWh/y, bringing the total to 150 TWh/y. As fuel cell boilers and CHP schemes would be about 90% fuel-efficient about 8.5 TWh/y of heat from the fuel cells would be lost from the fuel cells' air exhausts though heat recovery may reduce this by several TWh/y at least. So the annual gas demand, including losses could amount to 76-83.5 TWh/y.

5.40 However, during severe cold spells, air source heat pumps would be relatively ineffective and additional gas would need to be burned in the boilers or direct electric heating from stand-by power stations. This additional severe cold weather demand may amount up to an additional 20 TWh/y or so depending on the ratio of air-source to ground-source heat pumps across the UK.

5.41 So the minimum gas demand (bio-methane, bio-hythane or hydrogen) would probably be in the region of 100 TWh/y. This gas demand could be augmented with natural gas or fossil-derived synthetic natural gas (SNG) if sufficient bio-methane was not available though this would depend on climate policies.

CHP versus CCGT

5.42 If micro-CHP boilers do not turn out to be consumer-friendly or affordable then back-up electricity at times of low renewables output would have to be generated in local or district CHP schemes and ultimately back-up gas power stations (CCGTs). As electricity generated in a gas power station would be around 55-59% fuel-efficient at best, compared to 90% or more in micro-CHP boilers and CHP schemes, the gas required by CCGTs to supply 50 TWh/y of electricity to the heat pumps would be about 75-91 TWh/y. When a contingency for cold snap heating is included (20 TWh/y) then CCGTs may need to consume an additional 35 TWh/y of gas to generate 20 TWh/y of direct electric heating.

5.43 The CCGTs' gas demand (110-125 TWh/y) in this scenario is not much more than the gas demand as the micro-CHP / CHP scenario (100 TWh/y) rather than very significantly more, depending on the cold snap contingency. This is because the heat pumps work less hard when the fuel cell boiler is operating because some heat is being provided by the fuel cell in the boiler.

5.44 However, in practice there would be overall benefits in the micro-CHP and CHP route. Firstly, less gas would be needed. Secondly, as about 12% less heat is taken from air or ground the heat pumps systems would be slightly smaller and less expensive, and ground-source systems may achieve better annual efficiency (higher annual CoP). Thirdly, at colder times air-source heat pumps are less effective anyway (lower CoP) and so gas would more efficiently be used in the boiler at 90% efficiency compared to direct electric heating from a CCGT at 59% efficiency.

5.45 Furthermore, if an additional heat pipe loop is fitted, ground-source heat pump installations can re-heat the ground to improve their annual CoP when unwanted heat is available in summer. The ground can store heat collected in summer by solar thermal schemes (heat travels about 1 meter per month through the ground). So excess heat from micro-CHP boilers and CHP schemes can be pumped back through the re-heat loop. Such 'inter-seasonal' heat storage systems have been successfully demonstrated.

Heat pumps in rural areas

5.46 In rural areas not connected to the gas network (with an estimated heat demand of 110 TWh/y in 2050), electricity from the grid would need to be available all year to supply the heat pumps. Some of this could be imported via the grid from micro-CHP boilers and CHP schemes in gas-connected areas if necessary. Alternatively, buildings in rural areas could use micro-CHP boilers if hydrogen or other fuel is stored on site and replenished periodically by tanker, as is the case with LPG and oil heating systems. Farm-scale bio-gas AD schemes could also supply local networks. To supply a rural heat demand of 110 TWh/y would require 37 TWh/y of electricity to power heat pumps to provide an additional 73 TWh/y.

The potential of heat pumps

5.47 In theory, if fully deployed across the UK in urban, sub-urban and rural areas, heat pumps could reduce gas and direct electric heating demand significantly. Fuel cell micro-CHP boilers and CHP schemes (at all scales) would add reliable, demand-responsive electricity and heat and would optimise and back-up the heat pumps and the grid.

5.48 At an average system efficiency of CoP 3 air and ground source heat pumps could harness up to about 280 TWh/y of renewable heat from the local environment in an ‘all-electric’ infrastructure system (in which the gas network is essentially abandoned). However, a reliable demand-responsive energy system in which intermittent renewables and fuel cell CHP boilers and systems are integrated and supplied by the gas network, about 230-250 TWh/y of renewable heat could also, in theory, be harnessed. Gas demand could fall to about 80 TWh/y though 100 TWh/y minimum may be more likely given some severe cold snap contingency. Grid electricity demand for heating would be minimised at just 90-100 TWh/y at the times it would be available from intermittent sources.

5.49 However, a more practical deployment scenario may be much less extensive, serving perhaps just over half the building stock’s heat needs (ie 244 TWh/y out of 424 TWh/y). The gas demand in this scenario would be about 150-160 TWh/y including some cold snap contingency.

Summary of infrastructure scenario assessment

5.50 In view of the infrastructure scenarios assessment above it is considered in this report that a more likely (as distinct from ‘possible’) heat pump deployment would be of the scale set out in Infrastructure Scenario 1. Consequently, Infrastructure Scenario 1 (mid-level heat pump deployment) is used in the 2030 and 2050 Reference Scenarios in this report. This mid-level deployment would harness around 150 TWh/y of renewable heat at UK level and 7.5+ TWh/y for Wales. The minimum deployment is assumed to harness 1 TWh/y in Wales.

6 Future use of the gas network

6.1 The gas energy required to power the micro-CHP and CHP scheme fuel cells in Infrastructure Scenario 1 is estimated to be 139 TWh/y in 2050. Including a 10-20 TWh/y contingency for cold snaps would result in annual demand of 150-160 TWh/y of gas energy. If heat pumps were not deployed at this mid-level the gas demand would be even higher. This gas demand could comprise 100% bio-methane if sufficient bio-feedstocks were available. However, a bio-methane gas supply could be augmented by adding in hydrogen to create a gas-mix called 'hythane'. Hythane mixes are used in some countries and the UK gas network comprised about 50% hydrogen before converting to North Sea gas (fossil methane) in the late 1960s. A third option would be to convert the gas network, in parts or whole, to 100% hydrogen. This chapter explores these options.

6.2 Sustainable bio-methane supplies would be highly constrained if shipping bio-fuels were prioritised for aviation fuel production, even assuming the UK had access to anything like a global fair-share bio-feedstock of 320 TWh/y. About 55 TWh/y of bio-methane may be available if all shipping switched to hydrogen and/or ammonia fuels by 2050 (which itself would only be practicable with global-wide agreements and infrastructure changes). Rail services and the contingency could add an additional 15 TWh/y at most. Even then, the most extensive deployment of heat pumps across the UK would still require a gas energy demand of at least 80 TWh/y and preferably 100 TWh/y. So a sustainable bio-methane or bio-hythane gas network could be possible (the bio-hythane would be predominantly bio-methane with 10-20% hydrogen content by energy).

A case for hydrogen

6.3 However, a more likely mid-level heat pump deployment scenario would require a gas demand of 150-160 TWh/y. At this demand even hythane mixes would be predominantly hydrogen by volume. Hydrogen, on a volume to volume (v/v) basis contains about one third of the energy as methane. So if each gas were to supply 50% (80 TWh/y) of the energy each then the hythane would need to be about 75% hydrogen by volume. At this level most appliances or the burners within them would need to be converted in what would be a substantial infrastructure change even if progressively rolled out over decades. Fuel cell micro-CHP boilers, which essentially require hydrogen fuel anyway (even if reformed from methane within the boiler) would benefit by a hydrogen supply. An additional benefit would be the absence of more than twenty million tiny point sources of carbon dioxide emissions (even bio-carbon dioxide) with no hope of capture.

6.4 At higher volumes of hydrogen gas demand there could also be volume constraints on some or much of the gas network (all pipelines have a limit to volumetric carrying capacity depending on diameter and pressures). However, the reduction in heat need due to higher building stock insulation and the increased use of direct electric heating and heat pumps would reduce the gas energy demand via the distribution networks substantially by 2050 (from about 500 TWh/y of methane to 160 TWh/y of whatever gas in a mid-level heat pump deployment). So hythane mixtures and even a 100% hydrogen supply would probably not be subject to volume constraints in the existing network.

6.5 Consequently, there is a case to progressively switch to 100% hydrogen supply in the UK gas network by 2050. This would also allow any available bio-feedstock supplies to be converted to bio-diesel mainly for the international shipping sector and would avoid the need for internationally agreed major infrastructure changes in port refueling facilities worldwide (to ammonia or liquid hydrogen or other hydrogen-carrying fuels and systems).

6.6 Hydrogen for distribution by the gas network could be produced in several ways from numerous sources. Low-carbon hydrogen can be produced in CCS gasifiers using coal. Lower-carbon hydrogen can be produced in CCS reformers using natural gas (potentially facilitating area by area transition to hydrogen). Carbon-neutral or mildly carbon-negative hydrogen can be produced by co-firing some biomass with coal in CCS gasifiers, and strongly carbon-negative hydrogen can be produced in biomass-fueled CCS gasifiers and AD plants. Carbon-neutral hydrogen can also be produced by the electrolysis of water at a conversion rate of 82% or more.

6.7 If the electrolysers are located within bio-refineries, industrial and urban CHP schemes or other appropriate buildings or settings the heat of electrolysis could be utilised. Heat networks around such sites would distribute the heat to building. Appropriate siting of electrolysers could result in conversion losses in hydrogen production being minimised or eliminated.

6.8 One possibility to produce green hydrogen is to use just the peak electricity outputs of intermittent renewable energy schemes, particularly from offshore wind farms, to generate hydrogen by electrolysis of seawater. Preliminary analysis (see Annex 1) indicates that a 10 GW offshore wind farm cluster could be peak-lopped by 50% and would still transmit 75% of its electricity production. The 25% not transmitted would be used to produce hydrogen in electrolysers and most of this (over 20% of annual output) would be converted to hydrogen with about 4.3% lost as heat in the electrolysers. At a stroke this 'peak-lopping' technique could significantly reduce the management issues of intermittent renewable generation.

6.9 For example, a 10 GW wind farm cluster would have an average output of about 3.6 GW (i.e. its capacity factor assuming 90% availability), peaks would become flattened 5 GW plateaus and the hydrogen produced would power demand-responsive fuel cells which would minimise the wind farms' output troughs and generally respond to instantaneous grid supply-demand requirements.

6.10 120 TWh/y of hydrogen could be produced (via electrolysis) by 50% peak-lopping of 190 GW of offshore wind farms (generating 600 TWh/y). Electrolyser heat losses would be about 26 TWh/y (possibly mostly utilised in coastal CHP schemes if electrolysers are onshore). Assuming bio-feedstock is constrained and 160 TWh/y of hydrogen were needed for the gas network then about 35 TWh/y of electrolyser heat would be generated, for loss or use, by peak-lopping at probably somewhere between 45-50% of installed capacity.

6.11 The Reference Scenarios assume that about 60% of electrolyser heat losses are recovered by urban CHP schemes (with installed electrolysers) and heat networks around bio-refineries and industry sites. The remaining electrolyser heat could partly be used at refinery and industrial sites but this is not included in the scenarios.

Hydrogen production in co-fired coal / biomass CCS gasifiers

6.12 If generating green hydrogen by electrolysis using intermittent renewable electricity is not a preferred option then hydrogen production by the gasification of coal with CCS would probably be the main other low-carbon option. This assumes that unconventional fossil energy sources, particularly shale gas, is constrained by 2050 (natural gas can be reformed to low-carbon hydrogen in CCS fitted reformers). Coal gasification with CCS, while co-firing whatever sustainable biomass were available, would minimise emissions and could enable highly carbon-negative hydrogen production. Indeed, co-firing at just 10% woody biomass would achieve net carbon-zero emissions. At around 40% co-firing highly carbon-negative hydrogen production would occur.

6.13 If up to 80 TWh/y of biomass feedstock were available (e.g. shipping partially or totally switches to hydrogen or ammonia fuels) then highly carbon-negative generation could even be achieved in co-fired coal gasifiers. A hydrogen supply of 160 TWh/y could be provided by co-firing 80 TWh/y of biomass with 133 TWh/y of coal in CCS gasifiers with water-shift plant (at about 58% overall conversion efficiency with CCS, external inputs and heat recovery). Co-firing at this level (at about 38% bio-energy) would result in *negative* emissions of about 20 million tonnes per annum at 90% capture. The UK building stock would become strongly carbon-negative not just zero-carbon.

6.14 About 20 million tonnes of coal would be needed each year which is equivalent to about 40% of 2009 coal consumption in the UK. Coal production in the UK was 18 million tonnes in 2009. If underground coal gasification is successfully demonstrated in the UK's thin and faulted coal seams then there would be some access to potentially billions of tonnes of unmineable coal (only a tiny percentage would be needed) and no need for any imports.

6.15 If the bio-feedstock resource for co-firing were very highly constrained then it would only take 10% co-firing to achieve carbon-zero hydrogen production. Producing 160 TWh/y of carbon-zero hydrogen would require 20 TWh/y of bio-feedstock co-gasified with 193 TWh/y (29 million tonnes) of coal. The process would require 15 TWh/y of external green energy (electricity, oxygen, hydrogen, or heat) and heat recovery around the gasifier site may be 14 TWh/y with final losses of 86 TWh/y.

CCS-fitted gasifiers - a transitional energy technology

6.16 The use of CCS-fitted coal/biomass gasifiers would be a major transitional energy technology facilitating the transition from a carbon-intensive fossil fuel based energy system to a carbon-negative renewable energy system by mid-century. The ability to provide increasingly carbon-negative hydrogen for the gas network from just 11% co-firing with woody biomass from about 2018 should be of great interest to policymakers. Over the decades the UK's hydrogen demand could be increasingly supplied by peak-lopping of intermittent renewable energy deployments, particularly offshore wind. However coal based CCS gasifiers would offer reliable and flexible back-up on while major offshore wind and other renewable deployments are rolled-out and the gas network moves from fossil methane to either bio-methane, hythane and or hydrogen.

