Technological Forecasting & Social Change 120 (2017) 1–13

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

Linking the multi-level perspective with social representations theory: Gasifiers as a niche innovation reinforcing the energy-from-waste (EfW) regime

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ARTICLE INFO

Article history:
Received 9 May 2016
Received in revised form 21 March 2017
Accepted 21 March 2017
Available online 12 April 2017

Keywords:
Multi-level perspective (MLP)
Niche innovation
Social representations
Municipal solid waste (MSW)
Advanced thermal treatment (ATT)
Gasification

ABSTRACT

The multi-level perspective (MLP) theorises technological change as a process of niche innovations competing with incumbent socio-technical regimes. As a mid-range theoretical framework, the MLP invites complementary, more detailed theorisation of salient issues, especially the roles of socio-political agency in changing regime rules around technological competition. Taking a socio-cognitive perspective, this paper links the MLP with social representations theory, to show how a new technology is diversely 'anchored' in a familiar one for different agendas. The case study is a specific niche innovation – thermal treatments of municipal solid waste (MSW) within the UK's wider regime of energy-from-waste (EfW). Through landscape-level changes, controversy over incinerators has destabilised the EfW regime's rules. This instability has opened up opportunities for gasifiers as a niche innovation, yet gasifiers have also become an extra focus for conflict over incinerators' wider role in the waste hierarchy. Agents compare thermal-treatment options for MSW according to various criteria which have unstable, changing rules. These express different socio-cognitive frameworks, analysed here as diverse social representations of novelty. The case study offers an insiders' perspective on endogenous enactment, i.e. the conflicting roles of socio-political agency in shaping transition pathways.

1. Introduction

According to the multi-level perspective, socio-technical transitions emerge through interactions between processes at three structural levels (Geels, 2010; Geels and Schot, 2007; Grin et al., 2010). The regime represents the status quo of a particular socio-technical system, with its incumbent actors, institutions and rules. Technological niches are seen as the location where path-breaking innovations may emerge. The socio-technical landscape is seen as an exogenous environment beyond the direct influence of 'niche' and 'regime' actors. Landscape-level change may pressurise and destabilise the socio-technical regime. This instability may offer opportunities for some niche-innovations to gain momentum and to change or displace the incumbent regime.

Alongside its explanatory strengths, this theoretical framework leaves many issues open to further theorisation, especially socio-political agency in changing the cognitive rules (see Section 1). Such theoretical issues are explored here with reference to a specific niche innovation – novel techniques of thermal treatment for municipal solid waste (MSW). After some material has been removed for recycling or composting (approx. 44% in 2016), the residual waste is generally landfilled or else combusted in mass-burn incinerators. Since the 1990s they have been generally designed as energy-from-waste (EfW) plants. Competing with incinerators, various innovation trajectories have been collectively named Advanced Conversion Technologies (ACTs), including Advanced Thermal Treatments (ATTs) such as gasification and pyrolysis. In the UK, proposals for new thermal-treatment plants have attracted controversy, especially for imposing health hazards and undermining efforts to recycle waste.

To enrich the MLP, this UK case study analyses agents' social representations (Moscovici, 1988). The latter 'anchor' a new technology (gasification) in a familiar one (incineration). The study highlights socio-cognitive aspects of the regime's rules and their changes which potentially shape socio-technical transitions.

For the paper's structure: Section 1 outlines the main theoretical perspectives, i.e. the multi-level perspective (MLP) and social representations theory, as well as the research methods. Section 2 analyses how landscape-level changes around the waste hierarchy have stimulated the UK EfW regime, while Section 3 analyses gasification as a niche innovation needing and gaining support measures in order to compete in the EfW regime. Section 4 analyses pressures and efforts for MSW

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http://dx.doi.org/10.1016/j.techfore.2017.03.028

management to move up the waste hierarchy, whereby rule changes open up opportunities for alternatives to incinerators. Section 5 then shows how gasifiers compete with incinerators amidst unstable rules, generating locally contingent outcomes. Finally the Section 6 conclusions suggest the broader relevance of linking the two theoretical perspectives.

