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# Socio-technical change linking expectations and representations: Innovating thermal treatment of municipal solid waste

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## Abstract

This paper combines two theoretical perspectives: future technological expectations mobilising resources, and social representations assimilating new ideas through anchoring onto familiar frames of reference. The combination is applied to the controversial case of thermal-treatment options for municipal solid waste, especially via gasification technology. Stakeholders' social representations set criteria for technological expectations and their demonstration requirements, whose fulfilment in turn has helped gasification to gain more favourable representations. Through a differential 'anchoring', gasification is represented as matching incineration's positive features while avoiding its negative ones. Despite their limitations, current two-stage combustion gasifiers are promoted as a crucial transition towards a truly 'advanced' form producing a clean syngas: R&D investment reinforces expectations for advancing the technology. Such linkages between technological expectations and social representations may have broader relevance to socio-technical change, especially where public controversy arises over the wider systemic role of an innovation trajectory.

**Key words:** technological expectations; social representations; incineration; municipal solid waste; advanced thermal treatment; gasification.

## 1. Introduction: Beyond incineration?

Promoters of technoscientific pathways generally solicit support on grounds which lie beyond evidence of technical progress. Such grounds have been theorised as technological expectations, i.e. 'real-time representations of future technological situations and capabilities' (Borup et al. 2006). Such expectations have been shown empirically to play a complex role in technoscientific trajectories and related policies.

In many cases, alternative futures and their technological trajectories compete for support. Beyond such competition, sceptics often question whether a future trajectory will alleviate a societal problem or instead perpetuate it (see Section 2). As a theoretical perspective, expectations cannot entirely explain those cognitive aspects, particularly the diverse framings and socio-psychological processes influencing support. To fill the gap, this paper combines the theories of technological expectations and social representations.

Our case study is the UK effort to innovate thermal-treatment options for municipal solid waste (MSW). After some recyclables have been removed, the residual MSW is generally combusted in

incinerators, often configured as energy-from-waste (EfW) plants (Breeze 2014). Proposals for new plants have attracted widespread controversy over health hazards and environmental sustainability.

In the EU, pressures for change have come from several targets e.g. for landfill reduction (alongside taxes), renewable energy supply, greenhouse gas savings and waste recycling. These pressures broaden opportunities for better alternatives to landfill (EC 1999). Diverse innovation trajectories have been collectively named advanced conversion technologies (ACTs), including advanced thermal treatments (ATTs) such as gasification. Their recurrent technical difficulties have prompted a practical question for the sector:

What can be learned from recent project failures? And what changes do we need to make to ensure future success? (World WtE 2016)

ATTs remain a broad, somewhat ambiguous category. For MSW treatment current gasification technology has been promoted as an improvement. At the same time, proponents distinguish between current commercial gasifiers and 'true' or 'advanced' gasifiers with greater benefits (see Section 5). In previous studies, technological

expectations have been analysed for gasification of homogenous biomass (Kirkels 2016), but not of heterogeneous MSW, nor with the aim to highlight socio-cognitive aspects of expectations.

Our research investigated strategies for promoting gasification of MSW. This paper addresses the following questions:

- How do stakeholders compare gasification with incineration, emphasising similarities or differences, in ways favourable or unfavourable to these options?
- How do their expectations for technological improvement help to mobilise policy support and investment decisions (by companies, local authorities, state agencies etc.)?
- How do their strategies or decisions link expectations with representations?
- How can linking those two perspectives (expectations with representations) illuminate wider dynamics of technological innovation?

To answer those questions, the remainder of this paper is structured as follows: Section 2 outlines the main theoretical perspectives and research methods. Section 3 describes new promotional opportunities for gasification, with expectations for moving up the waste hierarchy. Section 4 analyses how key actors in the UK EfW system have represented gasifiers *vis-à-vis* incinerators, blurring the distinction. Section 5 shows how some local authorities compared the technologies for decisions on waste-management contracts. Section 6 analyses the promotion of truly 'advanced' gasifiers which clean the syngas. Section 7 presents our conclusions bringing together answers to the above questions.

## 2. Cognitive perspectives and research methods

Whether or not a technological innovation gains large-scale commercialisation depends on supportive actors, networks, institutions and policies (Carlsson and Stankiewicz 1991). This case study emphasises cognitive perspectives on how novelty is represented in socially shared ways that inform collective action. First, technoscientific development depends partly on expectations of future benefits that help to mobilise various resources, thus potentially fulfilling the original expectations. Secondly, through social representations, novel ideas or artefacts may be integrated into pre-existing cognitive frameworks: such integration can either have a favourable or pejorative meaning. Both cognitive perspectives encompass temporal change resulting from stakeholders' strategies. These two perspectives are elaborated in turn, for application to our case study.

### 2.1 Expectations around contested futures

Technoscientific development has been shaped by contending expectations for potential benefits:

... the future of science and technology is actively created in the present through contested claims. (Brown et al. 2000: 5)

Commercial innovation needs to attract R&D investment on grounds that lie beyond evidence of technical progress. For pre-market applications, practical utility and value have yet to be demonstrated: their progress depends not only on demonstrable efficacy to date, but also expectations for their future development. In promoting clinical biotechnology, for example:

... ambitious expectations are seen to be rhetorically characteristic of very new or exotic areas of R&D. (Brown and Michael 2003)

Whenever limitations arise in technoscientific development, expectations can be shifted to newer trajectories. Actors discursively:

... differentiate between old failing innovations and new promising innovations.

Such accounts:

... are performative: they serve to enable some technoscientific worlds, and disable others. (Brown and Michael 2003: 14)

In so doing, expectations may differ among various groups and may change over time (Brown and Michael 2003).

Expectations can become 'part of a generalised and taken-for-granted social repertoire'. They become a 'depersonalized social construction'. Whenever they become societal assumptions, such expectations can even guide or justify the actions of those who do not necessarily share them (Konrad 2006: 431).

In competing for policy support and R&D investment, favourable technological expectations are often criticised, generating public controversy. For example, in the global biofuels controversy since 2006, featuring disputes over un/sustainable biomass, promoters raised expectations that 'advanced' biofuels would fulfil earlier claims by using non-edible biomass. Such expectations became a key basis for government policy to expand a biofuel market which could thereby incentivise the necessary technological advance (Palmer 2010; Levidow et al. 2013). This new rationale was criticised on various grounds, for example, that the initial biofuel market was locking in first-generation biofuels and so could impede future ones (Berti and Levidow 2013). In such controversies, technological novelty was represented differently by advocates and critics, as elaborated next.

### 2.2 Social representations of novelty

Social representations theory is a social-psychological theory of cognition and its societal influence. As a central perspective, actors attempt 'to anchor strange ideas, to reduce them to ordinary categories and images, to set them in a familiar context'. In this process, some aspects are omitted, while others are brought more sharply into focus (Moscovici 1988).

Those seeking to establish particular social representations generally aim:

... to make something unfamiliar, or unfamiliarity itself, familiar. (Moscovici 1984: 24)

This is done in two complementary ways. First, representations conventionalise new concepts and give them a recognisable common form, thus enhancing communication and coordination within a group:

These conventions enable us to know what stands for what.