6.17 As more renewables come on-line by mid-century the gasifiers could be kept as a strategic reserve. CCS gasifiers could produce low-carbon or carbon-neutral liquid bio-fuels if bio-feedstocks are unavailable or significantly disrupted. Assuming a co-fired CCS gasifier (to liquids) conversion rate of 50%, at 60% biomass co-firing to achieve near carbon-zero emissions from the refinery, it would require 164 TWh/y of fuel input, including 100 TWh/y of dry woody feedstock, to produce half (82 TWh/y) the bio-kerosene needed to meet 2050 aviation (international share and internal) demand.

7 Carbon-negative energy generation

7.1 CCS technology can be used in conjunction with bio-energy resources to store carbon dioxide extracted from the atmosphere by crops for at least thousands of years or geological timescales. Such a carbon-negative process could be used to reduce, if not potentially to reverse, the increasing concentrations of carbon dioxide in the atmosphere from fossil fuel burning. The process is known as Bio-energy with Carbon Capture and Storage (BECCS or BECS).

7.2 Additionally, if direct air-capture (DAC) technologies become cost-effective then carbon dioxide captured directly from air for bio-fuel synthesis or immediate storage could be carried out at potentially very large scale.

7.3 The contribution to global warming mitigation by BECCS will depend on the global availability of sustainable bio-energy feedstocks. Estimates of future levels of sustainable bio-feedstock cultivation are contested and controversial due to concerns about competing demands for suitable land and water resources on which to grow food for over 9 billion people by 2050. The Reference Scenarios in this report use a global fair-share figure extrapolated from IEA and UN IPCC estimates. This report also describes how aviation demand for liquid bio-kerosene could be produced synthetically if global bio-energy resources are severely constrained or essentially unavailable. Shipping and other sectors could switch to hydrogen, or even ammonia fuels if climate policies or the diminishing availability of fossil or bio-fuels required it.

7.4 A bio-conversion efficiency of 75% is assumed in this report, which reflects the possibility of maximising bio-fuel production by using external energy to convert bio-carbon dioxide produced within the refinery processes to bio-fuel.

7.5 Other bio-fuel demands, particularly by international shipping, some rail services and even HGV (manufacturers and hauliers) may wish to avoid switching to non-bio low-carbon fuels and would create additional liquid bio-fuel demand. Bio-methane demand for use in gas networks would be another potentially large draw on bio-feedstocks. This report indicates that there is barely sufficient bio-feedstock globally to support likely levels of future aviation and shipping demand. However shipping particularly could switch to other fuels if necessary and gas networks could switch to hythane mixtures or 100% hydrogen.

7.6 The 2050 Reference Scenario estimates that all energy generation by then is either essentially by carbon-neutral renewable energy technologies or by carbon-negative (to some degree) bio-fuel production processes even if some coal or natural gas is co-fired. In producing the 234 TWh/y of liquid bio-fuels at bio-refineries either in the UK or overseas, about 46 million tonnes per year of bio-carbon dioxide would be captured and stored in geological formations. Theses carbon-negative emissions would be allocated to UK and Welsh greenhouse gas (GHG) inventories. For Wales this would amount to about 2.3 million tonnes per year by 2050.

7.7 It is difficult to estimate future carbon emissions from industrial sources but most of their on-site fuels and external energy demands could be renewable by then and any significant industrial carbon emitters could be fitted with CCS. Other greenhouse gas emissions could also be substantially reduced or avoided by emerging and future technologies and processes.

7.8 Carbon dioxide and other greenhouse gas emissions from the agricultural sector would also contribute to national emissions inventories but would be much more difficult to reduce significantly. Emissions of carbon dioxide and methane from land-use, land-use changes, forestry, and livestock, particularly from bio-energy cultivation and food production, would continue to make substantial contributions. The maximum reduction on current levels would be about 20%.

7.9 So, factoring such emissions in, by 2050 the net UK carbon dioxide or greenhouse gas emissions could be 34-42 Mt CO2, minus many million tonnes of carbon-negative emissions from bio-fuel production in CCS refineries achieved. So, the UK national emissions in the 2050 Reference Scenario, in which bio-fuel production is 46 mt CO2 carbon-negative, would be *minus* 4-12 mt CO2 carbon-negative. At Wales level this may approximate to 0.5 mt CO2 per year net carbon-negative. However, some declining or residual coal use or other fugitive emissions may result in emissions nearer net carbon zero for a period after 2050.

7.10 However, if shipping and all rail and any other liquid bio-fuel users all switched to non-bio fuels, then some 70 TWh/y of bio-methane or bio-hydrogen could be produced for CHP energy generation or the gas network. In that scenario the amount of bio-CO2 which could be captured and stored could be increased significantly. The amount of offshore wind that would need to be converted to hydrogen by electrolysis would fall substantially. 70 TWh/y of bio-methane production would enable 18.2 Mt per year of bio-CO2 storage, and 70 TWh/y of bio-hydrogen production would enable 30.1 Mt per year of bio-CO2 storage. This compares with 13.7 Mt per year of bio-CO2 storage in the production of 70 TWh/y of liquid bio-fuels. This could increase carbon-negative emissions by 4.5-16.4 Mt.

7.11 Aviation demand of 164 TWh/y would enable the capture and storage of 32 Mt bio-CO2 per year. So if shipping, rail and any other sectors fully converted to non-bio low-carbon fuels (eg hydrogen or ammonia / fuel cell electric), and the 5% (13 TWh/y) contingency were included, then 50-62 million tonnes of bio-carbon dioxide could be sequestrated per year by 2050 at UK level. This would amount to about 2.5-3 million tonnes bio-carbon dioxide per year for Wales.

7.12 In terms of national greenhouse gas inventories this level of carbon-negative fuel production or BECCS could achieve net *negative* UK emissions of between 8 and 28 million tonnes of carbon dioxide per year by 2050. In the 2050 Reference Scenario, in which the gas network has switched to 100% hydrogen the higher figure would more likely be achieved if agricultural emissions were to fall by nearer 20%. For Wales this would amount to 1.4 million tonnes bio-CO2 stored (ie net carbon-negative) per year by 2050, though considering agricultural and other uncertainties 1 million tonnes of bio-CO2 per year stored would be a more likely possibility.

7.13 The carbon-negative potential of DACCS is currently more uncertain than the availability of large-scale sustainable bio-energy resources for BECCS. Technically, carbon dioxide can and has been captured from air using chemical means. However the processes demonstrated to date have been very energy intensive and not cost-effective. With continuing research and development this could change and at some point, probably depending to a considerable extent on global bio-energy feedstock availability and carbon prices, could become cost-effective for some or most potential customers, particularly airlines.

7.14 If DACCS did become cost-effective for general bio-fuel production and renewable energy technologies then potentially significant climate protection could be achieved, particularly as process costs decreased over time. A 50 ppm reduction or more in atmospheric carbon dioxide levels could become possible by 2100.

Carbon dioxide storage and the Eastern Irish Sea

7.15 Locations for storing carbon dioxide from energy generation, industry and bio-refineries, be it from predominantly fossil fuels before 2050 and predominantly bio-energy sources after 2050, are both accessible and capacious for the UK. The North Sea has potentially very large storage capacity in depleted oil and gas wells and other geological formations and this has drawn most of the attention to date. However, the storage potential in depleted gas fields in the Eastern Irish Sea is very substantial and its high value should not be under-estimated.

7.16 Indeed, much of the current infrastructure used for extracting and piping natural gas to Deeside from the Hamilton gas fields in Liverpool Bay could also be used for CO2 storage operations when the fields are depleted. Depletion in the Hamilton fields, just 20 miles north of Prestatyn, is forecast in the 2014-2017 period. These fields are estimated to have about 150 million tonnes of carbon dioxide storage capacity. The larger Morecambe Bay gas fields, at around 40 miles from the north Wales coast, have an estimated storage capacity of some 1,000 million tonnes of carbon dioxide, and are estimated to become gas depleted through the 2020-2030 period.

7.17 So the UK and Welsh Government CCS strategy, particularly timing and location planning, is key to optimal and cost-effective re-utilisation of pipeline and other Irish Sea infrastructure that would otherwise be decommissioned. The Eastern Irish Sea, unlike most North Sea storage sites, is also relatively sheltered and the Hamilton storage sites are just 20 miles from the north Wales and Lancashire coasts. There are also potential storage opportunities in the Celtic Sea to the south west of west Wales.

7.18 These favourable factors suggest that Wales could lead the way in carbon-negative energy generation particularly from sites in north Wales, as part of its on-going commitment to sustainable development.

Chapter 8

An energy system to supply future demands

8.1 This chapter shows how the future energy demands in chapters 2 and 3 are met by the renewable resources available in chapter 4, using the energy generating and distribution infrastructure described in chapters 5 and 6. The 2050 and 2030 Reference Scenarios referred to in the preceding chapters are summarised in Table 7. The table also shows the conversion and distribution energy losses in producing useful fuels from widely dispersed energy resources with which to supply the widely dispersed energy demands at the time the demands are made.

The 2050 Reference Scenario

8.2 The energy system in the 2050 Reference Scenario is based on the current electricity and gas networks, with new electricity links to renewable energy schemes. The gas network is progressively converted to 100% hydrogen by 2050. The hydrogen is produced by peak-lopping of intermittent renewables, particularly offshore wind at electrolysers located at coasts in refineries, other industrial sites and urban CHP schemes. About 220 TWh/y of hydrogen is distributed per year in the Reference Scenario but the system's flexibility could facilitate significantly less or more depending on the extent of heat pump and other renewable deployments and system requirements. The hydrogen is supplied to a combination of micro-CHP boilers in individual buildings and CHP heat networks, and to HGV and other heavy vehicle refueling depots and forecourts.

8.3 The system could comprise millions of fuel cell micro-CHP boilers in residential and other buildings in suburban and most urban areas, with some larger heat networks around bio-refineries, industrial sites and urban CHP schemes.

8.4 Solar panels on most if not all southerly facing roofs and other facades also provide distributed energy. Most panels would be PV due to the availability of sufficient hot water in summer from micro-CHP boilers and CHP schemes providing electricity for grid balancing. In rural area off the gas network, a higher mix of PV and thermal panels would provide heat if future heat pumps and PV did not effectively supply hot water demand. A mid-level deployment of heat pumps is modeled in the Scenario rather than saturation deployment in all buildings.

8.5 Depending on the extent of heat pump deployment the corresponding hydrogen gas supply is produced and distributed from electrolysers located at refinery and other industrial sites and in urban CHP schemes. If there were a low deployment of heat pumps then more hydrogen would provide the heat required. More hydrogen would be produced by additional peak-lopping of intermittent renewables using electrolysers. Most of the additional heat produced in the electrolysers could be used in CHP schemes. So the system would offer significant flexibility with little loss of efficiency. CCS coal/biomass gasifiers would provide strategic back-up if required.

8.6 The hydrogen would fuel micro-CHP boilers and CHP schemes to provide reliable power to the heat pumps, other electricity demands and balancing power and back-up power to the grid. The demand-responsive distributed generating capacity balances the intermittent inputs and variable daily consumer demands on the electricity grid. Combined process heat and power schemes in industry, using high temperature solid oxide fuel cells or molten salt stores, also provide substantial balancing and back-up services for the electricity grid.

8.7 Electrolysers located at bio-refineries, other industrial sites and urban CHP schemes provide hydrogen for the gas network, industry and the refineries themselves using peak-lopped electricity from renewable schemes particularly offshore wind farms. The oxygen produced would be supplied to the oxygen-blown gasifiers. Most HGVs and longer-distance bus and coaches are fuel cell/hydrogen powered by 2050 and smaller vehicles are electric battery or fuel cell/hydrogen powered. Most rail services are electric or fuel cell/hydrogen with some bio-diesel train along branch lines. Air and sea ports are supplied with liquid bio-fuels in much the same way and capacity as currently.

8.8 CCS pipeline infrastructure will be fitted to gas-fired power stations, industrial sources and coal/biomass gasifiers between 2020 and 2040 and will link all bio-refineries, industry and power stations to sub-sea geological formations in the Irish Sea and North Sea. Some CCGT power stations and CCS coal gasifiers/biomass built by 2020 play a back-up role before 2050 and could be retained as a strategic reserve by 2050.

Geographical considerations of energy production, distribution and refueling

8.9 Electricity demands from all sectors, including homes and offices, electric vehicles, plus industry and refinery needs, would be highly dispersed and would partly be supplied by the electricity grid. This would incur distribution losses along the transmission lines. Some electricity would be supplied by micro-CHP boilers in buildings or CHP schemes in which the distribution losses would be far smaller.

8.10 Electricity grid distribution losses comprise heat energy losses in transmitting electricity via the high-voltage (HV) Grid and low-voltage (LV) networks. The losses in transporting the 349 TWh/y of electricity generated and supplied to the grid in 2009 amounted to 27 TWh/y. Of these losses (equivalent to 1 TWh/y loss per 11.9 TWh/y distributed), 22% were along the high voltage grid system and 74 % were in the low voltage distribution network.

8.11 Most electricity distribution losses are incurred within the low voltage distribution lines. Losses in the HV and LV networks could be higher due to increased currents caused by a near doubling of electricity demand. However, future losses (per TWh distributed) are assumed to fall to 1 TWh per 13 TWh distributed due to year on year LV and HV Grid system improvements and capacity upgrades, and the avoidance of peaking losses due to distributed mCHP boilers and local CHP schemes exporting electricity to local demand.

