Programme Area: Bioenergy

Project: Energy From Waste

Title: AEA Technology Landscape Review Technical Summary

Abstract:

This document is Appendix B1 (of 3) of the Energy from Waste UK Benefits Case (Deliverable 2 of 2 in Work Package 4).The ETI commissioned AEA to provide an up-to-date assessment of current development and demonstration activities in EfW technologies, including both Advanced Thermal Treatment (ATT) and Anaerobic Digestion (AD) technologies. This document is the Executive Summary of AEA's review. Appendices B2 and B3 are the full reports for each technology family.

Context:

The Energy from Waste project was instrumental in identifying the potential near-term value of demonstrating integrated advanced thermal (gasification) systems for energy from waste at the community scale. Coupled with our analysis of the wider energy system, which identified gasification of wastes and biomass as a scenario-resilient technology, the ETI decided to commission the Waste Gasification Demonstration project. Phase 1 of the Waste Gasification project commissioned three companies to produce FEED Studies and business plans for a waste gasification with gas clean up to power plant. The ETI is taking forward one of these designs to the demonstration stage - investing in a 1.5MWe plant near Wednesbury. More information on the project is available on the ETI website. The ETI is publishing the outputs from the Energy from Waste projects as background to the Waste Gasification project. However, these reports were written in 2011 and shouldn't be interpreted as the latest view of the energy from waste sector. Readers are encouraged to review the more recent insight papers published by the ETI, available here: http://www.eti.co.uk/insights

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Energy from Waste Technology Landscape Review

Executive Summary

A Report for the Energy Technologies Institute

AEA in Confidence
ED45634.020/ES/FR01
Date 15/07/2011

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Executive Summary

Project Context and Scope

This review is part of a wider Energy from Waste (EfW) project, in which the Energy Technologies Institute (ETI[1]) is seeking to examine the technology development and demonstration needs required to allow a wide range of wastes to be used for energy production purposes. This Flexible Research Project (FRP) is currently being delivered by a Caterpillar-led consortium that includes Cranfield University, The Centre for Process Innovation (CPI), EDF Energy and Shanks Waste Solutions. Hereafter, the commissioner of this report is referred to as the Consortium.

Purpose and Structure of This Review

The Consortium's requirement for this project was an up-to-date assessment of current development and demonstration activities in EfW technologies, with reference to NASA's Technology Readiness Level scheme, which assigns a score from 1-9 to reflect the maturity of each technology.

The full scope of the project included reviews of both Advanced Thermal Treatment (ATT) and Anaerobic Digestion (AD) technologies. During the course of the project, it became clear that these two groups of technologies are at quite different levels of development, and that their reviews should accordingly focus on different aspects. For that reason, it was decided to write two parallel reports – one each on ATT and AD – and an overarching summary report (this document) pulling together conclusions and findings from the two technologies.

Through discussions between the Consortium and AEA, it emerged that the key requirements for the review were:

+ to create a "long-list" of all major "enterprises" (including companies, suppliers, distributors, technology providers, research institutes and universities) involved in EfW technology;
+ to determine criteria that could be applied to the "long-list", in order to obtain a short-list of about 20 enterprises to review in detail;
+ to make good use of AEA's extensive body of public and private resources (including project reviews, journals, papers, conferences, reports, site visits and supplier publications) in assessing the individual enterprises;
+ to assess the current TRLs of the key unit operations that constitute the enterprises; and
+ to conclude from the information provided the key opportunities and threats associated with the EfW technologies.

AEA's Body of Evidence

AEA is the UK's leading provider of technical environmental advice and support to UK Government, and is a trusted advisor to local government and the private sector. We have been operating in the UK, Europe, US and China for over 40 years and employ over 1,000 staff, many of whom are world-leading experts in their fields. AEA was voted Number One Consultancy for Climate Change and Renewables by our peers in the prestigious Edie Awards in 2006, 2007, 2008 and 2009.

AEA has worked on technology development, procurement, evaluation and delivery in both the thermal and biological areas for over 30 years, supporting developers, financiers, users and their contractors in designing solutions for waste treatment. We have assisted Government Agencies in evaluating new technology delivery, and in reviewing technology development and providing technical support to grant programmes designed to support technology advances.