2. Theoretical perspectives and research methods

The case study is analysed by linking two theoretical perspectives. The multi-level perspective (MLP) emphasises conflicts around cognitive rules, where socio-political agents' strategies warrant further theorisation. To help fill this gap, the paper analyses 'social representations' from a social-psychological theory of cognition, as explained below.

2.1. Multi-level perspective: theoretical ambiguities

As Geels and Schot state: The multi-level perspective understands transitions arising through interactions among processes at these three levels:

(a) niche-innovations build up internal momentum, through learning processes, price/performance improvements, and support from powerful groups,
(b) landscape-level changes create pressure on the regime and
(c) regime destabilisation creates opportunities for niche innovations (Geels and Schot, 2007: 400).

If adequately aligned, those processes together enable novelties to break through into mainstream markets, where they compete with the incumbent regime (Geels, 2010, 2011). The MLP framework drew on the 'technological regime' concept as shared cognitive routines among engineers and technologists (Nelson and Winter, 1982). This was extended by sociologists of technology to include all relevant actors and their interpretations of a technology (Bijker, 1995) and/or its socio-technical system (Geels and Schot, 2007).

'Normal' innovation patterns reproduce socio-technical regimes. By contrast, regime change results from two processes: shifting selection pressures on the regime, and the coordinating resources for adapting to these pressures (Smith et al., 2005). Regime shifts occur through interlinkages and interactions between multiple developments on the three levels (Smith et al., 2010: 441). From this theoretical schema, many questions arise, amongst which the following are particularly relevant here:

- How does socio-political agency generate landscape-level changes, regime instability and technological competition?
- How does a niche innovation compete with the incumbent regime in ways accommodating, stretching or changing its cognitive rules, especially regarding environmental sustainability issues?
- How do such rules undergo change, along lines which become more widely shared?

Niche innovations can compete with the existing regime in various ways, which have been theorised as ideal-type pathways. An apparently major change may be deceptive: 'What looks like a regime shift at one level may be viewed merely as an incremental change in inputs for a wider regime at another level'. The question arises: 'Do niche-innovations and landscape developments have *reinforcing* relationships with the regime or *disruptive* relationships through pressure or competition?' (Geels and Schot, 2007: 400, 406). Amongst four potential ideal-type pathways, the most relevant to the case study are P1 and P4, as follows:

> P1. *Transformation pathway*: If there is moderate landscape pressure ('disruptive change') at a moment when niche-innovations have *not* yet been sufficiently developed, then regime actors will respond by *modifying the direction* of development paths and innovation activities (Geels and Schot, 2007: 406). An example: Urban cesspools originally provided fertiliser for farmers, but this regime came under pressures of environmental-health problems and rising urban population, providing a stimulus for a transition to sewer systems (ibid: 407; Geels and Schot, 2010: 58-62).
>
> P4: *Reconfiguration pathway:* Developed in niches, symbiotic innovations are initially adopted in the regime to solve local problems. If they have symbiotic relations with the regime, they can be easily adopted as add-on or component replacement. They subsequently trigger further adjustments in the basic architecture of the regime (Geels and Schot, 2007: 411). As a detailed example, the US traditional manufacturing regime shifted to mass-production factories through multiple innovations (Geels and Schot, 2010: 72-74).

In our case study, those two pathways are in competition. P1 describes incremental improvements in incinerators. P4 describes a gasifier being combined with an on-site Mechanical and Biological Treatment (MBT) plant. To be analysed are the characteristics, role and determinants of such different pathways.

Some studies anticipate how a niche innovation could follow different future pathways, contingent on specific types of landscape-level changes and regime-level selection pressures. As substitutes for the internal combustion engine, for example, hydrogen and battery fuel cells could follow diverse pathways (van Bree et al., 2010). Likewise photovoltaic power systems have different potential pathways: either fit-and-conform to the incumbent regime by accommodating to its current selection pressures, or else stretch-and-transform through different sustainability criteria (Smith and Raven, 2012).