8.12 In 2050 about 577 TWh/y of electricity will be transmitted by the grid (147 TWh/y for heat pumps +120 TWh/y appliances +50 TWh/y cooling +260 TWh/y industry) so losses incurred in 2050 are 44.5 TWh/y. Offshore wind and wave schemes are assumed to use HVDC links incurring 0.75% converter losses at either end or about 9 TWh/y. Consequently, grid distribution losses amount to 53.5 TWh/y in 2050. The avoided LV losses due to conversion in electrolysers and transmission of hydrogen via gas network amounts to 14.5 TWh/y.

8.13 The gas network also incurs distribution losses though much less than the electricity grid (approximately 2%). Future gas distribution losses in transmitting anything from 100% methane, hythane blends to 100% hydrogen through the gas network is assumed to be the same. Three times more hydrogen volume has to be transmitted for the equivalent energy of methane but there are less frictional losses within pipelines by a similar proportion. Infrastructure Scenario 1 requires 160 TWh/y of gas for mCHP boilers and CHP schemes, and HGVs and buses require a further 60 TWh/y of hydrogen, amounting to 220 TWh/y distributed. Consequently, in 2050 gas distribution losses amount to 4.5 TWh/y.

Conversion losses

8.14 Electrolyser efficiency is assumed to be 82% resulting in 13 TWh/y of electricity losses in producing 59 TWh/y of hydrogen for HGVs, bus and coaches in 2050. The production of 160 TWh/y of hydrogen for the gas network incurs 35 TWh/y losses in 2050. About 60% of the losses are assumed to be recovered as hot water by locating electrolysers in CHP schemes, refineries, other industry and even larger buildings. If electrolyser efficiency were lower than 82% then more electricity would need to be converted but additional heat would also become available.

8.15 Hydrogen for HGV, buses, coaches and other larger or longer-distance vehicles would mostly be obtained from the gas network or on-site electrolysers at refueling depots. Where bio-methane or bio-gas sources are available, for example at AD schemes in rural areas, then cold-plasma devices may also feature as the carbon-black byproduct would be a useful industry feedstock and the bio-carbon dioxide emissions would be avoided. Any remaining diesel rail services would be supplied with bio-diesel from existing or new re-fueling depots from UK refineries.

8.16 Welsh and UK bio-fuel demand for the aviation and shipping sectors partly arises at UK airports and seaports and partly occurs abroad providing fuel for return journeys. The 2050 Reference Scenario demands for international and internal aviation and shipping amount to 216 TWh/y in 2050 comprising 164 TWh/y and 52 TWh/y respectively. Actual distribution to and refueling at UK airports and sea ports amounted to 120 TWh/y and 30 TWh/y respectively in 2009. This demand includes that by non-UK residents flying via UK hub airports.

8.17 Site specific re-fueling demand in the UK is estimated to remain essentially the same (falling slightly by 4 TWh/y to 146 TWh/y) in the coming decades for the reasons set out in the aviation and shipping paragraphs. So, to account for the UK’s 2050 share of aviation, shipping and other liquid fuel demand (amounting to 164 TWh/y) the remaining 70 TWh/y of UK energy demand (3.5 TWh/y for Wales) for liquid bio-fuels in 2050 is deemed to occur at air and sea ports abroad.

8.18 As over half the UK fair-share of bio-energy feedstocks are cultivated abroad in the Reference Scenarios (see Section 3) the actual fuels supplied to air and sea ports in the UK and abroad to meet UK demand would probably be supplied by refineries abroad using foreign bio-feedstocks available to the UK on a fair-share basis. More specifically, these liquid bio-fuels may well be produced at refineries in the bio-feedstock producing countries to reduce transportation of bulky feedstocks, or sited in countries with high renewable energy resources to supply green energy to refineries to increase bio-fuel yield. Refineries abroad may also be sited at locations with good access to geological storage capacity of CCS depending on the global demand for carbon-negative bio-fuel production.

8.19 Consequently, the Reference Scenario assumes that about half of all liquid bio-fuels to meet UK liquid bio-fuel demands are refined abroad (ie 120 TWh/y out of 234 TWh/y in 2050). These liquid bio-fuels would be partly distributed to air and sea ports abroad to meet UK demand (70 TWh/y) and the remainder (50 TWh/y) imported to the UK to part meet the 146 TWh/y of demand at UK air and sea ports.

8.20 Bio-refineries in the UK would refine most indigenous and some imported bio-feedstocks to produce the remaining 114 TWh/y of liquid bio-fuels to meet UK demand. Most of the liquid bio-fuels would be distributed to UK air and sea ports to meet the 146 TWh/y of site-specific demand, and 5 TWh/y being distributed to rail depots (with a 13 TWh/y contingency at UK level). The 13 TWh/y contingency is assumed to be a refinery conversion loss unless conversion and yield maximisation processes achieved a 75% bio-conversion rate. If the 75% rate were achieved there would be either a reduced bio-fuel demand (about 0.5 TWh/y at Wales level) or that much additional bio-fuel available to meet un-forecast demand.

Energy demand and supply at bio-refineries

8.21 Due to potentially major constraints on global supplies of sustainable bio-feedstocks (including indigenous bio-resource) liquid bio-fuel production is maximised in the Reference Scenarios. Yield is maximised by using external (green) energy at the refinery to reach 75% bio-energy conversion efficiency. At 75% conversion efficiency the woody bio-feedstock demand to produce 234 TWh/y in 2050 would be 312 TWh/y (156 TWh/y by 2030) to meet mainly aviation and shipping demands. So the bio-conversion losses at the refinery would be 78 TWh/y in 2050.

8.22 External energy (electricity, oxygen, hydrogen or heat) is used to convert some of the bio-carbon dioxide produced within the refinery processes to bio-fuel, and to provide auxiliary power demands around the refinery site, including torrefaction and other fuel preparation. External energy could include use by the refinery of heat and oxygen from on-site electrolysers (eg in producing hydrogen for the gas network). In 2050, 234 TWh/y of liquid bio-fuels are produced (164 bio-kerosene +57 bio-diesel +13 contingency) requiring 58 TWh/y of external energy.

8.23 Significant amounts of the heat of bio-conversion are assumed to be recouped by heat recovery systems around the refinery (e.g. for feedstock drying) which could be used to supply local industry or any buildings in the area with hot water via heat networks. Heat recovery is assumed to re-coup 27% of the bio-conversion losses (39 TWh/y in 2050) incurred at UK refineries in the Reference Scenarios and amounts to 10.5 TWh/y in 2050.

8.24 A further 23 TWh/y (electricity and heat) is used to drive CCS plant to capture 46 million tonnes of bio-carbon dioxide which would be otherwise released from the bio-refinery sites (UK and overseas). This energy demand is optional, being dependent on future climate concerns and policies, but is included in the Reference Scenarios (for indigenous and imported bio-fuels). The 234 TWh/y bio-kerosene and bio-diesel produced would be moderately carbon-negative (minus 0.195 million tonnes per TWh of fuel) as 46 Mt bio-CO2 would be captured and stored in 2050. The emissions would be accounted for as such in Welsh and UK emission inventories with passengers and consumers paying the additional cost on the fuel.

8.25 As a consequence of overseas refining about half (51.3%) the refinery energy demand for yield maximisation and CCS, and heat recovery, occurs abroad as a result. As 114 TWh//y of liquid bio-fuels are refined in the UK in 2050 the energy required to maximise yield amounts to 29 TWh/y, heat recovery is 10.5 TWh/y, and the CCS demand is 11.5 TWh/y to store 23 Mt bio-CO2.

8.26 The bio-conversion losses (78 TWh/y in 2050 of which 39 TWh/y would be incurred in the UK) are not a final energy demand and so are not included in the Final Energy Demand total but are fully accounted for in the resource assessment in Chapter 4. About half the 2050 production rates are assumed in 2030 to provide a trajectory to achieve 2050 demands.

Table 7: Energy demand sub-sector estimates 2030 and 2050 (Reference Scenarios)

UK final energy by sector	2009	2030	2050
Transport (inland and coastal, UK aviation)	471	247	161
International civil aviation fuel to UK airports	120	118	117
Marine diesel fuel to UK seaports	29	30	29
Electricity lighting & appliances	174	140	120
Heating : residential & non-res + losses - indirect	535	477 + 35 - 40	460 + 20 - 35
Cooling	30	40	50
Industry	311	285	260
Non-energy uses (eg chemicals, plastics, C-fibre)	106	90	90
distribution losses (Grid + gas network)	27 + 20	50	53.5 + 4.5
Energy Demand (inc distribution, ex conversions)	1,823	1,472	1,330
Aviation : international (minus UK distribution)	150 - 120	155 - 118	150 - 117
Shipping : international (minus UK distribution)	45 - 29	50 - 30	45 - 29
Demand (inland + international, ex conversion)	1,869	1,529	1,379
Electrolysis losses : HGVs, etc - CHP recovery	-	6 - 3	13 - 8
Electrolysis losses : gas network - CHP recovery	-	15 - 9	35 - 22
Bio-fuel yield maximisation at UK refineries	-	17	29
Conversion heat loss recovery (28 % of losses)	-	minus 5	minus 10.5
(Optional) carbon-negative CCS at UK refineries	-	(up to) 5	(up to) 11.5
Contingency (5 % bio-fuels aviation & shipping)	-	6	13
UK Final Energy Demand (Wales)	1,869 (93.5)	1,561 (78)	1,440 (72)
Losses : synthetic liquid bio-fuels (0 if imported)	-	0 - 89	0 -177

Notes on Table 8.1

1. Primary Energy Supply (PES) at UK level was 2,560 TWh/y in 2009 and after conversion to usable fuels and distribution (e.g. 120 TWh/y of aviation fuel to UK airports) the UK Final Energy Demand (FED) was 1,776 TWh/y. Including distribution losses of 47 TWh/y the final 'supply' would have been 1,823 TWh/y.
2. In 2050, bio-kerosene demand from international and internal aviation is 164 TWh/y and bio-diesel demand from international and coastal shipping and some rail services reaches 57 TWh/y. A 5% (13%) liquid bio-fuel contingency is additional). Half the liquid bio-fuel demand is met by imports from refineries overseas or consumed abroad by Welsh and UK residents. By 2030, liquid bio-fuels refinery capacity and supply reaches about half the 2050 figure (ie 117 TWh/y), comprising approximately 50 % blends of bio-kerosene and bio diesel with fossil equivalents, and is mainly supplied to the aviation and shipping sectors (some to rail and HGVs).
3. Conversion losses at bio-refineries (in Wales, UK and abroad): the yield in (carbon-negative) liquid bio-fuel production is maximised (per unit of bio-feedstock) by using external (green) energy at bio-refineries (due to constrained fare-share bio-resource). In 2050, 234 TWh/y of liquid bio-fuels are produced (164 bio-kerosene + 70 bio-diesel) requiring 58 TWh/y of external energy (ie electricity, oxygen, hydrogen or heat) to drive auxiliary refinery processes, and 23 TWh/y (electricity and heat) to drive the CCS plant. About half the 2050 amounts are used in 2030 as bio-resource supply chain and bio-refinery capacity increases. The bio-kerosene and bio-diesel produced could be strongly carbon-negative as refineries with access to pipelines to offshore geological storage sites could relatively easily be fitted with a CCS plant. Up to 22 mt bio-CO2 could be stored per year by 2030 and 45.6 mt bio-CO2 stored per year in 2050. The Reference Scenarios include CCS at bio-refineries in UK and abroad.
4. International energy use: aviation fuel demand as supplied to UK airports (117 TWh/y in 2050) is listed in Row 2 and marine bunker fuels for shipping supplied to UK ports or exported (29 TWh/y) is listed in Row 3. The UK share of international aviation (150 TWh/y) and shipping (45 TWh/y) is listed in Row 12 and Row 13 respectively with the fuel supplied in Rows 2 and 3 subtracted to avoid double counting.
5. In 2009 CHP (mainly industrial schemes) comprised 5.5 GWe and generated 28 TWh/y of electricity and 51 TWh/y of heat (totaling 79 TWh/y). About 10% of capacity was for non-industrial sectors (essentially domestic and service). The table assumes about 11% (9 TWh/y) of 2009 CHP electricity and heat is generated and consumed in the domestic and service sectors and this energy is included in the 'Heating - domestic & service' row, leaving 70 TWh/y for industrial demand.
6. Electrolysis heat losses assumed to be partly recovered (60%) in urban heat networks from CHP schemes incorporating electrolysers, and heat networks around industry and bio-refineries with on-site electrolysers. Other electrolyser heat losses assumed to be partly utilised at bio-refineries and industry but are not included.

Methodology for assessing future energy demand and renewable energy supply

In order to find out if and how Wales can be become fully renewably powered by around mid century the analysis in this report followed an iterative process as a demand-responsive, robust reliable and secure energy system is more than just the sum of parts. The energy demand and resource assessments set out in the report were then assessed in terms of system integration which included transmission, distribution, demand-response, extreme weather events and fuel flexibility and wider security. There are numerous ways in which sector energy demands can vary depending on future renewable resources including cost prospects, technology and fuel choices for large-scale deployments, imports, system integration and other infrastructure considerations. Indeed, supplying demands creates demands in itself depending on fuel choices the associated conversion and distribution losses, and the implications for fuel choices in other sectors.

The energy demands shown in Tables 2 and 3 show what is considered possible and plausible in 2030 and 2050 and are called the Reference Scenarios. The main focus has been on the 2050 Reference Scenario and the 2030 Scenario indicates plausible if not probable energy demand and supply trajectories along the route.

The iterative process commenced by assessing the most probable level of energy demand in 2030 and 2050. This was done by estimating future energy demand in the residential and non-residential, transport (national and international), and industrial sectors. Recent academic and professional literature about how future technology may affect sectoral demand (e.g. fuel-efficiency of cars and HGVs, housing stock insulation, appliances etc) was used to help inform and support the estimates made in this report. The estimated 2030 and 2050 heat demand of the residential and non-residential sectors are summarised in Table 2, and 2030 and 2050 transport demands are listed in Table 3 and UK sector energy demands in Table 7.