Our team's technical and process technology expertise is underpinned by a thorough understanding of both the energy and waste markets, and associated data (e.g. feedstock availability and characteristics). Our market knowledge of new technology development was critical to the successful delivery of this assignment, enabling us to cut through the marketing literature on each technology and focus on their strengths and weaknesses, in order to short-list appropriate technologies on a robust evidence base. We know many of the technology providers and are in touch with numerous

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[1] http://www.energytechnologies.co.uk/Home.aspx

technology start-up companies and universities, having undertaken similar research assignments for several clients in the last two years. This insight has ensured that our scores and commentary are based on real evidence and visibility of the operations in question and not on the promotional literature available on the web.

That said, however, much of our work in the recent past has been on confidential studies, on topics such as feedstocks, technology options and process efficiencies for private sector clients including Hills, Shanks, Biossence, and Dairy UK. In addition, some of our on-going work for the International Energy Authority (IEA), DECC, Defra and WRAP is currently confidential. Although these studies are not publically available and so cannot be presented within this report, we have taken the lessons learned and the perspectives of the key technical staff who have worked on these projects to inform our technology appraisals. To give an idea of the extent of this body of evidence, the electronic "research" library within our system folder for this project contains almost 300 files, including reports, case studies and presentations.

Some examples of recent projects that have been utilised to inform our position on specific technologies include:

+ **Secretariat and Lead Research Partner of the International Energy Authority's Bio-Energy Task Force** (see box below)

AEA was appointed as the secretariat and lead research partner of the International Energy Authority's Bio-Energy Task Force. IEA Bioenergy is an international collaborative agreement set up in 1978 by the International Energy Agency (IEA) to improve international cooperation and information exchange between national bioenergy RD&D programmes. IEA Bioenergy aims to accelerate the use of environmentally sound and cost-competitive bioenergy on a sustainable basis, to provide increased security of supply and a substantial contribution to future energy demands. The work within IEA Bioenergy is structured in a number of Tasks, which have well-defined objectives, budgets, and time frames. Recent tasks have included the

+ Promotion of information exchange and deployment of environmentally sound energy recovery technologies;
+ Stimulation of interaction between RD&D programmes, industry and decision makers, and
+ Identification and interaction with appropriate international organisations.

The scope of the project has continually evolved, with a number of new research themes identified, including:

+ Product Stewardship/Producer Responsibility
+ Greenhouse Gas balances for MSW Systems
+ Micro-particulate emissions – PM10
+ Mechanical Biological Treatment
+ Thermal Treatment of Sewage Sludge

AEA is responsible for peer reviewing all work done by the partners, co-ordinating visits, meetings and research, and for publishing the final reports.

+ **Implementation of Anaerobic Digestion:** Multi-criteria optimisation for Defra (current). Development of a decision-making tool to identify the optimal type, scale and locations of AD plants in England and Wales.
+ **Monitoring of Anaerobic Digestion Demonstration Projects for WRAP (2010).** Monitoring of six innovative AD plants that are at commissioning stage.
+ **Evaluation of Energy from Waste Options for Hills Waste Solutions (2009).** A critical evaluation of current and near future thermal treatment technologies.
+ **CHPQA -** DECC CHP quality assurance programme to annually validate and audit the performance of 1300 CHP sites including several EfW and biomass sites and proposed technologies such as plasma gasification.