Second, representations prescribe ways of thinking about topics:

... they are forced upon us, transmitted, and are the product of a whole sequence of elaborations and of changes which occur in the course of time and are the achievement of successive generations. (Moscovici 2000: 22, 24).

Thus representations are dynamic, changing as new ideas are taken up. Drawing on Moscovici's perspective, Bauer and Gaskell (1999) visualise social representation as a dynamic triangular relationship between: first, the subjects, or carriers of the representation; second, the object that is being represented; and third, the

‘pragmatic context’. Social representation theory concerns the interaction between all three. Through a time-axis, the triangular relationship is constantly changing, visualised as a ‘Toblerone’ dynamic model of social representation.

For example, representations of hydraulic fracturing for natural gas (‘fracking’) have made the technology either favourably or negatively familiar. Through various strategies:

... alternative anchors – ways of making new phenomena familiar – form part of the competitive environment in which different, partly substitutable technologies are developed and promoted. (Upham et al. 2015)

At the same time, different actors may give favourable or pejorative meanings to the same anchor e.g. its alignment with current socio-technical pathways or alternative pathways (Upham et al. 2015: 136).

In the UK debate a pervasive anchor for fracking has been the oil industry. Hence advocates have favourably associated fracking with local employment and domestic (national) energy security. Opponents have pejoratively associated fracking with greedy companies buying off communities to pollute the environment (Upham et al. 2015). Germany’s fracking debate has at least two different anchors. Through favourable comparisons with natural gas, fracking has denoted a relatively clean energy, providing a low-carbon transitional technology as well as energy security, especially via independence from Middle East oil. Conversely, the oil industry has been a pejorative anchor within the same national debate, where fracking has denoted industrial pollution that threatens *Trinkwasser*, crucial for purity standards of the nation’s brewing industry (Upham et al. 2015: 131–32). Section 3 shows how actors’ various agendas anchored gasification in incineration.

### 2.3 Research methods

The principal data for this study are the views and interactions of UK stakeholder groups involved in EfW, focusing particularly on thermal-treatment options for residual MSW. The sources draw on a broad classification of system actors from innovation system analysis (Hekkert et al. 2007; Meijer et al. 2007), namely: technology developers; potential adopters (i.e. potential buyers and users of the technology); governmental bodies, which include regulators and innovation agencies; and intermediary organisations (Howells 2006).

To investigate the representations promoted by these actors, we used four overlapping methods. First, document analysis: we analysed numerous documents for how they compare gasification with incineration, along the lines of our research questions above.

Secondly, we used interviews. The document analysis informed interview questions for 15 key actors as regards several issues: how they foresee the UK waste system developing towards better energy recovery from MSW, especially the residual fraction; how they characterise and envision the interactions between the main elements and actors in the UK waste-management system; the benefits, drivers and barriers of different socio-technical pathways; how they envision their organisation as potentially influencing such pathways; whether they envisage the various technological pathways as complementary or competing; and how they view the overall prospects for greater commercial adoption of gasification.

Thirdly, we surveyed the decision-making criteria of local authorities for waste-management contracts, especially in comparing options. A detailed case study of one city analysed numerous documents and stakeholder interviews (see Section 4).

Fourth, drawing on all this material, we compiled a long matrix of how key actors compare ATTs with incineration, especially

favourable and negative comparisons. Criteria include: future benefits, reliability, feedstock flexibility, energy efficiency, hazardous emissions, relation to recycling etc. This matrix helped to identify convergent and divergent frameworks, linking expectations with representations.

The above provided a basis to analyse stakeholders’ cognitive framings as social representations and/or expectations, as summarised in Table 2. Interview statements guided our choice of document citations. By default the analysis treats each stakeholder group as a coherent actor, unless finding evidence to the contrary in documents or interviews.

### 3. Gasification opportunities: Moving up the waste hierarchy?

For the EU waste-management sector, a fundamental policy tenet is the waste hierarchy: policies address the potential conflict with all forms of EfW, especially incineration. Pressures to move waste higher up the hierarchy bring opportunities for alternatives such as gasification—but also controversy. We now present the EU–UK policy context for those competing options, whose differentiation has been somewhat ambiguous and contentious.

As a policy concept and principle, the waste hierarchy links waste management with environmental sustainability. It establishes a general order of preference: waste prevention, reuse, recycling, recovery and disposal (landfill) being the least preferable option. In Europe the framework has stimulated and institutionalised a shift of EfW facilities higher up the hierarchy than landfill or incineration without energy recovery.

The 2008 EC Waste Framework Directive gives the waste hierarchy a statutory basis. It requires that a recovery route should be given preference over disposal. For a waste combustion plant to be a recovery operation, it must generate sufficient energy to fulfil the 65% efficiency threshold. This is calculated with the R1 formula, which relates the feedstock’s calorific value to the net energy produced as electricity and/or heat, though it is not an index of energy efficiency. Below the threshold, a plant is classified as disposal (EC 2008). Many electricity-only EfW plants have gained R1 classification. Many more would do so if they submitted a request (Kaminski 2015; Goulding 2016a).

Although R1 classification is generally optional, it is a mandatory condition for a plant to import waste feedstock from across national borders. It is also a criterion for some national and local authorities to support a new EfW facility (e.g. with planning permission or finance). A plant must have R1 status and be combined heat and power (CHP)-compatible to be eligible for Wales’ subsidy of gate fees (Welsh Government 2012: 228).

The R1 recovery versus disposal distinction matters for representing a technology as an improvement. Under EU criteria, incineration encompasses:

... thermal treatment processes such as pyrolysis, gasification or plasma processes insofar as the substances resulting from the treatment are subsequently incinerated. (EC 2000)

These all count as waste disposal. Plants count as recovery only where:

... the gases resulting from this thermal treatment of waste are purified to such an extent that they are no longer a waste prior to their incineration and they can cause emissions no higher than those resulting from the burning of natural gas. (EC 2010: Chapter IV)

At present nearly all ATTs for MSW combust the syngas, counting as resource disposal.