A specific pathway-outcome depends more fundamentally on how regime actors influence landscape-level changes and their manifestation at regime level. Conflicting interests seek to influence policies supporting a transition and thus its trajectory; 'actors are engaged in transforming and intervening at all levels'. Their activities comprise an unstable nexus of sense-making, alliances and interventions, around which specific configurations may emerge (Jørgensen, 2012: 1000, 1008).

These dynamics depend on socio-political agency, whose role is open to different theorisations. A multi-paradigm approach considers the following bases of agency: rational choice; interpretation; power; and the deep structures in which fundamental assumptions reside. All these may be applied to the analysis of transitions, within a 'rule-based model of action, on which the MLP is based' (Geels and Schot, 2007, p. 415). Actors use rules to interpret the world, make sense and reach decisions:

> 'Hence, actors use cognitive rules and schemas, some of which are shared with others. Formal rules, role relationships and normative ties also enter in decisions and actions, because actors are embedded in regulatory structures and social networks' (ibid: 403).

In those ways, the MLP emphasises changes in various rules constraining or enabling actions, and related practices central to regime maintenance or transformation. Until recently, however, these dynamics have not an explicit object of systematic study in technological change. The MLP pathway-typology has given little explicit attention to agency and institutions in changing regime rules (Geels et al., 2016: 896).

Going further, the theory has been recently reformulated as 'endogenous enactment', whereby diverse agents continuously enact and contest potential pathways. With this emphasis, the P1 transformation pathway denotes incumbent actors modifying the regime through incremental improvements. By contrast, the P4 reconfiguration pathway denotes new entrants challenging and/or allying with incumbents, by adding on or combining new technologies to solve local problems. This focus helps to identify 'shifts between transition pathways, based on actor struggles over technology deployment and institutions' (ibid: 911).

For example, the UK's support for low-carbon transition pathways illustrates variations in a P1 pathway. Emphasising climate change as an imperative from 2000 onwards, the New Labour government strengthened support for renewable electricity technologies; financial incentives maintained the power of large energy utilities, thus constituting a deep transformation pathway. Yet subsequent governments weakened those incentives, while favouring natural gas and nuclear power. This shift limits the UK's transition, resulting in a weaker transformation pathway (ibid: 906–09).

As cited above, changes in the cognitive rules can arise through bottom-up learning, including the 'social construction of shared meanings'. Small changes in normative rules can occur through negotiation; new norms become internalised through greater experience and endorsement by authoritative actors (Geels and Schot, 2010: 50-51). In recent decades, regimes have been increasingly confronted with new sustainability criteria. 'Growing environmental awareness is a socio-cultural development that can be considered a landscape process, and which is questioning the performance of multiple regimes, whilst generating opportunities for niches' (Smith et al., 2010: 441)

In the MLP, causal agents are typically collective actors (classes, industry associations, social movements, special-interest groups) with conflicting goals and interests. Dominant groups use their power – force, domination, control, exclusion – to protect their interests against subordinate groups that seek change (Geels, 2010). In this process, agents of actors negotiate rules, e.g. belief systems, interpretations, guiding principles, regulations, roles, etc. These contests are played out in policy debates, at conferences, in journals, at workshops, struggles for research grants, etc. (Geels and Schot, 2007: 405).

2.2. Socio-cognitive representations of novelty as familiar

Social representations theory is a social-psychological theory of cognition and its societal influence, whereby actors generally aim 'to make something unfamiliar, or unfamiliarity itself, familiar'. They attempt 'to anchor strange ideas, to reduce them to ordinary categories and images, to set them in a familiar context' (Moscovici, 1984: 24, 29). In this process, some aspects are omitted, while others are brought more sharply into focus. While the phrase 'collective' representations imply universality or consensus, this theory instead emphasises 'a plurality of representations and their diversity within a group' (Moscovici, 1988: 219).