+ **Analysis of Renewable Technologies Growth to 2020 for DECC (2010).** A review of renewable energy (including AD, liquid biofuels/bioethanol and energy from waste) deployment and projected development in the UK.
+ **An assessment for waste technology investment opportunities for Shanks Waste Management (2009/10).** A study to inform their five-year investment plan.
+ **UK and Global Bioenergy Resources and Prices, DECC (2010).** A study of the availability of bioenergy feedstock (including waste) in the UK.
+ **Bio-energy Review for the Environment Agency (2008).** Examination of the development of bio-energy in England and exploration of likely future development.
+ **Design of a Renewable Heat Incentive for DECC (2009-10).** Quantitative and qualitative cost benefit analysis to support the development of the Renewable Heat Incentive.
+ **An assessment of waste technology options for Essex Waste Partnership (2009/10).** As part of their PFI funded residual waste treatment procurement project.
+ **Management of two databases on behalf of DECC (current):** RESTATS, the UK's Renewable Energy STATisticS database, and REPD, the Renewable Energy Planning Database project that tracks the progress of new projects from inception to operation.
+ **Ofgem** - Development of Syngas metering & sampling methodology for RO 2009 for use when assessing how a generating station should meter syngas and calculating its ROCs allocation.
+ **NNFCC Suitability of UK-Derived Biomass Feedstocks for Energy Generation** – Assessment of the biomass, energy crops and agricultural residue applicability to combustion technology and prime mover options
+ **Bioenergy Capital Grants Scheme** – Technical application reviews including gasification, ORC, CHP and AD applications.
+ **Evaluation of Opportunities for converting indigenous UK wastes to fuels and energy** – Review of UK waste arisings and technology options available to use various waste fractions as feedstock.
+ **Welsh Assembly Government** - Modelling of Impacts for Selected Residual Waste Plant Options using WRATE, specifically modeling EfW technology options including gasification, slow pyrolysis, fast pyrolysis and combustion for projected waste arisings, with and without CHP.
+ **DECC EfW Workshops for Local Authorities** – Authoring and presentation of EfW options providing understanding of their operation and performance.

The AD Assessment

In order to identify areas for further development, it is useful to categorise AD plants according to their different scales and application types:

+ **Large-scale merchant AD plants (Type 1).** These are typically based on food waste from municipal and C&I origins but also accommodate other wastes such as livestock slurries. Over 100 such plants exist in Europe[2] and several are installed in England.
+ **Medium-scale farm enterprise AD plants (Type 2)**. These are typically based on co-digestion of various feedstocks but the main component tends to be livestock slurry with energy crops. Thousands of such plants are installed in Europe, notably in Germany, and some are also implemented or being implemented in several locations in England.
+ **Small-scale on-farm AD plants (Type 3)**. These are defined as AD plants that deal with livestock slurry, agricultural residues and energy crops drawn from within the confines of the farm.

From our wide search, AEA identified over 60 operational AD plants for consideration for this project (see AD Report Annex I). Plants were chosen for further consideration for one of the following reasons:

+ **Y1** Because the plant has a relatively high biogas yield;
+ **Y2** To provide coverage of the mix of different technologies; or
+ **Y3** Because the plant has suffered relatively poor performance.

In most of the plants we identified, biogas is converted in CHP plant to produce electricity for export and heat for maintaining the process. However, in a few cases (for example Gustrow and Tilburg), the biogas is being produced for the purposes of injecting into the natural gas network. These were selected on that basis.

In devising the short-list, AEA tried to balance the requirement for access to relevant process data (which tended to favour UK plants, where much of our experience has been gained) with the desire to cover as many countries as possible. The final short-list of the plants is presented in Table 1.

Table 1: AEA Anaerobic Digestion Plant Shortlist

		Site Name		Technology	System
Y1	21	Pellmeyer Biogas Plant II	DE	UTS	Multi (2 Stage)
	24	Biogas Benet	FR	Entec Biogas	Wet: Multi (acidification, CSTR Digester, Post Digester)
	25	Nakasorachi	JP	Entec Biogas	Wet: Multi (2 stage)
	36	Cassington, Oxford	UK	Agrivert	Multi stage
	53	Selby Renewable Energy Park	UK	Entec Biogas	Wet: Multi (acidification, CSTR Digester, Post Digester)
Y2	4	Brecht II	BE	OWS (Dranco)	Dry: Single (Plug)
	14	Jessen	DE	Strabag	Dry: single
	23	Gustrow Bioenergy Park	DE	Envitec	Wet: Single
	26	Tilburg	NL	Valorga	Dry: Single (Plug)
	27	Waterschap Veluwe	NL	HoSt Bioenergy Installations	Multi (2 Stage)
	30	Barkip	UK	Xergi	Multi (2 stage)
	56	Twinwoods, Beds	UK	WELtec, BiogenGreenfinch	Single
	61	Tel Aviv	IR	ArrowBio	Wet
Y3	42	Holsworthy	UK	Farmatic	Wet: Single (CSTR)
	55	Stornoway	UK	Strabag	Dry

[2] Luc de Baere, 2010; General trend of the AD technology implementation and their types in Europe'; paper presented at the Biowaste Conference, February 2010.