In preferentially ranking waste-management options (e.g. recovery over disposal), the waste hierarchy reconceptualises waste as a resource. This has been analysed as a ‘farewell to wastefulness’ narrative:

The model unites the two governance alternatives of reducing waste and extracting value from it into a single progression . . . The narrative forces all organizations involved in waste governance to reflect over the contradictory dynamics of waste. Waste organisations need to develop new technical and social competencies, invent new business models and offer waste-management services that correspond to the narrative that waste is no longer a problem but a resource. (Corvellec and Hultman 2011: 5–6; 2012)

In such ways, the European waste hierarchy (EWH) blurs the stereotypical dichotomy between environmental and economic criteria:

This is illustrated both by how the rationale for developing the EWH shifts between environmental and economic motives, and by how these motives reinforce each other . . . The EWH connects society and nature, and infrastructure is transformed from barrier to mediator. (Hultman and Corvellec, 2012: 2418)

The waste hierarchy has been a reference point for UK policy debate on waste-management options:

Government policy is driven by the desire to drive waste up the hierarchy. (DEFRA 2014a: 67)

According to campaign groups and some experts, however, long-term contracts for large incinerators do the contrary: they generate pressures to ‘feed the beast’ and so deter greater recycling (Connett 2013; *Gloucestershire Echo* 2013; Marton cum Grafton 2011). The nongovernmental organisation, UK Without Incineration Network (UKWIN), argues that all thermal treatments contradict the waste hierarchy:

At present there is too much focus on incineration (including gasification and pyrolysis), and not enough focus on anaerobic digestion (AD) for food waste. . . Incineration poses a real threat to the higher tiers of the Waste Hierarchy. . . An unintended consequence of a ban or restriction just on landfill is further long-term ‘lock-in’ of compostable/recyclable/preventable material into incineration, which not only runs contrary to the Waste Hierarchy but also represents a loss of valuable resources. (UKWIN 2014: 1)

Others reject the criticism, the Renewable Energy Association (REA 2011) argues that:

EfW does not act as a disincentive to materials recovery and recycling. Evidence from Europe indicates that high recycling (including composting) rates can be sustained alongside high energy recovery rates.

Responding to the controversy, the UK government likewise portrays incineration as potentially compatible with recycling:

At the more local level, the risk that energy from waste can compete with, not complement, recycling does exist. However, it is an avoidable risk if contracts, plants and processes are flexible enough to adapt to changes in waste arisings and composition. (DEFRA 2014a: 3)

This reassurance leaves vague the appropriate flexibility to complement recycling. Financial support from state bodies has been justified on grounds that new technologies will eventually bring facilities

higher up the waste hierarchy. For the past decade, technological expectations have anticipated improvements in energy recovery (DEFRA 2007), though this remains only a potential:

Advanced conversion technologies (ACTs) have the potential to deliver more efficient generation in the long term and have the potential to deliver further benefits beyond renewable electricity generation’, e.g. through a clean syngas that can substitute for fossil fuel. (DECC 2012: 72)

Regardless of the technology, energy conversion and capture efficiencies are poor if there is no economic use for the heat produced, such as a nearby district heating system. Waste heat has been used in only 2% of the UK’s EfW schemes (DEFRA 2014b), partly because state subsidy, market incentives and distribution infrastructure are weaker for heat use than for electricity. Likewise subsidies for ATTs that generate electricity: Renewable Obligation Certificates (ROCs) may be earned for electricity generated from waste (not meeting the definition of biomass) if the waste is processed by AD, gasification or pyrolysis (together known as ATTs); or if the waste is used alongside other fuels and the overall biomass content of the fuel mix is greater than or equal to 90%; or if the plant can provide combined heat and power (Ofgem 2015; DECC 2014).

#### 4. Differentiating ATTs from incinerators?

ATTs have been promoted for greater potential recovery of energy and materials, while also reducing emissions hazards and other waste problems (see Table 1). Yet the distinction between the two technological categories—ATTs and incineration—is ambiguous, even contentious. Both categories continually undergo development; and each can be configured in various ways. Social representations include expectations about how each category will improve, along lines correlating with stakeholders’ preferences for future waste-management practice.

##### 4.1 Questioning thermal treatments

Health hazards from toxic emissions have remained contentious. Although EU law sets emission limit values (ELVs) (EC 2000), they are sometimes breached by incinerators. These reduce the waste volume that needs disposal but generates a hazardous fly ash, which can escape in the flue-gas exiting the plant without adequate end-of-pipe flue-gas cleaning (Peña et al. 2006). According to the UK Health Protection Agency, referring to the post-cleaning emissions, ‘any possible health effects are likely to be very small, if detectable’ (HPA 2009). Its Scottish counterpart more cautiously reversed the uncertainty: ‘small but important effects might be virtually impossible to detect’, citing a US agency report. For emissions from incinerating MSW, the overall body of evidence ‘is inconsistent and inconclusive’ (SEPA 2009: 66–7).

Responding to public protest, the Health Protection Agency began a review of health hazards. Some experts advocated or anticipated more stringent ELV. Although a Health Protection Agency report was originally planned for 2014, the timetable was postponed twice, provoking further public suspicion. In particular, the Breathe Clean Air Group accused the government of a ‘cover-up’ (AQN 2014).

Future uncertainty over ELVs has led some waste-management companies and local authorities to choose a gasifier, whose relatively low-temperature process can more easily accommodate tighter

standards for NO<sub>x</sub> emissions. Yet public suspicion is also directed against this technology, which has sometimes exceeded statutory limits (e.g. the Energos demonstration plant) (Sloley 2010). In 2012 Scotgen’s Dargavel pyrolysis-gasification plant was shut down after a waste line breached ELVs for dioxins and furans. Improvements were required before restarting the plant (Environmentalist 2013; SEPA 2012).

Operational difficulties have resulted from extending an old technology to new purposes. Gasification originated two centuries ago in a process converting peat or coal to a synthetic gas, known as syngas. In the 1990s the technology was extended to biomass fed to integrated gasification combined cycles for high-efficiency power production. From 2000–2004 onwards the focus changed to producing various biofuels. Both trajectories had some technical failures (Piterou et al. 2008; Kirkels 2014). Further investment depended on raising confidence.

In the past decade gasification R&D has been extended to heterogeneous feedstocks, especially MSW. The process often generates tar-forming contaminants in the syngas. MSW feedstock poses difficulties that can disrupt the treatment process and reduce energy recovery. A reliable process depends on feedstock pre-treatment, thus reducing net energy yield. According to government guidance on gasification:

... due to lower operating temperatures, steam pressure and parasitic loads (i.e. energy required to run the plant) the overall process may be less efficient than conventional incineration. (DEFRA 2014a: 29)

For treating MSW, early gasifier designs prioritised regulatory compliance rather than resource recovery:

ACTs-ATTs promise better recovery of resources. But this has not been generally the priority for plant designs, which instead have aimed to improve environmental compliance for waste disposal, by effectively destroying air pollutants and vitrification of the solid-process residues partly with materials recovery using high combustion or gasification temperatures, thus saving disposal costs or raising additional revenue, though largely at the expense of overall energy output. (Malkow 2004: 56)

Commercial gasifiers treating residual MSW burn the syngas in a steam turbine, with a result similar to EfW incinerators. Other features are represented as a modest improvement, either within or beyond incineration. Hence:

... whilst this [gasification] is not incineration, the differences between the processes in practical and efficiency terms are much more modest. (DEFRA 2013: 5)

Indeed, cognitive distinctions between the categories of incineration and gasification can be subtle, even contentious, despite the technical distinction between them. With this caveat in mind, Table 1 differentiates among thermal treatments according to their promoters. All options are amenable to moving up the waste hierarchy, for example, via a prior recyclables-separation, heat export and post-treatment vitrification of bottom ash; the latter has been rare for incineration in the UK. Stakeholders’ representations differ in significant ways, as analysed in the following sections and summarised in Table 2.