Secondly, to meet this future demand, the practical range (likely maximum and minimum) of all indigenous renewable energy resources around Wales is assessed (i.e. wind, solar, tidal, heat pumps, biomass etc) as well as possible renewable energy imports (i.e. biomass feedstocks, produced biofuels, solar and wind derived electricity, etc). Recent academic and professional literature about a technology's potential ability to harness resources cost-effectively is used to help inform and support the estimates made in the briefing. Imported renewable resources are assessed on a fair-shares (based on global population) and sustainable production basis. Existing nuclear power stations are assumed to run to the currently forecast decommission timescales (only Sizewell B operates for a few years beyond 2030) and no new stations are built.

The estimated 2030 and 2050 energy resources by technology are listed in Table 3. In the Table nuclear power, along with offshore wind and imported biomass are assessed in terms of their 'UK share' in order not to distort the analysis of Wales' indigenous renewable resources or infrastructure capability.

Thirdly, the 'worst case' shortfall in renewable sources to meet forecast 2030 and 2050 energy demand is estimated by summing all of the minimum likely contributions estimated for each technology. Any shortfall is assumed to be supplemented with fossil fuels with Carbon Capture and Storage (CCS) technology fitted where applicable. The report indicates how CCS infrastructure, which can be applied to and used by biomass as well as fossil fuels, could be integrated into possible low-carbon and eventually carbon-negative energy pathways for Wales.

Fourthly, the resources are assessed in infrastructure scenarios to identify what infrastructure needs to be built to integrate and manage the energy supplied by the various highly intermittent renewable sources. The scenarios describe how related energy technologies (e.g. fuel cell boilers, electrolysers) could be used to provide effective and reliable response to the varying daily and seasonal consumer demands of the population. The degree of climate protection provided by the Reference Scenarios and other possible energy pathways is also assessed. This includes the potential of CCS being applied to co-fired and biomass technologies to provide carbon-negative energy generation, the choice of fuels for shipping, the gas network and HGVs. Hydrogen use in part or whole of the gas network is also assessed to identify any significant energy, carbon emission or resource benefits over natural gas and bio-methane.

Fifthly, the various renewable technology and infrastructure pathways are compared and contrasted in terms of self-sufficiency, security, climate protection and cost-effectiveness to identify the optimum pathways in meeting the proposed objective of achieving a renewably powered Wales by 2050. This analysis is used to inform the the sector demands and conversion losses in the Reference Scenarios for 2050 and 2030.

Energy units in this report

The two main energy units used in this briefing are tera watt hours per year (denoted TWh/y) and kilowatt hours per day per person (denoted kWh/day per person).

The TWh/y unit is more useful and manageable when referring to the annual energy use or output of a technology at national or sector level, for comparative purposes, and it aligns with units used in many official publications. It is not dependent on population.

One TWh/y is one million Mega-watt hours per year (million MWh/y), or one billion kWh per year.

The kWh/day per person unit aligns with information presented in some recent publications, particularly the 2010 Welsh Assembly Government (WAG) document entitled ‘A Low Carbon Revolution’ and the Department for Energy and Climate Change (DECC)’s 2010 consultation document entitled ‘2050 Pathways’.

This unit, which takes account of the national population at the time referred to, was first popularised in the 2008 book ‘Sustainable Energy without the Hot Air’ (http://www.withouthotair.com/) by then Cambridge academic David Mackay who became chief scientific adviser to DECC in 2009.

The unit is useful as a kWh is an amount of energy that a wide audience can relate to (eg a one bar electric fire for one hour costing between 10-15 pence). The unit can help show how energy demand varies by day particularly between summer and winter when the energy infrastructure in Wales is operating in its most different ways.

Where helpful, the equivalent figure in TWh/y units is included in brackets after the kWh/day per person figure when the latter unit is used and vice versa.

To convert TWh/y to kWh/day per person, the TWh/y figure needs to be divided by 365 (days per year) and multiplied by 1,000 (a scaling factor), then divided by the population in millions in the particular year. The Welsh population in millions was ‘3’ in 2009 and forecast at ‘3.55’ in 2030 and ‘3.75’ in 2050, and ‘62’ at UK level in 2010 rising to ’71’ in 2030 and ‘75’ in 2050.

For example : 10 TWh/y = 10 x 1,000 / 365 / 3 = 9.13 kWh/day per person (in Wales in 2010).

Assuming the population in Wales rises to 3.75 million by 2050 then :

10 TWh/y = 10 x 1,000 / 365 / 3.75 = 7.3 kWh/day per person (in Wales in 2050)

Data sources used in this report

The main data sources used in this report are listed below. Other references are included as footers on the relevant pages.

* Digest of UK Energy Statistics 2010 - this compendium of official energy data covers in depth energy us in the UK in 2009 and trends in recent years. This publication is referred to as ‘DUKES 2010’ in this report.

* Department of Energy and Climate Change (DECC) 2050 Pathways consultation document issued in 2010 - this document covers many aspects of future energy demand in the UK to 2050 and puts forward forecasts using estimates for energy production and use in existing, emerging and possible technologies. This document is referred to as ‘DECC 2050 Pathways’ in this report.

* Heating and Hot Water Pathways to 2020 a March 2010 publication written by the Heating and Hot Water Taskforce facilitated by the Energy Efficiency Partnership for Homes and documented and edited by Purple Market Research Ltd. This publication provides much data on the UK heat sector and provides trends and assessments of the heating industries capacity to deploy new heating technologies to 2020 and beyond.

Annex 1 Electrolysis

Hydrogen production in offshore wind turbines

This worked example below assesses the energy losses and output benefits of peak-lopping offshore wind farm output to provide hydrogen for the gas network. The analysis is intended as a broad guide until more accurate research data can provide more accurate figures.

The analysis below is partly based on a report entitled: The sufficiency of transmission capacity to accommodate wind farms and manage security of supply (K.R.W. Bell, University of Strathclyde, 2006):

http://www.google.co.uk/search?client=safari&rls=en&q=sufficiency,+beell+strath&ie=UTF-8&oe=UTF-8&redir_esc=&ei=JxP-TdvCM9S38gPAqa2qCQ

The report studies the time distribution of electricity generated, amongst other things, of a total of 99 MW of wind farms dispersed around southern Scotland over a two year period (from April 2003 to March 2005). This report, particularly Figure 3 on page 6, suggests that the percentage of the annual output of a wind farm generated at more than 50 - 60 % of its installed capacity could be relatively small. If this is the case for offshore wind farms (though the wind regime could be much less peaky) then the savings on cable costs may mitigate much of the costs of electrolysers and hydrogen pipelines to shore.

For example, it may be that a HVDC electricity cable link of 50 % of installed capacity of the wind farm may be sufficient to transmit about 75 % of the annual yield.

If so, a 10 GW offshore wind farm cluster (generating 31 TWh/y at 90 % availability or 36 % capacity factor) then a 5 GW HVDC electricity cable would transmit 23.25 TWh/y (ie 75 % of annual output) and 7.75 TWh/y (the 25 % of generation not transmitted) would power electrolysers to generate hydrogen (producing 6.4 TWh/y at 83 % conversion rate). This amount of hydrogen is 20.6 % of annual output and heat losses in electrolysers would be 1.35 TWh/y or 4.3 % of annual wind farm yield.

This hydrogen would be piped ashore and via the gas network supplied to micro-CHP and CHP schemes. It would provide about 5.8 TWh/y of useful energy in fuel cells (2.9 TWh/y of electricity and 2.9 TWh/y of heat).

The wind farm output which would average 360 MW (ie 36 % load factor) would and could not exceed 500 MW and the hydrogen fuel would supply micro-CHP boilers and CHP schemes during times of low or zero winds.

For example, for a 600 TWh/y wind farm output, then 25 % (150 TWh/y of electricity) converted to hydrogen would produce 124 TWh/y of hydrogen and 26 TWh/y losses (or 34 TWh/y losses for 160 TWh/y).

Researchers at Berkley have developed a molybdynum catalyst which works with sea water : http://xinca.com/a-new-electrolysis-catalyst-3050.html

Annex 2 Maximising bio-fuel production and bio-fuel synthesis

The future global cultivation of sustainable biomass feedstocks for bio-fuel production appears likely to be constrained at some level, possibly considerably so (eg by competing requirements for food production, land and water availability). So, maximising the bio-fuel output from the bio-carbon content of the feedstock could be the primary consideration at the bio-refinery, rather than venting bio-carbon dioxide to atmosphere or geological sequestration to reduce dangerous atmospheric carbon dioxide concentrations (ie carbon-negative fuel production see Annex 3). This annex describes why and how bio-fuel production can be maximised per tonne of woody bio-feedstock by using renewable energy or coal (and optionally contaminated residual waste) with CCS. Other yield maximising processes may be applicable for wetter bio-feedstocks such as bio-oil production from algae.

Rationale for maximising bio-fuel production in the 2050 Reference Scenario

The UK fair-share of bio-feedstock is constrained at 320 TWh/y maximum, and it could be much less. From this maximum feedstock this report estimates a 2050 demand for 164 TWh/y of bio-kerosene could be needed for the aviation sector (international and internal), 52 TWh/y of marine bio-diesel (international and coastal) and 5 TWh/y of bio-diesel for rail would possibly be needed in meeting 2050 (international and internal) aviation and shipping demands. A contingency of about 5 % (13 TWh/y) is additional and included for two reasons explained below. Including the 5 % contingency (13 TWh/y of liquid bio-fuel) a total of 234 TWh/y of liquid bio-fuels would be needed.

However, considering the bio-feedstock availability, only 1.37 TWh of feedstock would be available to produce each 1 TWh of bio-kerosene or bio-diesel (ie 320 / 234). At 64 % bio-conversion efficiency 320 TWh/y of bio-feedstock would produce 205 TWh/y of liquid bio-fuels, which is not sufficient to meet the Reference Scenario aviation and shipping demands.

Raising the bio-conversion efficiency using external energy at the refinery to increase conversion of the bio-carbon in the feedstock to bio-fuel (eg from 64 % to 75 %) would enable the production of an additional 35 TWh/y (240 - 205) of fuel. Using the extrapolated fair-share IEA estimates of bio-feedstocks a 75 % bio-conversion efficiency would just be sufficient to meet the 234 TWh/y demand, requiring 312 TWh/y. This would leave about 8 TWh/y of bio-feedstock for other uses (eg farm-scale AD bio-gas schemes and wood-burning CHP schemes and stoves in rural areas away from the gas network).

Techniques and processes to increase bio-fuel production rates

If dry woody bio-energy crops are gasified in oxygen-blown coal gasifiers then the highest proven conversion (energy) efficiency (feedstock input to product output energy) during refining to bio-methane in a methanisation plant is about 75 % (ie conversion of bio-syngas in a methanisation plant). That is, 100 TWh/y of bio-feedstock would yield 75 TWh/y of bio-methane. To convert syngas to hydrogen would require a little more energy and a 70 % conversion efficiency may be achieved (ie conversion of bio-syngas in a water-shift plant). In the production of liquid bio-fuels a bio-conversion efficiency of over 60 % may be achieved (conversion of bio-syngas via Fischer-Tropsch process in a liquefaction plant).

The production of bio-fuels from raw biomass feedstocks begins with the gasification of the feedstock to synthesis gas or bio-syngas (a mixture comprising about 38 % bio-hydrogen, 17 % bio-carbon monoxide and 32 % bio-carbon dioxide) which is then converted to bio-methane in a methanisation plant, or bio-hydrogen in a water-shift plant, or liquid bio-fuels in a Fischer-Tropsch plant.

The first way to increase bio-fuel output is to use external energy sources to drive as many of the bio-refinery processes as possible rather than using some of the bio-syngas itself. Otherwise some syn-gas would need to be diverted away from bio-fuel production to fuel an on-site gas turbine CHP unit (or some of the hydrogen to fuel an on-site fuel cell CHP unit). External sources would include electricity from the Grid to power various pumps, fans and compressors and the oxygen production plant. The oxygen production plant, which produces oxygen for injection into the gasifier, is relatively energy-intensive and could be a proven Air Separation Unit (ASU) device or a more energy-efficient membrane technology which is under development. Hydrogen to provide chemical energy, oxygen (eg as a byproduct of electrolysers) and possibly heat for drying feedstock could also feature.

If the external energy sources are carbon-neutral (eg electricity from wind farms) then the bio-fuel produced would not incur any additional lifecycle carbon emissions (to any incurred in feedstock cultivation and transportation to refinery). Such external supply of ‘green’ electricity, oxygen, hydrogen and heat would energy-efficiently increase bio-fuel output up to a point.

Alternatively, heat energy and black hydrogen from coal could be used, essentially by co-firing the gasifier with coal and biomass feedstock*. The carbon dioxide released by the coal or waste along with a small amount of bio-carbon dioxide could be captured and stored to essentially neutralise the refinery emissions.

The considerable quantities of bio-carbon dioxide in the bio-syngas is separated out and vented in a basic process. This bio-CO2 would essentially be low or carbon-neutral depending on the lifecycle emissions of the bio-feedstock gasified). However, much of this bio-carbon dioxide is captured within the plant and such ‘pre-captured’ carbon dioxide is valuable in itself. Venting to atmosphere represents a loss of value for little benefit. Alternatively, it could also potentially be converted to produce additional bio-fuel, via fuel synthesis, to maximise the fuel productivity of the constrained resource.