AD TRL Assessment Results

The difficulty with assigning TRL scores for the chosen AD plants was that, because all the plants are operational, the TRL scores must trend towards the full 9 score, associated with “actual system proven through successful operation”. Even for the two projects cited as “unsuccessful”, Holsworthy is now performing well enough on a different feedstock under a different economic model, while we believe that the Stornoway plant is coping with its waste, but is receiving much less material than its design capacity. For these reasons, in Table 2 below, which presents a summary of the assigned TRL scores, it can be seen that TRL assessments of 9 abound.

Table 2: Summary of AD TRL Assessments

Site Name	Technology	Pre-Treatment	Conversion Technology	Post-Treatment / Clean-Up	Power Generation	Integration
Pellmeyer Biogas Plant II	UTS	9	9	9	9	9
Biogas Benet	Entec Biogas	9	9	9	9	9
Nakasorachi	Entec Biogas	9	9	9	9	9
Cassington, Oxford	Biogas-Weser-EMS	9	9	9	9	9
Selby Renewable Energy Park	Entec Biogas	9	9	9	9	9
Brecht II	OWS (Dranco)	9	9	9	9	9
Jessen	Strabag	9	9	9	9	9
Gustrow Bioenergy Park	Envitec	9	9	7	8	8
Tilburg	Valorga	9	9	9	9	9
Waterschap Veluwe	HoSt Bioenergy Installations	9	9	9	9	9
Barkip	Xergi	9	9	8	9	9
Twinwoods, Beds	WELtec, BiogenGreenfinch	9	9	9	9	9
Tel Aviv	ArrowBio	8	9	9	9	9
Holsworthy	Farmatic	9	9	9	9	9
Stornoway	Strabag	9	9	9	9	9

Future Developments in AD

All of the above plants are of Types 1 and 2. Only a handful of Type 3 plants have been developed to date, though they have the potential to address a number of objectives, including:

+ improved livestock slurry management as well as reduced on-farm GHG emissions;
+ generation of energy on-farm for use within the business and in local communities;
+ opportunities for on-farm diversification activity as well as development of rural jobs; and
+ reduced watercourse pollution risk due to enhanced nutrient release from digestate.

Going forward, AEA considers that incremental changes in the performance of AD technologies will occur in multi-stage AD plants for Type 1 applications, and around the effective use of biogas (50-100kW) at small scale (Type 3).

We see four potential opportunities for disruptive or step-change innovations in the market:

1. Biogas cleaning and compression (for gas grid or vehicle use) for Medium Scale AD plant applications generating around 300kW and 1500 kW of biogas (Type 2) applications;
2. Multi-stage AD plant for Type 2 applications;
3. Thermo-chemical pre-treatment of wastes to increase biodegradability of feedstock; and

4. Single stage AD plant for dairy farms (Type 3).

As might be expected, there are countless enterprises carrying out various development projects in AD of waste. Scottish Enterprise has recently funded work towards second and third generation biofuels to deal with AD engineering, micro-biological and implementation aspects. For instance:

+ Abertay University was examining co-digestion at high temperature (thermophilic) range;
+ Newcastle University was using mixed beach-cast seaweed to examine methane yields;
+ Glasgow Caledonian University was developing microbial cultures suitable for efficient conversion of seaweed;
+ Zebec Systems was developing enzymes for use in seaweed AD plants; and
+ B9 Organic Energy in association with Questor (Queens University) was examining optimisation of seaweed and possible co-mixed waste AD process.

If the Consortium decides it wishes to investigate further what is being done, AEA suggests these enterprises could be a good starting point.

The ATT Assessment

AEA produced a catalogue of 165 different ATT technologies (see ATT Report Annex I), before undertaking a screening exercise to identify successful processes, by applying the following criteria:

+ the processes needed to be operational, ideally with several examples; and
+ sufficient information should be readily available to carry out the review.