#### 4.2 Blurring the technological distinction

ATT and incinerators have become more blurred, but from two contrary standpoints. Opponents and supporters of incineration emphasise its negative and positive features, respectively. As a cognitive anchor, incineration serves two opposite strategies.

**Table 1.** MSW thermal treatments according to promoters

| Technology  | Objectives or advantages   |
|---|--|
| Incineration followed by landfill of bottom ash or reuse after clean-up | Cost minimisation (under present policy regime for waste and climate issues)<br>Tolerance of heterogeneous feedstock<br>Flue-gas combustion of hazardous substances                              |
| Gasification (two-stage combustion) followed by vitrification           | Waste-volume reduction with inert output<br>In-built combustion of hazardous substances, needing less (or no) end-of-pipe flue-gas cleaning<br>Scalable (i.e. financially viable at small scale) |
| Gasification with plasma-fication: experimental stage                   | High-quality clean syngas production<br>High-temperature process tolerating heterogeneous feedstock  |

On one side, gasification is ‘incineration in disguise’, according to the Global Alliance for Incinerator Alternatives (GAIA). Despite claims for safe and green ATTs:

... all these technologies emit dioxins and other harmful pollutants into the air, soil and water, and they are defined as incineration by the U.S. Environmental Protection Agency and the European Union. (GAIA n.d.)

For the main UK campaign group involved in opposing thermal-treatment proposals:

People should focus on the exit strategy for incineration, not whether one form of incineration should be preferred over another. (UKWIN 2010)

Conflating various types of thermal treatments as ‘incineration’, the campaign group opposes them all for wasting financial and material resources:

Incineration depresses recycling, destroys valuable resources, releases greenhouse gases, and is a waste of money. Incineration has no place in the zero waste closed-loop circular economy we should be working towards. (UKWIN 2010)

On the other side, incinerators have undergone improvements. Public protest has stimulated technological change for better flue-gas cleaning to comply with legal requirements. Some new incineration plants adopt a technology which could fulfil more stringent standards, anticipating future regulatory changes (JRC 2011: 8).

Moreover, incineration promoters emphasise the benefits of energy recovery, which gains no inherent advantages from ATTs (CIWM 2013). According to one company, its ‘mass-burn’ technology is already an ATT, on grounds that its novel low-oxygen combustion process reliably increases the potential for efficient recovery of energy and materials, avoids hazardous emissions or even the need for stacks to eliminate them (Sigg 2014). A company manager promotes an industry-wide argument for incineration on the grounds that it achieves much higher energy efficiencies than gasification:

Various organisations are looking to promote new technologies, when the established ones [incineration] are at the forefront of technological development.

**Table 2.** UK cognitive framings of ATT (Advanced Thermal Treatment) for MSW

| Actors  | Aim or strategy  | Social representations (anchors) and expectations   |
|---|--|---|
| Nongovernmental organisations (e.g. UKWIN)                | Oppose incineration, including any ATT   | Anchor ATTs in negative features of incineration (e.g. hazardous emissions and bottom ash, dependence on 'feeding the beast', recycling deterred, surplus heat vented etc.)<br>Raise doubt about private-sector investment in 'advanced' gasification (bottom row) and thus doubt about its promoters' expectations   |
| EfW industry, CIWM<br>DEFRA, GIB and REA (and affiliates) | Support mass-burn incineration as ATT<br>Promote two-stage combustion gasifier as an advance beyond incineration | Compare incineration improvements with gasification's positive features (e.g. control of hazardous emissions, waste-volume reduction, bottom-ash reuse)<br>Anchor gasifiers in incineration's positive features (reliable operation and bankability), while avoiding or improving its negative features (e.g. via in-built combustion of toxins, small-scale financial viability, need for only local waste etc.)<br>Promote technological expectations to mobilise support from state bodies and private finance<br>Turn expectations into requirements via incentives (e.g. DEFRA's demo projects, DECC's electricity subsidy for ATTs (Renewables Obligation Certificates), GIB's co-investment for a 'demonstration effect')<br>Demonstrate reliable operation to 'prove' technologies and so build confidence, as a step towards investment in 'true' or 'advanced' gasifiers (see bottom row) |
| Local authorities (a few cases (e.g. MK, Glasgow))        | Justify a new thermal treatment facility with a two-stage combustion gasifier                                    | Anchor small-scale gasifier in incineration's positive features, while avoiding or overcoming its negative features (as above), thus avoiding stigma of incineration<br>Base 'proven' reliability on reference plants, including UK demo plant. Also base financial viability on operational subsidy. Both supports arise from technological expectations of UK state bodies (as above)<br>Justify a new thermal treatment facility as better than (or not) incineration  |
| DECC, DEFRA, ETI, REA (esp. Air Products and APP)         | Promote plasma-gasification for cleaning syngas  | Anchor ('true' or 'advanced') gasification in natural gas and/or hydrogen for fuel cells as flexibly substituting for fossil-fuels<br>Raise such expectations to mobilise state investment in experimental plasma-gasification plants (e.g. ETI/APP)  |

See the References section for full names of actors

Lower three rows show how stakeholders combine expectations with social representations

Providers of established technologies also undertake significant work to reduce emissions: 'plants operate well within the defined limit'. On all these grounds, the sector questions support measures favouring ACTs-ATTs over conventional incineration:

ATT is driven by the UK subsidy regime, which perversely gives more support to unproven technologies in the UK residual waste treatment market. (Allin 2015)

By contrast, other stakeholders represent ATTs as advantageous in numerous ways (e.g. as localising waste management). MSW gasifiers were initially small-scale plants, that were necessary to obtain external finance and investment decisions for a novel technology before it was widely seen as 'proven'. According to the European Commission:

In contrast to mass burn incineration, which is optimised around large-scale single site implementation, many gasification and pyrolysis processes lend themselves to economic implementation at smaller scale. (DG Envt 2003: 7)

Gasifiers are commercially scalable: they 'can operate at higher efficiency on a smaller scale than traditional incineration plants' (Spice 2013), given the latter's fixed costs for end-of-pipe flue-gas cleaning.

A similar localisation perspective comes from the Energy Technologies Institute (ETI):

Most UK communities don't produce enough MSW to be economically viable for current-scale technologies, e.g. incineration. A town scale plant is a major development opportunity [offering] benefits in efficiency and reductions in transport impacts including costs. (Evans 2014)

According to this expectation, small-scale plants will avoid the 'feed the beast' driver of mass-burn incineration, while also more readily finding nearby users for the heat.

As a widespread technological expectation, ATTs carry the further promise of cleaning the syngas for independent use outside the EfW plant, thus allowing more flexible substitution of fossil fuels (cf. DECC 2012: 72). According to the ETI's Chief Executive:

... we believe that improved technology for the integrated gasification of waste together with gas clean-up and subsequent combustion of this cleaned gas in either a gas reciprocating engine or turbine would provide an effective and efficient solution. (ETI 2012)

According to an expert talk for the Renewable Energy Association (Stone 2012: 5), thanks to their versatility:

... the technologies could in time deliver biofuels to replace fossil fuel, or chemicals such as ammonia, or indeed gas to the gas grid.