Fischer-Tropsch fuel synthesis with co-electrolysis of carbon dioxide

Increasing bio-fuel production could potentially be increased by converting some of the carbon dioxide in the bio-syngas in a process called ‘reverse water-shift’ (also called carbon dioxide hydrogenation) within the Fischer-Tropsch plant.

(REF Fischer-Tropsch synthesis using bio-syngas and CO2 : http://dspace.library.iitb.ac.in/jspui/bitstream/10054/703/1/56456.pdf). Energy would be needed in the form of hydrogen and ‘green’ hydrogen produced by electrolysis using electricity from green sources such as wind and solar PV would be used. The reaction equations for Fischer-Tropsch synthesis using CO2-rich bio-syngas are as follows :

$$CO + 2H_2 \rightarrow -CH_2- + H_2O + 165 \text{ kJ/mol}$$

$$CO_2 + 3H_2 \rightarrow -CH_2- + 2H_2O + 125 \text{ kJ/mol}$$

The CH2 molecules produced would then form long chains of liquid hydrocarbons in the FT reactor vessels. Additional hydrogen may also be added to achieve the optimum hydrogen carbon ratio in the FT vessel. It can be seen that the conversion of carbon dioxide to fuel chain molecules (CH2-) requires more hydrogen and produces more water.

The REF XX (http://sktk.che.itb.ac.id/indarto/book/Chapter-8.pdf) paper estimates that high temperature co-electrolysis in a solid oxide fuel cell with Fischer-Tropsch conversion process may be 58 % efficient and that 45 TWh/y of wind-generated electricity may produce 26 TWh/y (LHV) of bio-kerosene. The co-electrolysis process may become significantly more efficient at high temperature and also a greater ratio of heat to electricity could be used to drive the process. The paper estimates that as much as 67 % of the conversion energy could be heat at 800 Centigrade, up from about 30 % at 25 Centigrade.

As the carbon dioxide would not necessarily have to be separated from the bio-syngas, as it would in the conventional FT process, and more bio-fuel is produced relative to the capital cost invested in the refinery, this process could be cost-competitive. Furthermore, the green hydrogen supplied could come from on-site electrolysers using peak-lopped intermittent electricity from renewable sources, particularly wind. Oxygen produced in the electrolyser could be used to augment the oxygen from the ASU to help blow the gasifer. The heat from the electrolysers might also be utilised improving refinery site energy efficiency even more.

Depending on the economics of bio-feedstock supply and liquid bio-fuel demand, additional amounts of bio-fuel could possibly be synthesised in bio-refineries using the various processes detailed above. To increase the bio-fuel yield from 312 TWh/y of bio-feedstock from, for example 200 TWh/y (at 64 % bio-conversion efficiency), to the 234 TWh/y required (75 % bio-conversion efficiency) would require processes that produce an additional 34 TWh/y (ie 234 - 200). If the co-electrolysis process is 59 % efficient then 58 TWh/y of external energy would be required (ie 34 / 0.59). This report assumes external energy demand of 58 TWh/y for yield maximisation is required to raise bio-conversion efficiency to 75 %. Oxygen and heat produced in electrolysers may reduce this demand.

The Reference Scenarios include a yield maximisation demand of 29 TWh/y at UK based refineries, much of which could be for the co-electrolysis process (see Row 16 Table 8.1).

Not all the carbon dioxide would be converted even at 75 % bio-conversion efficiency and whatever residual emissions did survive could be captured, compressed and stored in geological formations to reduce emissions to atmosphere. So the bio-fuel production would be carbon-negative to some degree.

Carbon efficiency

The ‘carbon’ efficiency (how much bio-carbon in the feedstock is incorporated into the produced fuel) depends on several factors. It depends on the carbon content of the bio-feedstock, the type of fuel produced, the use of external energy to supply the refineries auxiliary processes (ASU, pumps, etc) and in the case of bio-liquids the use of external energy (ie electricity, hydrogen, oxygen, heat) to maximise bio-fuel production by hydrogenating CO2 in the bio-syngas and optimising the hydrogen content of the bio-syngas.

In theory a carbon efficiency of 100% would be achieved if, for example, 1 TWh of woody biomass feedstock (containing about 98.2 ktonnes of bio-carbon) could be part refined, part synthesised to 1.38 TWh of bio-kerosene (containing about 98 ktonnes of bio-carbon) or 1.89 TWh of bio-methane (containing about 98 ktonnes of bio-carbon). However, such a process if it were possible would probably become highly energy-intensive the more bio-carbon dixode in the syngas is converted.

This report assumes that using external energy to supply hydrogenation, co-electrolysis or auxiliary energy demands at the refinery site enables a 75 % bio-conversion efficiency to liquid bio-fuels (bio-kerosene and bio-diesel).

The carbon efficiency of gasifying 1 TWh of woody bio-feedstocks (which contains 98,200 tonnes of bio-carbon which would release 360,000 tonnes of CO2 per 1 TWh if burnt) to 0.75 TWh of bio-methane assuming 75 % conversion (energy) efficiency is **39.6 %** (ie 1 TWh of bio-methane releases 190,100 tonnes CO2 when burnt so 0.75 TWh would release 142,600 tonnes CO2).

The carbon efficiency of gasifying 1 TWh of woody bio-feedstocks (averaging 360,000 tonnes of CO2 per 1 TW if burnt) to 0.65 TWh of liquid bio-fuel assuming 65 % conversion (energy) efficiency were achieved would be **46.9 %** (ie 1 TWh of liquid bio-fuel releases 260,000 tonnes CO2 when burnt, so 0.65 TWh would release 169,000 tonnes CO2).

So the carbon efficiency of gasifying 1 TWh of woody bio-feedstocks (averaging 360,000 tonnes of CO2 per 1 TW if burnt) to 0.75 TWh of liquid bio-fuels assuming 75 % bio-conversion (energy) efficiency would be **54.2 %** (ie 1 TWh of bio-diesel releases 260,000 tonnes CO2 when burnt so 0.75 TWh would release 195,000 tonnes CO2).

The external energy required to achieve 75 % bio-conversion efficiency is accounted for separately in this report and a liquid bio-fuel contingency is also included (13 TWh/y if required). Refineries producing 234 TWh/y of liquid bio-fuel require 58 TWh/y of external energy so the overall energy input would be 370 TWh/y (ie 312 + 58) and the overall energy efficiency would be 63.2 % (ie 234 / 370). If the contingency is required to cover conversion losses then the overall energy efficiency achieved would fall to 59.7 %.

A liquid bio-fuel contingency is included for the following reasons :

i) in case a bio-conversion rate of 75 % (carbon efficiency of 54.2 %, overall energy efficiency of 63 %) cannot be achieved in practice - in which case this energy would be lost in conversion process (and would achieve an overall energy efficiency of just under 60 %)

ii) to cover for, or facilitate, either aviation and shipping demand greater than that forecast in Chapter 2 if a bio-conversion rate of 75 % is achieved

Maximised liquid bio-fuel production in the Reference Scenarios

To produce 164 TWh/y in 2050 of carbon-negative bio-kerosene would require about 218.7 TWh/y of woody feedstock and 70 TWh/y of bio-diesel about 93.3 TWh/y of woody feedstock, totaling 312 TWh/y of woody bio-feedstock which is just within the extrapolated UK fair-share. The improved bio-fuel production from the constrained bio-feedstock supply would require 58 TWh/y of external energy, of which 21 TWh/y of heat may be recoverable from around the refinery site. About 23 TWh/y of external energy would be required to supply the CCS plant demand.

Liquid bio-fuel production from non-woody bio-feedstocks, particularly algae cultivated in desert regions, might predominate in overseas refineries. About half (120 TWh/y) of the Welsh and UK liquid bio-fuel demand is assumed in the Reference Scenarios to be produced abroad because over half the available bio-feedstocks would be cultivated abroad. Of the 120 TWh/y produced for UK consumption abroad, 50 TWh/y is imported to the UK by tanker and 70 TWh/y is distributed to overseas air and seaports.

Improved capture rates per unit energy are being developed and the estimated storage of 45.6 million tonnes per year may be improved on.

Reference Scenarios : the carbon-negative liquid bio-fuel production route detailed above, producing 234 TWh/y of liquid bio-fuels requiring 58 TWh/y of external energy and 23 TWh/y to drive the CCS plant, is used in the 2030 and 2050 Reference Scenarios. The bio-kerosene and bio-diesel would be produced in bio-refineries in the UK and overseas and would be strongly carbon-negative (45.6 mt bio-CO2 in 2050, possibly slightly more).

The bio-feedstock demand would be 312 TWh/y of which about half (116 TWh/y) would be woody feedstocks, would be supplied to UK refineries. Algae and other feedstocks may predominate in overseas refineries. The bio-conversion losses (at 75 %) in the UK would be 39 TWh/y with an assumed possible heat recovery rate of between 25 % to 33 % or 10.5 TWh/y (27 %). External energy demand would be 29 TWh/y and the CCS plant demand of 11.5 TWh/y. These figures are listed in Table 8.1.

About 23 mt bio-CO2 would be captured and stored from UK refineries and the remaining 23 mt bio-CO2 would be captured and stored from refineries abroad and the carbon-negative emissions allocated to the UK (assuming the necessary inventory allocations and payments are made). For Wales the carbon-negative production would amount to about 2.3 million tonnes of CO2 per year.

Note : if shipping, other bio-feedstocks, and the contingency amounting to 70 TWh/y at UK level were used to produce bio-methane or bio-hydrogen for shipping and the gas network the amount of bio-CO2 which could be captured and stored would be 18.2 mt bio-CO2/y or 30.1 mt bio-CO2/y respectively. Aviation demand of 164 TWh/y would enable the capture and storage of 32 mt bio-CO2 per year. So if shipping and all rail fully converted to non-bio low-carbon fuels then 50-60 million tonnes of bio-carbon dioxide could be sequestrated per year by 2050. This would amount to about 2.5-3 million tonnes bio-carbon dioxide per year for Wales.

Annex 3

Carbon-negative energy generation

The carbon-negative potential of various bio-fuels produced in CCS-fitted bio-refineries depends on the bio-carbon content of the feedstock and the conversion efficiency achieved. Due to a constrained bio-feedstock resource the bio-fuel production efficiency is maximised using various techniques in this report, rather than maximising the carbon-negativity of the fuel. See Annex 2 for more detail about maximising bio-fuel production from constrained bio-feedstocks using fuel synthesis (including carbon dioxide co-electrolysis and hydrogenation within the Fischer-Tropsch process).

Carbon-negative fuel production

In the refinery process the bio-carbon in the feedstock not turned into bio-fuel converts to bio-carbon dioxide. About a third of the bio-syngas output from a gasifier would be bio-carbon dioxide and more would be produced in downstream processes. Most if not all of this bio-carbon dioxide is produced within parts of the plant where it is essentially pre-captured. So, it would be relatively easy and energy efficient to capture and compress this gas for subsequent storage in geological formations. For example, a bio-refinery in north Wales could use storage sites under the Irish Sea or Liverpool Bay.

As the carbon dioxide would be essentially from biological sources (ie bio-carbon dioxide) the life-cycle emissions of the produced fuel become ‘carbon-negative’ to some degree. This is because bio-carbon dioxide has been extracted from atmosphere by the crop and the CCS refinery would have stored much of that bio-carbon dioxide under the sea-bed (so it has been removed permanently from air).

Some residual bio-carbon dioxide emissions from the feedstock would be released by the refinery. Typically about 90 % of the emissions are captured and stored and 10 % released. The remaining bio-carbon is locked within the bio-fuel until it is burnt (oxidised) to bio-carbon dioxide and released to atmosphere when the fuel is finally used in aircraft turbines, ships engines and CHP boilers, etc.

The actual emissions released when the fuel is finally combusted in ships’ turbines, aircraft engines or fuel cell boilers would be carbon-neutral. However, the additional costs of the CCS plant and its energy consumption would be recouped by selling the carbon credits for the bio-carbon dioxide stored. The value of the credit will be dependent on future carbon prices and climate protection policies which would reflect the seriousness of the climate crisis.

The carbon-negative ‘credit’ of a fuel would vary from fuel to fuel, refinery to refinery and crop to crop. The precise credit can be closely calculated by metering the carbon-dioxide stored. The approximate maximum carbon-negative credit for different fuel types are shown in the Table A3 below which summarises the three worked examples below.

The bio-carbon content and bio-carbon dioxide emissions from various crops and derived fuels are :

Coal (average)	25.4 tonnes carbon / TJ	releases	335,300	tonnes CO2 per TWh when burnt
Diesel oil	19.9 tonnes carbon / TJ		262,700	tonnes CO2 per TWh
Bio-diesel	19.7 tonnes carbon / TJ		260,000	tonnes CO2 per TWh
Natural Gas	14.4 tonnes carbon / TJ		190,100	tonnes CO2 per TWh
Woody biomass	28.0 tonnes carbon / TJ		369,600	tonnes CO2 per TWh

Agri residues 26.0 tonnes carbon / TJ 343,200 tonnes CO_2 per TWh

Table A1 below summarises the carbon-negative potential of bio-fuels produced in CCS bio-refineries assuming bio-conversion rates of 75 % and assuming 90 % capture rates (see worked examples below).

Table A1

Fuel produced in CCS bio-refinery	Carbon negative emissions of bio-derived fuel	Carbon positive emissions of fossil / wood equivalent
Bio-diesel / kerosene	upto MINUS 195,000 tonnes /TWh	+ 263,000 tonnes / TWh
Bio-hydrogen	upto MINUS 430,000 tonnes /TWh	+ 360,000 tonnes / TWh (wood)
Bio-methane	upto MINUS 260,000 tonnes /TWh	+ 190,000 tonnes / TWh

Bio-kerosene / bio-diesel - Worked example 1

Dry woody energy crop would be converted to bio-diesel / bio-kerosene at 75 % bio-conversion efficiency with external energy inputs (to minimise bio-syngas diversion to supply on-site power generation and for bio-CO_2 hydrogenation in the FT process). This bio-conversion rate would need to be demonstrated in gasifiers and FT plant capable of gasifying 100 % woody bio-feedstocks.