From this process, AEA identified three technologies for further investigation, as indicated in Table 3.

Table 3: Selected Successful Projects

	Process Name	Process Description	Reactor type
1	Ebara	Innovative twin internally circulating fluidised bed. Known to have lower pre-treatment requirements	Close coupled combustion
2	Scotgen	Batch slow pyrolysis with low level air injection	Close coupled combustion
3	Thermoselect	Updraft gasifier, wet scrubbing, wet ESP, syngas supplied to gas engines or steel manufacture	3 stage combustion

A similar approach was taken to identify unsuccessful technologies. The term "unsuccessful" is quite subjective, but AEA's intention with this category was to select a number of projects that we consider have not met their original expectations, and from which lessons can be learnt concerning the difficulties that can affect ATT plants. We identified unsuccessful projects by applying the following criteria:

+ processes that, between them, provide an insight into the many problems that can occur when developing ATT processes; and
+ amongst those processes, those about which AEA has the most information.

Table 4 presents the processes / organisations that were selected for review.

Table 4: Selected "Unsuccessful" Projects

Process Name		Process Description	Process Type
4	ARBRE	This was the first IGCCGT in the UK. Shut down after a short operating period due to syngas clean-up, financial and contractual problems.	Fluidised bed gasifier with gas turbine combined cycle
5	Brightstar	Scheme failed due to problems with gas clean up and by-product char management.	Close coupled combustion
6	TPS Greve	Circulating fluidised bed gasifier open steam cycle and direct firing of cement kiln. Failure due to organisational problems and retrofitting existing equipment.	Circulating fluidised bed gasifier, with remote combustion
8	Energos (Isle of Wight)	Close coupled gasification and combustion, plants currently operational delivering heat in Norway. Demonstration project in Isle of Wight currently experiencing difficulties caused mainly by retrofitting existing boiler.	Close coupled combustion
9	GEM (Yorwaste)	Fast pyrolysis of feedstock using rotating ablative heated surface. Technical progress stalled by financial constraints and difficulties managing by product char.	Ablative kiln fast pyrolysis

	Process Name	Process Description	Process Type
10	Hudol / Prestige	Entrained flow with multiple extraction points and temperature profile control. Continuous feed, designed for feedstock flexibility. Pilot plant in Wales; additional plants under construction in England. Huntingdon Pure Power plant experiencing technical problems, causes unclear.	Updraft
11	Refgas (UEA)	Refgas developed an advanced gasification CHP system to produce renewable energy. However, current plant installed at University of East Anglia still commissioning. Problems with ancillaries and tar production.	Downdraft
12	Stein	Rotating kiln pyrolysis/gasification with steam injection to reduce char production. Innovative energy recovery char & waste gas use. Technical progress stalled by financial constraints.	Rotating Kiln

ATT TRL Assessment Results

The results for the two assessments can be found in Table 5.

Table 5: Summary of ATT TRL Assessments

	Successful			"Unsuccessful"								
Technology	**Ebara**	**Scotgen**	**Thermoselect**	**ARBRE**	**Brightstar**	**Compact Power**	**Greve**	**Energos (Isle of Wight)**	**GEM Yorwaste**	**Hudol / Pure Power Huntingdon**	**Refgas (UEA)**	**Stein**
Process Type	G	G	G	G	G	G	G	G	FP	G	G	SP
	ST	ST	RE	IG	RE	-	ST	ST	RE	RE	RE	RE
Pre-Treatment	9	9	9	9	7	7	9	9	8	9	7	7
Conversion Technology	9	9	9	9	6	9	9	9	4	7	4	7
Post-Treatment / Clean-Up	9	9	9	5	6	9	9	9	6	7	5	9
Power Generation	9	9	9	8	7	9	9	9	7	9	9	9
Integration	9	9	9	7	6	9	5	7	6	6	5	7
Overall	**9**	**8**	**9**	**6**	**7**	**7**	**9**	**9**	**7**	**7**	**5**	**7**

G = Gasification ;FP = Fast Pyrolysis; SP = Slow Pyrolysis
ST = Steam Turbine; RE = Reciprocating Engine
IG = Integrated Gasification Combined Cycle Gas Turbine

As might be expected, the assessment scores for the three successful projects are very high. Ebara and Thermoselect are rated at a TRL of 9 for all aspects, because they have multiple plants and have been running for many years. Scotgen is slightly marked down for its overall TRL only because it has not been running for a particularly long time. The Greve and Energos plants are also given overall scores of 9, because their technologies have generally been well developed, even if the integration in the two particular plants reviewed fell short of what would have been wished.