ATTs have a flexibility which:

... enables production of renewable heat and power, fuels, gases such as hydrogen, and/or chemical intermediates. (REA 2014)

The latter benefits conflate future expectations with current technology.

Despite its early limitations, syngas combustion can be done at higher temperatures. This offers potentially greater energy efficiency than directly combusting the original fuel, thus going beyond the inherent thermodynamic limits of incineration. Advocates expect gasifiers to eventually improve energy efficiency, as an extra reason to invest in current plants and thus to build confidence for future investment (interview, Green Investment Bank, 17 December 2015).

The UK government likewise has emphasised expectations for energy benefits from future gasifiers, as a rationale for subsidising current two-stage combustion gasifiers through the Renewables Obligation (RO; section 3.1):

In the longer term, as the technology becomes more advanced, the use of syngas may make a significant contribution to our renewable energy and low-carbon ambitions and it has therefore been afforded the same financial support as biogas produced from anaerobic digestion under the RO. (HMG 2009: 110)

Waste provides a potentially valuable source of biomethane through number of technologies including anaerobic digestion, gasification and pyrolysis. (DEFRA 2011: 11)

This despite the fact that only AD was already providing clean biomethane.

Operational subsidy has been a crucial but insufficient basis for investment decisions. Uncertainties about reliable operation have high stakes: any malfunction would create a large waste backlog, thus reverting to landfill and incurring financial penalties. Investor confidence depends partly on due diligence assessments of engineering risk and hence financial risk.

DEFRA has sought to provide such confidence for less-well proven alternatives, by testing technological expectations through plant performance. Its New Technology Demonstrator Programme (NTDP) aimed:

... to prove the economic, social and environmental viability (or not) of each selected technology.

The layout of projects was designed to allow visitors to see the positive features (Reno 2011). Of the nine projects funded by the NTDP, two were gasifiers. In particular, Energos' pilot plant was retrofitted into an old incinerator in the Isle of Wight. The company represented the gasifier as a localised energy solution (MPS 2007). Experts raised doubts about whether the two-stage combustion process 'is really a gasifier' (interview, DEFRA, 14 April 2016). After the company negotiated Ofgen's technical criteria for an adequately low-oxygen process, the technology was officially validated as 'gasification' – the first ATT to be accredited for ROC subsidy.

After starting operation in 2008 the Energos plant initially breached statutory limits on dioxin emissions, though the problem was later resolved (*Let's Recycle* 2011). The dioxin was attributed to parts of the old retrofitted incinerator installation (Mott MacDonald 2012: 12); this fault was represented as separate from the gasifier. Other operational difficulties persisted, so the Council eventually sought:

... to reduce reliance on the gasification plant, which has in the past proven to be unreliable. (Sloley 2011; IoW 2012: B-3)

Nevertheless the plant became a national showcase for gasification and its ROC eligibility, in turn helping to gain contracts from several local authorities (see Section 5).

Some two-stage combustion gasifiers are considered technically 'proven' and so warrant investment, according to the Green Investment Bank. Moreover, these are a transition (or gateway) technology towards future MSW gasifiers that can produce a clean syngas for a gas turbine. More operational data on current gasifiers is sought to address concerns about financial risk, to achieve a 'demonstration effect' and thus to encourage private-sector investment in advanced gasifiers (interview, Green Investment Bank, 17 December 2015). As an extra expectation for inward investment:

... the Government's support for new ACTs means that the UK has become an internationally appealing market for the development of energy-from-waste projects using newer gasification and/or pyrolysis technologies. (GIB 2014)

Together these future expectations have informed the Green Investment Bank's decisions to co-finance at least four different two-stage combustion gasifiers, including an Energos plant for a waste-management contract with Derby Council (see Section 5.1).

Although ATTs carry the promise of better energy recovery, few have fulfilled the statutory criteria, for several reasons. Tars make the syngas unsuitable for any external use, so it is generally combusted on-site, thus counting as disposal. Reliable operation depends on energy input to pre-treat the feedstock, thus imposing a parasitic load and reducing the net energy output or efficiency relative to incinerators. Given this energy loss, achieving the R1 65% threshold depends on significant heat use (e.g. via a district heating system, which cannot easily be retrofitted).

Citing the EU criteria, the protest group UKWIN opposes ATT plants as similar to incinerators regarding energy inefficiency:

Chapter 5 also makes clear the general unacceptability of incinerators that fail to meet the Waste Framework Directive definition of Recovery. This is bad news for the large number of Gasification and Pyrolysis plants currently proposed because they would be so inefficient that they would not meet the unambitious R1 Formula Threshold. The EFW Guide makes clear that incinerators are Disposal unless demonstrated otherwise, placing them at the bottom tier of the Waste Management Hierarchy. (UKWIN 2014)

Moreover, argue such critics, optimistic expectations are repeatedly shifted to future trajectories:

Where gasification or pyrolysis facilities have been attempted, they have either failed to live up to these promises or have been suspiciously quiet about reporting their actual performance. Proponents of such technologies appear to lurch from one supposedly 'sure bet' technology to another, leaving a trail of failures and bankruptcies in their wake. (UKWIN, personal communication, 20 March 2016)

Regardless of the technology in a new thermal-treatment plant, public objections generally associate ATTs with incineration. They emphasise amenity issues such as: odour, dust, noise, traffic, litter etc. From DEFRA's perspective, health concerns are more a matter of perception than substance. Public concern founded upon valid planning reasons (known as 'material considerations') can be taken into account when considering a planning application (DEFRA 2013: 32). Hence UK planning applications for ATT plants have drawn similar objections as conventional incineration (EA 2014; Llanelli Star 2014). Partly for such reasons, several proposals for ATTs have been delayed or rejected by local authorities. Section 5 examines how some local authorities have anticipated or addressed such concerns.



## 5. Local authorities comparing options

When local authorities consider and plan new waste-management facilities, various treatment options are in competition. In general, contracts have been gained for conventional EfW incinerators as reliable, familiar, bankable technology. Exceptionally, so has Energos' two-stage combustion gasifier in Glasgow, Milton Keynes and Derby, the latter plant co-funded by the Green Investment Bank. All benefited from the Isle of Wight plant demonstrating eligibility for ROC as well as operational feasibility. These decisions illustrate a temporal change in social representations, both influencing and reflecting socio-technical change.

This section analyses how similar issues were represented for different decisions by local authorities. Within this broad category of practitioner, favourable representations of gasifiers are only shared to some extent. Their commercial prospects depend partly on a differential anchoring in positive and negative aspects of incineration, while also validating earlier expectations for combustion gasifiers.

### 5.1 Representing gasification *vis-à-vis* incineration

Several years before Leeds City Council solicited tenders for an energy recovery facility, the Council had expressed a preference for incineration. This was:

... primarily due to the likelihood of [PFI] funding being received, as the technology is well understood, safe, proven and reliable, and can complement recycling and recovery programmes.