A maximum rate of 75 % bio-conversion is assumed for the purposes of this report, compared to 65 % or lower if no external energy is supplied. The CCS energy requirement is estimated in Annex 4 to be 0.5 TWh per 1mt CO_2 captured and sequestrated.

100 TWh of energy crops (having a C content of 36 mt CO_2 ie 100 x 0.36) produces 75 TWh of liquid bio-fuel (containing 19.72 mt CO_2 ie 75 x 0.263 mt). So the conversion process produces 16.27 mt CO_2 (36 - 19.72) within the gasifier / Fischer-Tropsch plant. Of this 14.65 mt CO_2 (at 90 %) could be captured and stored. The energy required to store 14.65 mt CO_2 would be 7.32 TWh/y (of external energy at 0.5 TWh per 1 mt CO_2).

So for every 1 TWh of liquid bio-fuel produced the CO_2 stored would amount to 0.195 mt CO_2 (ie 14.65 / 75).

So the specific emissions of liquid bio-fuels (from a CCS refinery) could be upto about MINUS 195,000 tonnes CO_2 per TWh of bio-fuel produced.

It is assumed in this report that 100 TWh of crops (primary input) would require in the region of 18.5 TWh of external energy (ie 100 x 58/312) at most to raise the bio-conversion efficiency to 75 % from around 60 - 65 %. That is, there would be net loss of 8.5 TWh to raise the yield 10 TWh/y to 75 TWh of bio diesel or bio-kerosene. This is a first approximation for external energy demand and schemes would need to be developed and optimised before accurate figures could be ascertained.

The CO_2 which could be captured would amount to 45.6 mt bio-CO_2 and the energy required by the CCS plant to store all this amount would be 22.8 TWh/y. The external energy and CCS energy required (from renewable sources) would consequently be 81 TWh/y (58 + 22.8).

Heat recovery from bio-refinery sites

There may be considerable potential to recover heat from around bio-refinery sites for use, for adjacent industrial processes or, via heat grids, district heat schemes. A first estimate of a practical heat recovery rate from the various heat sources around a gasifier / refinery site could be between 25 % to 33 % of the bio-conversion losses (excluding any external energy used). A heat recovery rate of 27 % is assumed for the purposes of this report.

In the 100 TWh/y example the bio-conversion losses would amount to 25 TWh/y (ie 75 / 3). So heat recovery around the refinery site might yield 6.75 TWh/y (ie 25 x 0.27). So net conversion losses may be 18.25 TWh/y (ie 25 - 6.75).

In summary, it would require 100 TWh of woody feedstock + 18.5 TWh/y of external energy + 7.32 TWh/y for CCS to produce 75 TWh of strongly carbon-negative bio-kerosene or bio-diesel. Refinery site heat recovery might reduce heat losses to 18.25 TWh/y.

Bio-hydrogen - Worked example 2 : dry woody energy crop are converted to bio-hydrogen at 75 % conversion efficiency in CCS-fitted gasifier using external energy to maximise bio-hydrogen production (estimated CCS energy demand of 0.5 TWh per 1 mt CO2 stored at a capture rate of 90 %).

1 TWh of bio-feedstock (dry woody) would yield 0.75 TWh of bio-hydrogen.

100 TWh of energy crops having a bio-carbon content equivalent to 36 mt bio-CO2 (100 x 0.36 mt) produces 75 TWh of hydrogen and generates the bio-carbon equivalent of 36 mt CO2 within the gasifier / water-shift / CCS plant. Following the water-shift conversion of the carbon monoxide to carbon dioxide, 36 mt bio-CO2 is produced, of which about 90 % would be captured and stored. So 32.4 mt bio-CO2 is stored and 3.6 mt bio-CO2 released to atmosphere (carbon-neutral). So for every 1 TWh of bio-hydrogen produced the CO2 stored would amount to 0.43 mt CO2 (32.4/ 75).

So the specific emissions of bio-hydrogen (from a CCS refinery) could be upto MINUS 430,000 tonnes CO2 per TWh or upto about MINUS 430 grammes per kWh.

The external energy required to raise bio-conversion rate from 70 % to 75 % would be in the order of 9 TWh/y per 100 TWh of feedstock (ie net loss of 4 TWh) or and the CCS energy demand would be 16.2 TWh per (100 TWh of bio-feedstock), totaling 23.7 TWh. This is a significant external demand for the production of 75 TWh of strongly carbon-negative hydrogen (up to 0.31 TWh per TWh of hydrogen produced), though any level of capture and storage can be applied to reduce either average or peak electricity demands (any releases to atmosphere are bio-CO2 and essentially carbon-neutral).

Note that the CCS energy demand is much higher for carbon-negative hydrogen production because there is no carbon content in the hydrogen fuel. Most is captured and stored so the carbon-negative credit of hydrogen can be larger than the hydro bio-carbon fuels.

The carbon-negative potential in the production of 160-220 TWh/y of bio-hydrogen should sustainable bio-feedstocks were available (eg synthetic fuels being cost-effective and available) would be a considerable 69-95 mt CO2 (see para 3.73).

Bio-methane - Worked example 3 : dry woody energy crops are converted to bio-methane at 75 % conversion efficiency in CCS-fitted bio-gasifier (estimated CCS storage energy requirement of 0.5 TWh per mt CO2 sequestrated):

100 TWh of energy crops having a 'carbon' content of 36 mt CO2 (ie 100 x 0.36 mt CO2) are converted to 75 TWh of bio-methane containing 14.25 mt CO2 (ie 75 x 0.19 mt). The gasification / methanisation produces 21.75 mt CO2 in the gasifier/ methaniser /CCS plant (ie 36 - 14.25) which is available for capture. Of this 19.57 mt CO2 (at 90 %) could be captured and stored and 2.2 mt bio-CO2 would be released to atmosphere (carbon-neutral).

So for every 1 TWh of bio-methane produced the CO2 stored would amount to some 0.26 mt CO2 (19.57 / 75).

To store 19.6 mt CO2 would require 9.8 TWh to power the CCS plant. This CCS plant energy demand, and the energy required to power the auxiliary processes at the gasifier site, would be provided from external sources if the amount of bio-methane produced needs to be maximised (as it does in the Reference Scenarios due to bio-feedstock constraints). This avoids using some of the syn-gas itself to supply the on-site power demands. However, the carbon-negativity of the bio-methane could be maximised by using syn-gas to supply the on-site energy demands and capturing and storing the bio-carbon dioxide released.

Maximising carbon-negativity of bio-methane output :

Either external green energy could be used as in the example above which maximises bio-methane output, or some of the syn-gas or bio-methane itself could be used to maximise the carbon-negative value. Some of the syn-gas or bio-methane (burnt in gas turbine or fuel cell) would be used to supply the auxiliary refinery processes and CCS plant. The emissions from the gas turbine or fuel cell would also be captured requiring a smaller amount of additional energy.

Burning 9.8 TWh of bio-methane would produce 1.86 mtCO2 of which 1.67 mt would be stored (requiring a further 0.84 TWh of energy at the CCS plant).

The bio-methane produced would be 75 - 9.8 - 0.84 = 64.36 TWh (after 10.64 TWh of CCS energy subtracted)
The bio-CO2 stored would be 19.57 + 1.67 = 21.24 mt bio-CO2 stored

So for every 1 TWh of bio-methane produced the CO2 stored would amount to some 0.33 mt CO2 (21.24 / 64.36).

In practice some efficiency losses in the gas turbine would result in less bio-methane availability and higher emissions to air (or further capture). A 20 % energy loss in the turbine/fuel cell would reduce output by about 2 TWh. So a more practical carbon-negative value may be around 0.34 mt per TWh of bio-methane (21.24 / 62.36). Note : the carbon-negativity rises due to efficiency loss in energy provision to CCS plant. However, more of a constrained biomass resource is lost in conversion.

Future demand for carbon negative fuels

Some ‘carbon-negative’ fuels (ie carbon-neutral fuels produced in carbon-negative processes) may be required to achieve climate policy objectives. Indeed, most intermittent renewables, nuclear and fossil fueled CCS technologies are low-carbon rather than carbon-neutral. Most such technologies will have so-called ‘specific emissions’ of between 10-90 ppm / kWh of electricity, though if powering a heat pump the emissions would fall by a factor of three. Such emission levels may still be too high if the adverse effects of climate change have been underestimated or the international response is slower than that required. So, it is useful when considering choice of fuels in system integration and infrastructure deployment and transport systems to consider the potential ‘carbon-negative’ capability.

The best example is bio-hydrogen produced in a CCS-fitted bio-gasifier could be highly carbon-negative, at over 0.4 million tonnes of carbon dioxide per TWh consumed. Bio-hydrogen could be used in highly electrically efficient fuel-cell powered HGV’s, ships, micro-CHP boilers and CHP schemes of all sizes and hydrogen could eventually be used to power aircraft.

The amount and type of bio-feedstocks is key as most carbon-negative fuels will require some degree of atmospheric carbon dioxide sequestration in geological formations. Producing bio-kerosine for aviation will consume much of the likely global resource, and about 70 % of Wales’s 16 TWh/y fair-share of estimated global sustainable bio-feedstock cultivation.

If anything like such levels of sustainable bio-energy resources are not available, and there may not be, then there are other low-carbon, carbon-zero and carbon-negative options for fueling some or all the UK energy generating infrastructure and transport systems be they aviation, shipping, HGVs and gas network :

* fossil sources blended with bio-sources - (natural gas, conventional oil) may continue to be used for longer if available and within climate policy
* hydrogen - derived from mainly fossil sources with CCS (coal co-gasified with 10 % biomass would achieve carbon-zero hydrogen), or renewable sources via water electrolysis, could also be used eventually in future aircraft engines
* synthetic renewable hydro bio-carbon fuels - can be manufactured in relatively energy-intensive chemical processes, by capturing carbon dioxide from what biological sources are sustainable (eg food waste or directly from air), and combining it with hydrogen over a catalyst. Synthetic manufacture may require nearly 3 TWh of electricity and heat to produce 1TWh of aviation fuel or diesel fuel. Such fuels would be highly carbon-negative
* ammonia - this zero-carbon fuel, of which there is little public awareness, is routinely manufactured, piped long distances and used within the chemicals industry. Ammonia, which releases only nitrogen and water when combusted, is a liquid of half the energy-density of diesel fuel, could potentially be used particularly as a marine fuel or in specialist applications
* dimethyl ether (DME), similar to bio-diesel (ie carbon-containing)

Conventional, and for that matter unconventional fossil sources could be used, with CCS and without co-firing, if available and climate policies allowed their use at whatever scale. Hydrogen produced by the gasification of coal in a CCS-fitted gasifier or by underground coal gasification with CCS, would be available to coal-bearing countries including Wales and the UK, and would release relatively small residual carbon dioxide emissions to atmosphere. Fossil fuels from some sources could have adverse environmental impacts which should preclude their use.

Hydrogen, which only produces water when combusted, can also be produced by the electrolysis of water including seawater using renewable electricity. Electrolysis can be used to help manage the intermittent output from renewable energy schemes. For example, by using just the unwanted peaks in intermittent output for electrolysis (called peak-lopping) produces hydrogen for subsequent electricity and heat generation in fuel cells when intermittent output is low.

Ships and HGVs could switch to such black or green hydrogen fuel and be propelled by fuel cell electric motors. The UK gas network or parts of it could increasingly use mixes of hydrogen and methane as was the case with ‘coal gas’ (http://en.wikipedia.org/wiki/Coal_gas) before the UK switched to North Sea natural gas (100 % methane) in the late 1960s. Coal gas had a hydrogen content of about 50 %. Coal gas also contained methane (typically 35 %) and highly toxic carbon monoxide (typically 10 %). Note that there is absolutely no suggestion from any quarter that carbon monoxide should ever be used again.

This report estimates a 2050 demand for up to about 164 TWh/y of bio-aviation fuel (international share and internal demand), of which 120 TWh/y would be supplied through UK airports as currently. The fuel would preferably be 100 % bio-derived if sustainable sources are available but could include fossil or synthetic if required, available or affordable considering the energy-intensive synthesis process. Bio-aviation fuel for distribution to UK airports and military bases could be either imported as a produced fuel or imported as raw (primary) biomass feedstock to UK bio-refineries along with any indigenous sources.

The conversion process in current bio-refinery technology, depending on the biomass feed-stock is estimated at about 64-71 % efficient (eg gasification / Fischer-Tropsch, page 162 DECC 2050 Pathways). So, to produce 164 TWh/y of bio-kerosene (JET A) could require some 225-250 TWh/y of primary biomass. This report assumes 75 % bio-conversion efficiency may be achieved by 2030 by using external energy to power as many refinery processes as possible and green hydrogen is added to hydrogenate some of the bio-carbon dioxide contained in the bio-syngas within the Fischer-Tropsch plant (see Annex 2). Bio-methane can be produced at 75 % conversion efficiency without external energy inputs in the ‘BGL’ slagging gasifier and methanisation unit.

If the bio-kerosene were produced in CCS-fitted bio-gasifiers (ie 100 % biomass gasifiers) then most of the bio-CO2 emissions produced in the conversion process could be captured and sequestered. Aviation demand of 164 TWh/y would enable the capture and storage of 32 mt bio-CO2 per year. Consequently, the bio-kerosene could have a considerable ‘carbon-negative’ credit although the actual aircraft emissions would be carbon-neutral. The carbon-negative emissions credit and the marginal additional CCS costs required to pay for the CCS energy demand would presumably be a reasonable price to help pay and account for the additional climate warming effect of high altitude aircraft emissions (eg water vapour).