There are some technical themes that reoccur in successful projects:

+ Gasification only succeeds when the feedstock is consistent. This can be achieved in waste installations by:
  - a preliminary pyrolysis step that presents char to a gasification step; or
  - extensive fuel preparation.
+ The pyrolysis route has worked at small and large scales; extensive fuel preparation is probably more appropriate to larger installations only.
+ Large fluidised bed gasifiers (several MW) have proved successful and reliable if the feedstock is controlled.
+ Char from pyrolysis should be converted to gas within the process and not removed. A pyrolysis process is only half the solution.
+ Ceramic filters remove dust from product gas effectively.
+ Organic scrubbing, particularly by esters, is effective at tar removal.

In contrast, many factors have caused the failure of projects, and some are seen to be repeated on a number of occasions. AEA draws the following general conclusions from the study:

+ Project development costs tend to be far more than expected. This places pressure on technical objectives and drives companies toward premature commercialisation to attract private equity. Adequate financial resources and clear technical objectives are required for success but very few, if any, UK developments have benefitted from these.
+ Gas turbines and reciprocating engines are very sensitive to the presence of contaminants in the syngas. The seemingly simple process engineering task of removing these has proved intractable and as a result there are very few examples of successful implementation, and many of failure. Successful projects have sidestepped this issue by using direct combustion in a boiler and steam cycle electricity generation.
+ The use of steam cycle generation means that there is a limited prospect for significant increases in thermal efficiency over incineration, and this comes with increased technical risk. It is debatable whether the increased performance is worth the risk premium in a conservative industry such as waste management.
+ The conclusion from the two points above is that understanding gas cleaning and developing commercially successful solutions are by far the most important research challenges in this area.

In summary, there are currently very few operational ATT processes, despite a wealth of investment and R&D input. There are far more examples of problems and failures than fully operational facilities. This is a reflection of the problems explained above and concerns about feedstock quality, consistency and the resources required to make these processes success when using waste as a feedstock.

Future Developments in ATT

AEA's research into the unsuccessful processes highlights that projects experienced difficulties in two key areas;

+ handling and cleaning dirty syngas once it was generated; and
+ processing char.

Developing technologies that could overcome these barriers would lead to a significant improvement in the success of waste gasification and pyrolysis processes. The options for overcoming the difficulties in syngas cleaning are:

+ the development of a conversion step that produces a syngas with lower tar and pyrolysis oils content than can be achieved currently;
+ improved unit processes / performance for removing syngas tars and oils to levels that enable sustained and long term operation of advanced prime movers such as engines or gas turbines; and

+ the development of prime movers that operate above the tar dew point (in excess of 300°C) avoiding the problems caused by the condensation of syngas tars and pyrolysis oils.

Char management is best dealt with by understanding the function of the conversion reactor and making provision for the steam and/or oxygen injection necessary for its conversion to fuel gas. In AEA's view, it is unwise to rely on a landfill or sales route for char disposal. Experience at Brightstar has illustrated that it can be a fire risk. No one that we are aware of has managed to sell by-product char into the established and highly specialised active carbon or thermal charcoal markets.

There are also obvious benefits in the development of prime movers, which are more efficient than the mature reciprocating engine, gas turbine and steam cycle systems (in either CHP or power only configurations). Thus, AEA has identified organisations who are working in the particular areas concerning syngas handling and prime mover development.