As it also acknowledged:

... some alternative technologies have gained credibility since the completion of the options appraisal, and the Council is therefore committed to ensuring that there is full opportunity for a range of solutions to come forward during procurement. (Leeds City Council 2007: 90, 11)

In 2012 the Council chose a tender proposing recyclables removal, mechanical pre-treatment plus conventional incineration (Leeds City Council 2013). Competing bids included Energos' gasifier, which Leeds Council staff considered (e.g. by visiting the company's Norwegian plants). But the Council had doubts about the gasifier's reliability and energy efficiency. Its concerns included: the need to avoid teething problems, experimenting and potentially crippling costs; also a high parasitic load that reduces the environmental benefit of the technology (interview, Leeds City Council, 6 July 2015).

By contrast, some local authorities have chosen a facility combining a gasifier plant with two others: a mechanical biological treatment (MBT) plant removes recyclables (especially dense plastics and metals), as well as removing biodegradables for an AD plant, generating biogas; the AD's digestate is sent to the gasifier. These material flows go higher up the waste hierarchy than incineration alone, yet the necessary energy inputs result in a minimal benefit for overall energy recovery (interview, DEFRA technical expert, 14 April 2016). The ROC subsidy helps indirectly to pay the extra costs of removing recyclables.

In some cases a gasifier has been chosen for one or more advantages. These include: an in-built control over hazardous emissions; the potential for further reducing such emissions to accommodate more stringent standards; lower-volume production of bottom ash, with potential for high-temperature vitrification; greater or financial viability for a small-scale plant, in turn sought for localising waste management (as regards waste transport and heat use), or simply for

a small available site. Such features have been represented as 'not incineration', though this distinction is criticised by the latter's opponents and advocates in various ways.

A market leader has been Energos' two-stage combustion gasifier, which already had a long track record in the company's base in Norway, where several small-scale plants were designed to supply heat for local users as well as power. By 2011 Energos' plants around Europe had been operating for a half-million hours, as a basis to carry out due diligence on plant reliability, alongside the DEFRA-funded demo plant, according to the trade press (*Let's Recycle* 2011). Energos:

... has delivered eight such facilities across Norway, Germany and the UK, accumulating more than 650,000 hours of operation over 15 years. (Messenger 2014)

The company promotes its 'fully proven, bankable gasifier' – by contrast with some designs which 'are horrendously complex' (Goulding 2016b).

In Glasgow's competitive bidding for an energy recovery facility in 2013, the Council chose Viridor's tender, which integrated three processes. Its new Glasgow Recycling and Renewable Energy Centre (GRREC) at Polmadie would combine Energos' gasifier with a smart materials recycling facility, diverting biodegradables to the AD plant. Outputs from both plants would provide a relatively homogeneous feedstock for the gasifiers to produce syngas. The gasifier and AD plant each qualify for double-ROC subsidy under current criteria. Viridor also set out a plan to supply residential and industrial heat users up to two kilometres away, qualifying for a subsidy under the Renewable Heat Initiative.

Among the several tenders received by Glasgow in 2012, Viridor's was chosen as best fulfilling the Council's overall criteria. The facility was designed for recycling and energy recovery, accommodating Scotland's zero-waste policy (interview, Viridor, 18 September 2015; cf. Natural Scotland 2010). As another advantage, the gasifier offers relatively more complete combustion of the hazardous gases NO<sub>x</sub> and SO<sub>x</sub>. This mattered for the Council's anticipation that UK emissions standards would soon become more stringent (interview, Glasgow City Council, 9 July 2015).

Glasgow's decision marked a shift from a few years earlier, when its own waste plan raised doubts about gasification as a reliable or bankable technology: expectations had been less positive. At that time, moreover, gasification was described as 'potentially perceived by public as incineration by another name' (Glasgow CC 2009: 27, 222). Greater operating experience by Energos helped to validate earlier positive expectations and hence strengthen positive representations, at least in Viridor's tender and in the local authority's public statements. When the company submitted its 2012 GRREC proposal (as above), a small protest group Glasgow Alternatives to Incineration negatively compared the gasifier to incineration (CCGC 2012) but was unable to block the proposal.

### 5.2 Choosing a gasification plant in Milton Keynes

Milton Keynes likewise illustrates a temporal shift towards a pro-ATT policy, whereby social representations reinforced the earlier positive expectations for Energos' technology. In 2012 Milton Keynes Council announced a contract with AmeyCespa for a new Waste Recovery Park integrating three plants: mechanical treatment (MT), biological treatment (BT) in the form of AD, and Energos' gasifier (MK Council 2012). The MT plant separates some recyclables and sends fine material to the AD plant, which in turn sends the digestate residue to the gasifier. The latter was successfully

promoted as better than mass-burn incineration, thus facilitating approval of the facility.

By contrast, when a waste company had proposed a new incinerator in 1999, public protest deterred its approval. The Council soon adopted a new policy: ‘no incineration in Milton Keynes Borough’. Afterwards a public consultation process revealed some ambiguity about the term ‘incinerator’. So the Council clarified that this term meant ‘mass-burn incineration’ — by contrast with modern or advanced thermal treatments. It also adopted the principles of proximity and self-sufficiency for waste treatment (MK Council 2005). Eventually this was clarified to mean ‘no sending waste to an incinerator anywhere’, while also exempting ATTs from the pejorative category.

As one of the UK’s fastest-growing cities, Milton Keynes anticipated a need for greater waste-management capacity. In 2006 the MK–Northampton joint waste authority was discussing a new facility, including a thermal-treatment plant. The authority foresaw ‘high-risk’ planning difficulties (Let’s Recycle 2006), given the public stigma of incineration. In 2010 this plan collapsed anyway when DEFRA withdrew Private Finance Initiative (PFI) funds, on grounds that most local authorities had sufficient waste-treatment capacity to fulfil their statutory obligations for landfill diversion.

The Council next translated its various environmental principles into criteria for a new facility. Its call for tenders sought the following:

Facilities which ideally provide a total solution from receipt of waste to final recovery on one site (a ‘closed loop’) ... The key driver for the Council is to drive waste up the waste hierarchy, removing reliance on landfill, and to generate energy ... The solution is expected to comprise of mechanical sorting, recycling, energy recovery and advanced thermal treatment. (MK Council 2011a: 3; for details see MK Council 2011b)

In parallel, general policy specified that any new facility must divert more biowaste from landfill and include a meaningful BT (MK Council 2011c).