In 2050, about 45 TWh/y of marine bio-diesel or green-hydrogen would be needed to achieve a low-carbon UK share of international shipping and a further 7 TWh/y for coastal shipping. Around 5 TWh/y of bio-diesel could be needed for trains providing services on branch lines. As with aviation fuel, the marine diesel distributed to UK ports could be imported either as produced fuel or as imported as feedstock for UK bio-refineries and included with indigenous biomass sources. Again, refineries in the UK or abroad, could be fitted with CCS to provide the option of a carbon-negative credit and premium on the bio-diesel fuel.

Though bio-diesel powered shipping is assumed in the Reference Scenarios, trials of hydrogen-powered ships are underway and a significant switch to hydrogen and fuel cell / electric propulsion could take place. LNG tankers also use the boil-off methane from the tanks to power the vessel so a switch to bio-methane is also technically possible.

Carbon-negative energy generation in the Reference Scenarios

The carbon-negative liquid bio-fuel production route detailed in Annex 2, producing 234 TWh/y of liquid bio-fuels requiring 58 TWh/y of external energy and 23 TWh/y to drive the CCS plant, is used in the 2030 and 2050 Reference Scenarios in Table 8.1. The bio-kerosene and bio-diesel produced would be strongly carbon-negative (45.6 mt bio-CO2 in 2050, possibly slightly more). The woody bio-feedstock demand would be 312 TWh/y. The conversion losses (at 75 %) would be 78 TWh/y with an assumed possible heat recovery rate of between 25 % to 33 % or 21 TWh/y (27 %). For Wales the carbon-negative production would amount to about 2.3 million tonnes of CO2 per year.

Improved capture rates (above 90 % used in this report) per unit energy are being developed and the estimated storage of 45.6 million tonnes per year may be improved on.

If all UK (and most global) shipping, and all rail services switched to hydrogen or other fuels not containing bio-carbon then up to 70 TWh per year of bio-feedstocks would be available (including the contingency) for producing bio-hydrogen or possibly bio-methane for the gas network and indeed shipping. The amount of bio-CO2 which could then be captured and stored would rise from 13.6 mt CO2 per year (for bio-diesel) up to 30.1 mt bio-CO2 per year (for bio-hydrogen) or up to 18.2 mt bio-CO2 per year (for bio-methane). Aviation demand of 164 TWh/y would enable the capture and storage of 32 mt bio-CO2 per year.

So if UK shipping and all rail fully converted to non-bio low-carbon fuels then around 50-60 million tonnes of bio-carbon dioxide could be sequestrated per year by 2050. This would amount to about 2.5-3 million tonnes bio-carbon dioxide per year for Wales. Taking account of agricultural emissions of around 40 mt CO2/y the net UK carbon-negative emissions may rise from a few million tonnes to 20 million tonnes per year by 2050, or 1 million tonnes carbon-negative per year at Wales level.

Annex 4 Energy required to capture and store 1 tonne of carbon dioxide

Different bio-energy feedstocks have different carbon contents to each other (per TWh of primary energy content) and considerably higher than that of typical coal sources. It is useful to understand how much electricity and heat energy is needed to capture and store the released CO_2 from bio-energy or coal (expressed in TWh of energy per tonne Mt CO_2 captured and stored) in this report. The figure is estimated below, based on a typical modern gasifying coal / biomass power station with CCS (Integrated Gasification and Combined Cycle - IGCC).

Capturing carbon dioxide from power station flue gases typically requires a heat driven chemical (amine) process to absorb and release the carbon dioxide and an electrically driven compression process to compress the carbon dioxide captured up to about 150 Bar (atmospheres) to enable pipeline transport and injection into suitable porous geological formations (which requires high pressure). The energy required to power the CCS process accounts for 20 % of a gasification power station electrical output. Roughly half of this is required as electricity to drive various pumps and the compressors and about half is steam at over 100 Centigrade taken from before the low pressure turbine. The amount of steam required to lower electrical output by 10 % could be roughly twice to three times the electrical energy loss.

An unabated coal gasifying power station at 45 % electrical efficiency will require a coal energy input of 2.22 times (100 / 45) the electrical output generated. In other words, for every 1 TWh of electricity 2.22 TWh of coal and biomass energy is required.

A typical coal containing 1 TWh of primary energy releases about 335,000 tonnes of CO_2 per when combusted. This means that generating 1 TWh of electricity would result in the release of 0.744 Mt CO_2 (335,000 x 2.22). The specific emissions of such an unabated power station is usually expressed as 744 grams/kWh (0.75 Mt/TWh). Therefore, a power station generating 5 TWh of electricity would release 3.75 Mt CO_2 (0.75 x 5).

Assuming the energy requirements of the CCS plant lowers electricity output by 20 % (for 90 % capture) the following conclusions can be extrapolated:
The abated power station would lose 1 TWh of electricity due to the CCS plant (i.e. 20 % of 5 TWh) to capture 3.37 $MtCO_2$ (3.75 x 0.9).

Therefore, it requires 1 TWh of electricity output (as distinct to steam) to capture and store 3.37 $MtCO_2$. However the thermal energy required to generate 0.5 TWh of electricity may be 1-1.5 TWh
As a result, this report assumes the amount of energy required to power the CCS plant to be 1.75 TWh (0.5 + 1.25) TWh/y per 3.37 $MtCO_2$ captured at a 90 % capture rate.

So energy required to capture and store 1 mtCO2 from coal gasifier could be about 0.5 TWh
This rate can fairly accurately be applied to carbon emissions produced by biomass gasification in the same gasifier

Annex 5 Heat pump system efficiency Coefficient of Performance 3.5

Future heat pump system efficiency improvements (CoP 3.5)

Developments heat pump systems may improve their system efficiency over the years. This could include inter-seasonal re-charge /storage for GSHPs, and fuel cell exhaust hot air re-couperation in air-source and ground-source systems. If improvements achieved an annual system CoP of 3.5 then it would have the following effects on the mid-level heat pump deployment. About 163 TWh/y of renewable heat could potentially be harnessed (up by 12 TWh/y from 151 TWh/y at CoP 3). The gas demand would fall by just 5 TWh/y from 139 TWh/y (at CoP 3) to 134 TWh/y. Grid electricity demand would fall by 8 TWh/y from 147 TWh/y to 139 TWh/y at CoP 3.

Infrastructure Scenario 1	**Heating system CoP 3.5**	**Time : 50 % Grid / 50 % CHP**
Heat need TWh/y		**Grid + (HP) + (mCHP e + th) + loss**
Urban 142 (132)	mCHP, few heat pumps	66 + 0 + (33 + 33) + 7
Suburban 158 (144)	mCHP + heat pumps	20 + (52 + 40)+ (16 + 16)+ 3
Rural 108 (100)	heat pumps, little CHP	29 + 71
New 52 (48)	mostly mCHP	24 + 0 + (12 + 12) + 2
Total 460 (424)		139 + 163 + 61 + 61 plus 12 losses
Heat pumps 163 TWh/y	Grid 139 TWh/y	Gas demand 134 TWh/y (inc 12 TWh/y loss)

Annex 6 Hydrogen production in co-fired coal CCS gasifiers

Hydrogen production via biomass and coal gasification is assumed to have a conversion efficiency (energy efficiency) of about 70 % in a basic gasification process (70 % probable for BGL slagging-gasifier - REF ?). By supplying external energy to obviate any diversion of syn-gas for auxiliary energy generation it is assumed in this report that conversion efficiency of 75 % can be achieved. A 75 % conversion rate has been achieved for methane production by a BGL slagging gasifier / methanisation plant - REF ?). Whether even higher rates could be physically or economically achieved would require demonstration.

The external green energy required to avoid syn-gas diversion would comprise an amount to power the on-site auxiliary processes plus the additional water-shift and clean-up processes for the additional hydrogen production plus CCS energy required to capture and store the 90 % of carbon dioxide released.

Accurate energy demand figures to achieve this higher conversion rate would need to be demonstrated in practice in commercial gasifiers and water-shift plants. For the purposes of this report an approximation is made as follows.

The worked example below shows how a hydrogen supply of 160 TWh/y could be provided by 80 TWh/y of biomass co-fired with 133 TWh/y of coal in CCS gasifiers, and would result in NEGATIVE emissions of 19.6 million tonnes of CO2.

Conversion efficiency assumed to be 75 % in BGL gasifier/water shift plant or similar gasifier plant.
The CCS energy penalty 0.5 TWh per mtCO2 stored (see Annex 4).

To produce 160 TWh/y of hydrogen would require a fuel input of 213 TWh/y (ie 160 / 75). The conversion losses would be 53 TWh/y (ie 213 - 160).

The fuel input in this case would comprise 80 TWh/y woody bio-feedstock + 133 TWh/y coal.
The carbon dioxide content / balance would be :
80 x 0.36 + 133 x 0.335 = 28.8 + 44.5 = 73.4 mt CO2 produced in gasifier/water-shift plant

Of the 73.4 mt CO2 produced 66 mt would be stored and 7.4 mt released. The process would be 21.4 mt CO2 (ie 28.8 - 7.4) carbon-negative.

To achieve a 75 % conversion rate would probably require about half the external energy required for liquid bio-fuel maximisation (58 TWh per 312 TWh of feedstock). So about 19.5 TWh may be needed (ie 58/2 x 213/312 The additional hydrogen energy produced would be about 11 TWh (ie 213 x 0.05).

The CCS plant demand to capture and store 66 mt CO2 is 33 TWh/y.

Heat recovery from bio-refinery sites

There may be considerable potential to recover heat from around bio-refinery sites for use, for adjacent industrial processes or, via heat grids, district heat schemes. A first estimate of a practical heat recovery rate from the various heat sources around a gasifier / refinery site could be 25% to 33 % of the bio-conversion losses (excluding any external energy used). A heat recovery rate of 27% is assumed for the purposes of this report. Higher rates of heat recovery would need to be demonstrated and lower rates might also only be achieved in practice.

In this example heat recovery would be about 14.5 TWh/y (ie [213-160] x 0.27).

So energy balance would be :

80 TWh/y bio + 133 TWh/y coal + 19.5 TWh/y external (yield) + 33 TWh/y external (for CCS) = 160 TWh/y of carbon-zero hydrogen + 14.5 TWh/y heat recovery + 91 TWh/y CCS refinery losses

Final refinery conversion losses would be about 43.5 TWh/y (ie 91 - 33 - 14.5) in this example.

The specific emissions associated with the hydrogen would be MINUS 134 g/kWh (134,000 tonnes per TWh) if 80 TWh/y were available for co-firing. The UK building stock would become carbon-negative rather than carbon-neutral given that all other energy uses in buildings would be very low carbon by 2050.

The co-firing rate in this case is 38 % (80 / 213) and the overall CCS refinery conversion efficiency is 57.5 % including external inputs, CCS losses and heat recovery (174.5 / 304).
The thermal energy content of coal is 6.67 kWh/kg or 6.67 TWh per megatonne. So 133 TWh/y of energy from coal would require 20 million tonnes of coal. This amount would be about 40 % of current coal consumption. UK coal consumption in 2009 was about 49 million tonnes of which 38.3 million tonnes were imported and 17.3 million tonnes were mined in the UK (including stock-build).

Lowest co-firing rate to produce 160 TWh/y carbon-zero hydrogen

Co-firing 20 TWh/y of bio-feedstock with 193 TWh/y coal would produce 160 TWh/y of hydrogen at net carbon zero emissions. This is just a 9.5 % co-gasification rate (20 / 213).

20 TWh x 0.36 mt/TWh + 193 TWh x 0.335 mt/TWh = 7.2 mt bioCO_2 + 64.7 CO_2 = 71.9 mt CO_2 of which 64.7 mt is captured (at 90 %) and stored and 7.2 mt released (which equals the amount of bio-CO_2 produced hence carbon-zero).

The external energy needed to improve yield to 75 % would be about 19.8 TWh (58/2 x 213/312) + the CCS energy (estimated in Annex 4 to be about 0.5 TWh per mt CO_2 stored). The CCS plant would require 32.3 TWh/y.

So energy needed to drive 160 TWh/y bio-hydrogen production in CCS gasifier at 75 % conversion rate would be in the order of 52 TWh/y (ie 19.8 + 32.3). There could be scope to recovery various heat losses for CHP schemes etc and 27 % of conversion losses is assumed in this report, or 14.5 TWh/y (ie [213-160] x 0.27).

So energy balance is :

**20 TWh/y bio + 193 TWh/y coal + 19.5 TWh/y external + 32.5 TWh/y CCS =
160 TWh/y of carbon-zero hydrogen + 14.5 TWh/y heat recovery + 90.5 TWh/y final refinery losses**

Annex 7 Bio-kerosene production in co-fired coal CCS refineries

Bio-kerosene production (gasifier with CCS) is assumed to have a conversion efficiency of 75 % (up from 65 % or less) using external energy to avoid bio-syngas diversion and to enable bio-CO2 hydrogenation. Additional energy would also required by a CCS plant to capture most of the carbon dioxide produced in the refinery processes for compression and subsequent transport and storage (at 90 % rate).

Note that a refinery producing liquid bio-fuels needs less energy for CCS as much of the bio-carbon is contained in the fuel (a hydro-bio-carbon fuel) which is not the case with hydrogen production. Green energy would comprise, renewable electricity, and green hydrogen, oxygen and heat from on-site electrolysers.

If there were not the desired amount of bio-feedstock or green energy available then coal could provide some of the required energy. By 2030 co-fired liquid bio-fuel production may be the more likely option for these reasons. The 2030 Reference Scenario assumes 82 TWh/y of bio-kerosene would be supplied and the worked example below shows how this could be produced in a coal co-fired CCS gasifier at net carbon-zero emissions. By 2050 the bio-kerosene demand is assumed to have doubled to 164 TWh/y.