Table 6: Selected Future Developments

	Process Name	Process Description
13	Bloom energy	SOFC manufacturer, Auto reforming fixed bed, modular design, flexible fuel use deployed to several sites in California
14	ECN	Developing Olga tar scrubbing technology. Pilot scale plant behind Bivkin reactor. Scrubber based on contact of gas with organic liquid. After separation contaminants recycled to gasifier. Successfully employed on biomass gasifiers.
15	Lurgi AG	Supplier of syngas cleaning processes for many decades using chilled methanol and amines
16	KBR	Currently Coal to Synthetic Natural Gas
17	Molten salt gasification	University of Maryland
18	Sasol	Fischer Tropsch liquids market leader has operating plants using coal and gas as feedstocks
19	Sumitomo Metal Industries (PreCon)	Molten Iron bath gasification - a new type of waste gasification and smelting system, using iron-making and steel-making technologies based on high-temperature metallurgy, has been developed for feedstock flexibility
20	Ze-Gen	Innovative liquid metal heat transfer medium in reactor

AEA considers that all of these businesses offer opportunities to improve the success of some ATT technologies. Which (if any) of the technology providers the Consortium may wish to investigate in more detail will depend to a large extent on the particular interests of the members.

More progress is now being made in the gasification of clean biomass with several installations now operating successfully, but these processes were outside the scope of this review. It would be valuable to extend this review to analyse the lessons from this field. Biomass gasifiers have now achieved many tens of thousands of hours of operational experience, most notably in Austria and Denmark.

Project Conclusions

It is evident that Advanced Thermal Treatment and Anaerobic Digestion are at quite different levels of development with respect to the treatment of waste.

For ATT, the successful development of a process (or processes) that can make use of biomass or waste derived material is relatively rare and is a difficult objective to achieve. Those projects that have been successful have tended to develop schemes based around a close-coupled open steam cycle process and have focussed on designing processes which are tolerant of variation in feedstock parameters, which has often been the most significant issue facing these processes.

In contrast, many factors have caused the failure of projects, and some are seen to be repeated on a number of occasions. Costs are always higher than expected; simple processes are favourable; tar cleaning can be a significant technical barrier to success.

There are currently very few operational ATT processes, despite a wealth of investment and R&D input. Going forward, innovation, development and deep pockets will be required to refine the better performing processes to ensure they are more robust and better designed for the job in hand.

A former colleague of one of this report's authors, Professor David Wilson MBE, published a standard textbook with Oxford University Press in 1981 on the then available technologies for municipal solid waste management. When asked recently for his thoughts on gasification and pyrolysis, Prof Wilson replied that, when he was researching his book in the 1980s, gasification and pyrolysis were the up and coming technologies and that it seemed to him that not much had changed in 30 years – the technologies then had not been proven on a commercial scale, and that is still the case.

For AD, the picture is much brighter. Single stage AD technology is relatively inefficient with respect to semi-solid waste, but will continue to be applied, with some modification, as it provides greater flexibility when feedstocks are prone to change from season to season or even daily. Meanwhile, multi-phase AD provides greater energy yield, but is relatively more costly (tankage, quality of digestate, high level of control etc).

Pre-hydrolysis, involving the use of chemicals or enzymes, may prove too costly (the digestate will require different handling) to reach financial viability, but it will be important to keep abreast of the development with second and third generation biofuels, which look more promising. Hydrolysis of the hemi-cellulose and cellulose fractions of ligno-cellulosic materials is still at the development stage, although there are plans for demonstrations in the EU and USA.

Going forward, AEA considers that incremental changes in the performance of AD technologies will occur in multi-stage AD plants for Type I applications, and around the effective use of biogas (50-100kW) at small scale (Type 3).

We see four potential opportunities for disruptive or step-change innovations in the market:

1. Biogas cleaning and compression (for gas grid or vehicle use) for Medium Scale AD plant applications generating around 300kW and 1500 kW of biogas (Type 2) applications
2. Multi-stage AD plant for Type 2 applications
3. Thermo-chemical pre-treatment of wastes to increase biodegradability of feedstock
4. Single stage AD plant for dairy farms (Type 3)

Overall, we have struggled to find noteworthy examples of ATT processes handling waste well for the production of energy, but there are many AD processes that are doing fine, and might, with more investment, do even better. If we were investing our own money, the authors would certainly be looking to AD technologies.

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