In that period Council waste-management staff anticipated difficulties in gaining planning permission:

‘Planning risk’ is always a major consideration on any waste project, from a simple waste-transfer station through to large scale EfW projects. There are many aspects to consider – e.g., site suitability, visual impacts, transport impacts, technology choice, need, etc. Clearly any EfW or MBT plant built in relation to the joint project would have a high planning risk. (interview, MK Council staff, 7 August 2015)

To deal with this political risk, the Council’s waste-management unit sought to persuade other staff and councillors about the relative benefits of waste-treatment technologies. Gasifiers were clearly distinguished from incinerators:

DEFRA’s New Technologies Demonstrator programme included gasification ... These plants showed that ‘small scale’ was possible and that ATT/ACT technologies had lower inherent emissions. Also MK Council worked with other waste-disposal authorities (Bucks, Beds and Northants) which all had tours of technologies in Germany and perhaps elsewhere too. These opened eyes to gasification, which wasn’t a new technology but had a new use for residual waste. I took Council members of all political parties to see the Energos plant in the Isle of Wight. Despite being retrofitted into an existing site, it worked well, which helped convince Council members that some thermal treatments are OK (personal communication, MK Council staff, Sept 2015).

Thus positive representations of ATTs drew on future expectations from demonstrable experience. This helped to validate Energos’ gasifier as fulfilling the requirements for reliable operation and emissions control:

... the Energos gasifier was bankable, due to its long operating hours in reference plants. (interview, MK Council staff, 7 August 2015)

An MT plant will pre-treat the MSW for the gasifier, which otherwise would have difficulty treating large, heterogeneous particle sizes. The overall facility will receive a double ROC subsidy for the gasifier plus AD plant.

Under a new business model, moreover the Council takes ownership of the completed facility, while sharing financial risks and benefits with the operator, as a basis for positive financial expectations associated with the technology. The waste-management contract is forecast to provide MSW feedstock for half the facility’s capacity (Hevia 2015), leaving the remainder available for third-party merchant contracts, i.e. for treating commercial and industrial waste:

Our plant does not have a ‘feed the beast’ issue because it is our plant, unlike a PFI contract. We could take the waste elsewhere, or recycle more, or put in more waste. We want to minimise our own waste input to the facility so that it can take more third-party waste and so increase the income. (interview, MK Council, 7 August 2015)

Alongside the Council’s proximity principle, the contract arrangement helped to avoid the familiar criticism about an in-built disincentive against recycling waste.

The integrated three-plant facility prioritised the Council’s objectives: reducing the waste sent to thermal treatment, and maximising energy recovery from the residual waste. According to the contractor:

This is a direct application of the waste hierarchy – not the cheapest solution for waste management. Any facility has a triple bottom line involving a difficult balance among the three objectives of economic, environmental and social sustainability. MK Council gave priority to the environmental objective ... The Council was able to pursue a small-scale facility because it had a clear vision of what it wanted. (interview, AmeyCespa, 7 August 2015)

The Council supported the contractor in carrying out a six-month borough-wide community consultation and liaison process (Messenger 2013). According to the contractor, the facility:

... will make the most of people’s everyday rubbish, ensuring as much is recycled as economically possible as well as generating renewable energy and creating electricity from waste which would otherwise have gone to landfill. (AmeyCespa, 2013)

The Council’s consultation strategy distinguished the plant from incineration:

Our publicity made clear that this is not mass-burn incineration and has a low chimney stack, with inherently low emissions; also that the mechanical pre-treatment plant removes recyclables. The process took only 11 weeks to get planning permission, faster than for many other kinds of consent .... The Council received only three objections, none directly about the gasifier (interview, MK Council, 7 August 2015).

Thus after several years’ discussion, the overall facility had a socially shared representation as better than (or as not) incineration and as environmentally desirable.

## 6. 'Advanced' gasifiers constructed

A next technological step cleans the syngas for independent use, resulting in 'true' or 'advanced' gasification (Jordan 2013; WtERT UK n.d.); this could more flexibly substitute for fossil fuels (see Section 3). Yet the clean-up effort requires plant downtime and careful maintenance to keep the plant running, as well as significant energy input. As extra technical challenges, 'EfW technologies must be able to cope with waste variabilities', including heterogeneous shape and moisture content (Evans 2014).

Gas tarring remains a key difficulty for gasification of heterogeneous feedstock such as MSW. UK government guidance emphasises difficulties in realising the optimistic expectations:

The latter routes have the potential to convert the energy from the waste more efficiently than through steam generation, which makes them attractive. However, they are technically difficult, relatively unproven at commercial scale, and some of the generated energy is used to power the process, reducing the overall benefits ...

The greatest challenge is ensuring the syngas produced is pure enough for the chemical reactions required to make the fuel to work. This purification or 'gas clean-up' step can be energy intensive and reduce the overall efficiency of the process. (DEFRA 2014a: 5, 31)

Citing those difficulties as financial disincentives, opponents from nongovernmental organisations question any positive expectations for future technological improvement:

The purpose of syngas cleaning is to remove as far as possible all solid and gaseous contaminant matter:

- that conflicts with the purposes to which it is desired to put the syngas ...
- that contributes to toxic emissions when the syngas is combusted ...

Such [cleaning] packages will be extremely costly and it is unlikely that the operators of waste gasifiers will wish to include one, relying rather on post-combustion capture of toxic emissions. (UKWIN 2010)

In this sceptical account, commercially viable gasification will effectively remain incineration in the long term.

For UK experimental plants that clean the syngas, company investment has depended on state support. The ETI co-financed the demonstration plant of one such operator, Advanced Plasma Products (APP). APP emphasises the benefits of its Gasplasma® process as follows:

For many years, developers have been trying to convert waste into a gas that can be used in a gas engine for electricity and heat generation. APP has overcome the major obstacle to the use of waste gasification to power such gas engines. (APP 2013)

A novel process is made familiar via anchoring in natural gas for its flexible energy advantages, especially substituting biodegradable waste for fossil fuels. For example, APP's Gasplasma® process:

... is a game changer for managing waste in the built environment as it produces no waste outputs and has low emissions.

Moreover:

APP is also pioneering the development of cost-effective hydrogen from syngas, which can revolutionise several industries... as this helps mitigate the fluctuation of gas pricing and supply. (cited in Reyes 2013)

The company has participated in the Bio-SNG project 'to transform waste into bio-substitute natural gas', a 'clean gas with multiple applications' (APP 2013). Promoting such expectations, the company gained a £11 government grant for a Swindon plant to turn household waste into vehicle fuel; APP leads a consortium including National Grid, Progressive Energy, and CNG Services, a company which provides gas for use in vehicles (BBC 2015).

Another UK company, Air Products (2012), likewise has emphasised 'syngas usage flexibility for future projects'. With private-sector finance it began constructing two plasma gasification plants using technology from Alter NRG, which has 'multiple plants in Japan with almost ten years operating experience'. As a key benefit, the high-temperature process can accommodate heterogeneous feedstock composition. The company also made a claim for better energy efficiency, on the grounds that the overall design compensates for the extra energy demand:

Parasitic load is higher than conventional incineration, but the combined cycle allows higher energy-recovery efficiency, giving higher energy output/tonne MSW and higher biogenic offset of CO<sub>2</sub>; ... the higher parasitic load is easily compensated by the higher generation of electricity per tonne of waste. (Air Products quoted in EA 2014: 23)

Extra benefits were expected from further technological development:

Longer term, this plant has the potential to generate a renewable source of hydrogen for commercial use, for example to fuel public transport. (Air Products 2011)

Taken together, these social representations for an energy transition beyond the internal combustion engine, reinforced beneficent expectations.