The practical maximum co-gasification rate guaranteed in, for example, BGL gasifiers* requires at least 40 % coal (by energy content). So co-firing with dry woody biomass at 60 % (by energy) would achieve as low emissions as possible from the refinery. To produce 82 TWh/y of bio-kerosene at a conversion rate of 75 % would require 109 TWh/y of fuel input (comprising 65 TWh/y of dry woody feedstock + 44.5 TWh/y coal).

The 82 TWh/y of bio-kerosene would release 21.3 mt CO2 when burnt in jet engines (ie 1TWh > 0.26 Mt).

44.5 TWh of coal x 0.335 mt/TWh + 65 TWh of biomass x 0.36 mt/TWh = carbon dioxide content
14.9 + 23.4 = 38.3 mt CO2 content of which 21.3 mt is eventually released from fuel

So 17 Mt CO2 is produced in the refinery of which 15.3 is captured (at 90%) and 1.7 Mt is released
The carbon dioxide content released to atmosphere = 21.3 + 1.7 = 23 Mt out of 23.4 Mt in bio-feedstock.

So, coincidentally, carbon-neutral bio-kerosene production would essentially be achieved at 60 % co-firing of dry woody biomass in a BGL gasifier (which is its current maximum guaranteed co-firing rate). If this preliminary estimation is accurate then to produce all 164 TWh/y in 2050 of bio-kerosene demand in biomass co-fired coal CCS refineries would require about 130 TWh/y of dry woody bio-feedstock. This would be about 60 % of the amount (220 TWh/y) used in the 2050 Reference Scenario.

The external energy required at the gasifier site will be the energy required to raise the bio-conversion efficiency to 75 % would be about 20.26 TWh/y (58 x 109/312) TWh/y + the CCS energy required to store 15.3 mt CO2 (7.65 TWh/y). Heat recovery around the refinery site could be about 27 % of the bio-conversion losses or in this example 7.5 TWh/y (ie [109 - 82] x 0.27) as hot water for CHP schemes. The overall conversion efficiency would be 63 % (excluding heat recovery and CCS) and would require 20.5 TWh/y to increase liquid bio-fuel productivity by 11 TWh/y.

So energy balance is :
65 TWh/y bio + 44.5 TWh/y coal + 20.5 TWh/y external + 7.5 TWh/y CCS = 137.5 TWh/y (input) = 82 TWh/y carbon-zero bio-kerosene + 7.5 TWh/y CHP heat + 48 TWh/y final refinery losses

* as well as clean dry woody bio-feedstocks, contaminated bio-wastes could also be co-gasified particularly in slagging gasifiers (eg the highly efficient British Gas-Lurgi design proven in the 1990s). The very high operational temperatures achieved in slagging gasifiers (over 1,200 Centigrade), due to the high energy content of coal, destroys organic toxins and heavy metal toxins are entrapped within an unleachable vitrified or glassy slag.

Minimal biomass scenario

For various reasons anything like the future global bio-energy feedstock or a sustainable fair-share (estimated in this report from UN figures to be 320 TWh/y and 16 TWh/y for UK and Wales respectively) may not be available. If this situation looked like arising then timely policies and infrastructure deployment could enable all shipping (international share and coastal) and HGV's and other heavy vehicles to progressively switch to either hydrogen, ammonia or other fuels not containing bio-carbon from bio-carbon feedstocks (other than fuels synthesised from carbon dioxide captured directly from air).

Aviation would be the last and most difficult sector to de-carbonise if bio-feedstocks were highly constrained. Other than fuel synthesis using bio-carbon dioxide captured directly from air (which is technically entirely possible) the minimum amount of bio-feedstock needed to enable the carbon-neutral production of bio-kerosene would be that co-gasified with coal in CCS refineries with external energy inputs powering as many auxiliary processes as possible.
The worked example above suggests that the minimum amount of bio-feedstock to meet 2050 aviation demand of 164 TWh/y would be about 130 TWh/y of woody materials, possibly including any arisings of contaminated bio-waste. Below that bio-feedstock level increasing fuel costs and air fares would reduce aviation demand and at some point synthetic bio-kerosene wold probably become cost-effective.

Annex 8 Carbon-negative energy generation at global scale

The 2050 Reference Scenario indicates that Wales and the UK could possibly achieve some level of net carbon-negative emissions by 2050. Between 2-20 million tonnes per year might be achieved by BECCS in the Reference Scenario at UK level after agricultural sector emissions of around 40 mt CO2 per year , and any other greenhouse gas emissions, were subtracted. This would be a carbon-negative storage rate up to 0.27 tonnes of bio-carbon dioxide a year for the 75 million UK population in 2050. Possibly significant quantities could be added using DACCS technologies if any of the technologies under development became cost-effective.

In the period up to 2050, it is probable that most of the CCS infrastructure built around Wales and globally would be to store CO_2 emissions from fossil sources particularly coal and natural gas but also unconventional sources such as shale gas and tar sands in some countries that choose to go down that route.

The amount stored from low-carbon bio-energy sources would depend greatly on government policies and the availability of sustainable bio-energy resources. Traditional bio-energy sources would be limited by the competing and priority needs of cropland for food production and rainforest for climate and biodiversity protection.

By 2040-2050 many of the power stations fitted with CCS plant would be operating at lower and lower capacity factor due to the increase in supply from renewable energy sources. Some gas power stations built by 2020 may well be being decommissioned due to age by then, or re-fitted to burn bio-methane. So there could be considerable CCS infrastructure (pipelines, injection wells, etc) becoming available for storage of bio-carbon dioxide.

If bio-energy could be cultivated at very large scale, probably in deserts and other arid lands around the world, or if direct air-capture (DAC) technologies became cost-effective, then the potential for significant carbon-negative energy generation at global scale could become a possibility, even before 2050, as fossil-fired generation declines

If many countries world-wide adopted similar energy system strategies and achieved similar or greater per capita levels of carbon-negative energy generation to what could be possible in Wales and the UK then the potential for a significant net reduction in atmospheric carbon dioxide levels may arise. This annex explores what may be possible.

A recent study by Element Energy for the North Sea Basin Taskforce (comprising the UK, Germany, Norway and Netherlands) stated that North Sea comprises about half of the European CO_2 sequestration potential (REF : Element Energy http://www.element-energy.co.uk/sectors/carbonCaptureStorage/OneNorthSea.pdf and http://www.ccsassociation.org.uk/docs/2010/Element%20Energy%20report%20on%20CCS%20in%20gas%20and%20industry%20June%202010.pdf).

Element estimated that the Taskforce countries could construct CCS infrastructure with a capture rate of over 270 Mt CO_2 per year by 2030, and more than 450 Mt CO_2 per year by 2050. While such high storage rates are technically achievable according to the study, it would require the rapid deployment of large-scale CCS infrastructure by 2030. Element concluded that this would require an ambitious improvement in planning co-operation amongst stakeholders, favourable economic conditions and notable CCS cost reductions.

At these sequestration rates, the North and Irish Sea Sea would play a leading and important role in European and global CO_2 emissions abatement. In other words, the UK would have sufficient storage capacity within its reach to meet the most challenging climate change mitigation scenarios.

The North Sea sub-seabed is estimated by the various sources cited in this report to contain about half the potential storage capacity around Europe, potentially several tens of giga-tonnes. By 2050, over 450 Mt CO_2 per year could be in the process of being captured, transported and stored by bordering countries. The population of the countries bordering the North Sea (UK, Germany, Denmark, the Netherlands, Norway and possibly including Belgium, Sweden and Ireland) total about 190 million people. By 2050, this population could be in the region of 200 - 225 million.

Consequently, the storage rate in 2050 could approach 2 tonnes CO_2 per year per person assuming a 450 Mt CO_2 rate is achieved. Similarly, a storage rate of 270 Mt CO_2 per year by 2030 would be equivalent to about 1.2 tonnes CO_2 per year per person. Assuming the DECC Pathways UK population estimate of about 71 million in 2030 and 75 million in 2050, the storage contribution by the UK may be 80 Mt CO_2 per year by 2030 and 140 Mt CO_2 per year by 2050.
Given the constraints on bio-energy resources and aviation demands the maximum carbon-negative emission that the UK could achieve (excluding agricultural arisings) would be around 40-60 million tonnes per year by 2050 and only then if most shipping and switched away from bio-diesel (see Annex 3). A considerable level of agreements and co-operation would be needed to achieve such a major switch in global shipping fuels due to necessary fuel infrastructure changes at ports globally, ship conversions, etc. This would be offset by UK agricultural emissions of around 40 million tonnes CO2 per year, reducing the maximum net national per capita negative emissions to just over 0.25 tonnes per person per year (ie MINUS 20 mt CO2 for 75 million people).

Consequently, it would require DACCS schemes at large scale to make a bigger contribution than BECCS if higher rates of reductions in atmospheric carbon dioxide concentration were needed to avoid dangerous global warming. Assuming 60 mt bio-CO2/y were captured and stored by BECCS by 2050 then there may be up to 80 mt CO2/y of storage potential for DACCS using synthetic fuels (assuming UK storage infrastructure capacity of 140 mt CO2/y was achieved by 2050). If agricultural sector greenhouse gas emissions are the only other significant emissions then net carbon-negative emissions of around 100 mt CO2 per year by 2050 may be possible.

This would amount to an actual storage rate of about 2 tonnes per person per year by 2050 and a net storage rate of around 1.33 tonnes bio-CO2 per person per year.

It certainly appears that there would be sufficient geological storage capacity around the UK and globally to achieve and sustain high (2 tonnes per person per year by 2050) carbon-negative CO_2 storage rates if DAC technology, fuel synthesis and bio-energy resources were sufficiently large-scale and CCS-fitted energy generating technologies were built at large scale. The IPCC has estimated that the global geological storage potential could be about 675-900 Gt CO2 in depleted oil and gas formations and up to 10,000 Gt CO2 in other geological formations (eg deep saline aquifers).

Even storage in just depleted gas and oil fields globally could achieve a significant reduction in atmospheric carbon dioxide concentrations. NASA climate scientist James Hansen has suggested that atmospheric carbon dioxide concentrations of about 350 ppm would be advisable, and a campaign group to that effect has been set up (www.350.org). Yet, levels of around 450 ppm of carbon dioxide equivalent are being forecast. For comparison, the weight of carbon dioxide in the atmosphere amounted to some 2,640 Gt CO_2 in 1998 (which then comprised 360 ppm by weight of the atmosphere). Hence, 730 Gt CO_2 would be equivalent to about 100 ppm of CO_2 excluding any effects on other sources and sinks, which could become significant in themselves due to adverse bio-sphere feedback effects.

If a combination of BECCS and DACCS energy schemes achieved a net carbon-negative storage rate of 0.5 mt CO2 per capita by 2050 and 50 % of the global 9 billion population achieved a similar rate then 2.25 billion tonnes of carbon dioxide could be removed from the atmosphere each year by 2050. It would take 100 years to remove and sequester 225 mt bio-CO2 from the atmosphere.

One possibility would be to use the high temperatures and hot water production available from concentrating solar thermal mirror schemes in deserts to drive DAC plants located above or near large suitable sub-surface geological formations. Such CSP-powered DACCS schemes could be entirely self-powered and located in remote areas. Desalinated seawater from solar powered schemes fed by pipelines from coasts could supply water requirements. Carbon dioxide storage in such stand-alone sequestration schemes could be paid for by countries without significant storage capacity themselves. For example if about 2 tonnes of carbon dioxide per person per year in the UK could be stored by 2050 (i.e. about 140 mt CO2/y by 70-75 million people) and similarly DACCS and BECCS technologies were undertaken globally at similar scale then the cumulative reductions over decades would begin to effect atmospheric carbon dioxide concentrations.

Assuming a fairly linear roll-out of CCS infrastructure by the North Sea countries from 2020 to a 450 Mt CO_2 per year storage rate by 2050, the amount stored under the the North Sea seabed between 2020 and 2050 could be in the region of 7 Gt CO2. If the 450 Mt CO_2 per year storage rate were maintained for the 50 years to 2100 an additional 22 Gt CO_2 wound be stored (assuming the energy generation sector and industry emitted that amount between 2050 and 2100).

If, for example, 7 billion out of 9+ billion 2050 global population, followed the North Sea countries lead and also deployed DAC and CCS infrastructure, the total amount stored could rise to around 110 Gt CO_2 by 2050. This assumes a global storage rate averaging 1.5 tonnes per person per year by was reached by 2050 starting from the mid 2020s.

Between 2050 and 2100, assuming some further CCS deployment, some 7 billion people then averaged a net sequestration rate of 1.75 tonnes per year per person. The amount stored between 2050 and 2100 would reach about 610 Gt CO_2 and the total amount stored from the 2020s would reach 720 Gt CO_2 by 2100. This would be equivalent to around 100 ppm excluding emissions from global agricultural and land-use changes and other climate-related sources and sinks.

This example does not imply that anything like such high carbon-negative storage rates of 100 ppm by 2100 or beyond are definitely required or achievable, especially when agricultural and land-use emissions are factored in. However, the amount of bio-CO_2 that could plausibly be stored, if it could be captured, by 2100 and beyond, appears to be significant in terms of avoiding dangerous atmospheric concentrations.

If large-scale sustainable bio-energy sources become available for BECCS, and DACCS also becomes viable at scale, then these technologies would be worth commencing as quickly as possible given that possible irreversible climate effects could occur as emissions and concentrations continue to rise.

Failing to explore such possibilities, especially as a large capacity of CCS infrastructure built for fossil emissions could be available, would represent a potentially highly regrettable lost opportunity, bearing in mind the risks of even a 2 Centigrade rise in global temperature.

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