Yet such expectations have been undermined by pervasive technical difficulties, partly due to the novel scale-up. According to an Alter NG engineer (Goulding 2016b):

The technology has been employed at several plants but never at 1000 tonnes per day. This [Tees Valley plant] is the first of its size and type, so start-up delays can be expected. (Goulding 2016b)

Why such upscaling? The project's private finance apparently depended on expectations for high-volume gate fees by the 2014 start-up.

Given the technical difficulties, the company stopped constructing one plant in autumn 2015 and then the entire facility in early 2016:

We pushed very hard to make this new EfW technology work [but] additional design and operational challenges would require significant time and cost to rectify.

Moreover, the company decided to leave the EfW business (Air Products 2016).

From this high-profile collapse, critics represented ATTs as destructive:

UKWIN is unsurprised that Air Products failed to get an unworkable technology to work. ... Investment should focus on sorting technologies [e.g. MBT] and other infrastructure that will move us towards a circular economy, not wasted on disposal technologies which – even if they worked – would still be destroying valuable materials whilst exacerbating incineration overcapacity. (cited in Perchard 2016)

Thus, the project's failure became an opportunity to criticise the systemic role of thermal treatment in the waste hierarchy.

## 7. Conclusions: Linking expectations and representations

As a relatively low-cost alternative to landfill, MSW has been increasingly sent to incineration, extended to EfW plants. Public controversy has opened up opportunities for alternative means of waste management. In particular, gasification plants have been gaining R&D investment, operational subsidy and local authority contracts, yet some proposed plants also attract controversy. Various comparisons with incineration arise in public debate, stakeholders' strategies and institutional decision-making.

Here we have analysed diverse cognitive framings of gasification *vis-à-vis* incineration among UK stakeholder groups. The analysis has linked two theoretical perspectives: future technological expectations mobilising resources (van Lente 2000; Borup et al. 2006; Konrad 2006) and social representations assimilating new ideas through anchoring onto familiar frames of reference (Moscovici 1984, 2000). Expectations relate entirely to the future, while representations relate largely to the present. Both undergo temporal changes which can overlap in stakeholders' strategies. And both can undergo a process of becoming socially shared, contingent on multi-stakeholder interactions and their discursive strategies. Practical linkages between these cognitive framings in our case study are summarised in Table 2.

Public controversy encompasses various social representations of thermal-treatment technologies, thus raising the stakes for any thermal waste-management technology and setting criteria for technological expectations. Incineration has been criticised on numerous grounds (e.g. for emitting harmful gases, for producing substantial quantities of hazardous bottom ash, and for demanding large-scale waste transport to 'feed the beast'), thus contradicting the waste hierarchy. In the polarised debate, some stakeholders favourably represent mass-burn incineration as already 'advanced', or pejoratively represent all thermal treatments as incineration. They emphasise the anchor's positive or negative aspects, respectively (Table 2, two upper rows). These contrary views have an analogy with previous case studies of social representations, e.g. the oil industry as a favourable or pejorative anchor for shale gas (cf. Upham et al. 2015).

In such ways, current gasifiers are weakly distinguished from incinerators—not only by opponents, but also in policy guidance and among practitioners. Critics cite official documents acknowledging the modest differences. A sharp distinction depends upon interactive argumentation among multiple actors in relation to the object.

Gasification is promoted in ways combining social representations and technological expectations, as summarised in the three lower rows. Through a differential anchoring, gasification is promoted as matching the positive features of incineration (i.e. reliable operation and bankability), while avoiding or improving the anchor's negative features (see Table 2, lower rows). In particular, the current two-stage combustion gasifier is promoted on several grounds at once. As somewhat socially shared expectations: its commercial scalability allows small plants to localise waste rather than feed the beast, its design has an in-built control over hazardous emissions, it minimises the volume of waste needing disposal, and it offers a potential transition towards truly 'advanced' gasification with greater benefits.

The extra adjective may seem tautological, given that gasification was already promoted within the broad category of ATT, all warranting state support despite their limitations. As in other technology cases, optimistic expectations can be shifted to newer trajectories (cf. Brown and Michael 2003). In the biofuel controversy, by

analogy, state support for a significant biofuel market has been justified as crucial for an eventual transition to 'advanced' biofuels, which thus carry the technological expectations for future sustainability.

In designing new waste-management facilities, a gasifier option has drawn on subsidy incentives or previous investment from state bodies, in turn from earlier expectations for technological improvement. In particular DEFRA's support for Energos' demonstration gasifier, turning technological expectations into performance requirements, facilitated such decisions by waste companies and local authorities. They could more readily represent the technology as reliable and bankable. In contrast, local authorities who opt for incinerators emphasise doubts about gasifiers, given their mixed record.

As gasifiers gain more positive representations, these ease political decisions which otherwise would be politically more difficult for an 'incinerator'. A few years earlier, Council staff had seen gasification as blurred with incineration or even as inferior. Eventually a gasifier was successfully represented as better than incineration, or as not incineration, within a larger three-plant facility moving the system further up the waste hierarchy. Those cognitive shifts illustrate how social representations have a temporal dimension, both influencing and reflecting socio-technical change (cf. Bauer and Gaskell 1999; Upham et al. 2015).

The two types of cognitive framings converge in direct finance for 'advanced' gasification, still largely in the realm of experimental and demonstration plants. If successful, this process would fully clean the syngas, generate a bio-substitute for natural gas and so more flexibly substitute for fossil fuels. Some technology developers anchor their experimental gasifiers in the familiar flexible qualities of natural gas, as in the current socio-technical energy regime. Others anchor their gasifiers in a link with hydrogen fuel cells, which themselves remain a future expectation. These social representations have helped mobilise R&D investment from state bodies and private investors. Such investment also reinforces expectations for advancing the technology from the current two-stage combustion gasifiers, despite recurrent technical difficulties.

In sum: linking the two theoretical perspectives, expectations and representations, highlights cognitive aspects of socio-technical change in the EfW sector, especially among key actors who publicly justify their decisions. By anchoring gasification *vis-à-vis* incineration in various ways, stakeholders' social representations set criteria for technological expectations, in turn becoming requirements to demonstrate improvement, in turn mobilising policy and financial support. By fulfilling demonstration requirements, some current gasifiers gain more positive representations, in turn influencing decisions on waste-management contracts and investment in future 'advanced' technologies.

As shown in this case study, stakeholders' linkages between technological expectations and social representations may have broader relevance to socio-technical change, especially where public controversy arises over the systemic role of a technological innovation. The hybrid perspective here can help to analyse contested representations of a technology, especially as regards its 'advance' towards an environmentally preferable one. Likewise the perspective helps to analyse how the latter representation plays a performative role in facilitating technoscientific development, contingent on whether favourable expectations can be credibly shifted to the future and whether these become socially shared among relevant groups (Brown and Michael 2003; Konrad 2006). Together these perspectives can illuminate technological innovation, its trajectory and commercial adoption.

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