Familiarity is sought 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 to perceive novelty: '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 along with new ideas.

As a technological example, social representations of hydraulic fracturing for natural gas ('fracking') have made the technology familiar in contrary ways. In the UK debate a pervasive anchor for fracking has been the oil industry. Advocates have favourably associated fracking with local employment and domestic energy security, while opponents have pejoratively associated fracking with greedy companies buying off communities to pollute the environment (Upham et al., 2015: 16).

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, as a pejorative anchor within the same national debate, fracking has denoted industrial pollution that threatens *Trinkwasser*, crucial for purity standards of the nation's brewing industry (ibid: 11–12). Through such strategies, alternative anchors serve to promote or oppose specific technologies ibid: 16).

2.3. Research methods

For this study the main data are the views and interactions of UK stakeholder groups involved in EfW, focussing 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 as buyers or users of the technology (waste-management companies and local authorities); governmental bodies, including regulatory and innovation agencies; and intermediary organizations such as consultancies or advisory bodies (Howells, 2006).

More specifically, the research investigated the basis for waste-management contracts, e.g. how local authorities set criteria for tenders, how waste-management companies anticipate or respond to those criteria, and how authorities make decisions. By analysing available documents, we identified several organisations which had evaluated MSW gasifiers or their prospects. We asked their views on efforts and trends relating to efforts to improve energy recovery from MSW, especially the prospective roles of gasifiers. We also asked about their roles and views in relation specific cases. As a window into regime rules, the approach empirically illustrates the innovation processes relevant to the theoretical issues in Section 1.

Our focus is how agents' promote new cognitive rules which become more or less widely shared, especially in relation to different socio-technical pathways. As cognitive frames, their social representations are both individual and collective, by relating individual agents to each other. To investigate these interactions, we used four overlapping methods.

i. Document analysis: we analysed numerous documents for how they compare gasification with incineration, along the lines of our research questions above.
ii. Interviews: the document analysis informed interview questions for 15 key actors.
iii. Decision-making criteria of local authorities and waste-management companies were surveyed.
iv. Comparative matrix: Drawing on all this material, we compiled a long matrix of how key actors compare ATTs with incineration. Criteria include: future benefits, reliability, bankability, feedstock flexibility, energy efficiency, hazardous emissions, relation to recycling, etc. This matrix helped to identify selection criteria and how they relate to social representations.

The above provided a basis to analyse stakeholders' social representations of novelty, as strategies to influence and use regime rules.

3. UK EfW regime facing the waste hierarchy

Policies to divert municipal solid waste (MSW) from landfill have stimulated more mass-burn incineration plants, which have faced pressures for improvement, framed by the 'waste hierarchy' concept. Together these impose new sustainability criteria. This section briefly explains the rise of the energy-from-waste (EfW) regime around incinerators and then pressures for change.

Waste has been undergoing a shift from an economic-environmental burden to a useful resource, as conceptualised by the waste hierarchy:

> 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; also 2012).

The European waste hierarchy sets a sequence of priorities: reduce, reuse, recycle, recover, dispose, e.g. landfill. This concept informs arguments and pressures for improvement at several stages: reducing landfill waste-disposal, removing recyclables, segregating organic material (for anaerobic digestion to generate biogas), better recovery from the residual waste, reusing the incinerator bottom ash and disposing of the rest. In Europe the framework has stimulated a shift towards Energy-from-Waste (EfW) facilities, going higher up the hierarchy than landfill or incineration without energy recovery.

Landscape-level changes were turned into policy changes, especially for waste recycling and resource recovery rather than disposal. The EU Landfill Directive (1999/31/EC) obliges Member States to reduce the amount of biodegradable municipal waste going to landfill to 35% of 1995 levels by 2016 – by 2020 for some countries, e.g. the UK. Implementing the EC Directive, the UK's Landfill Tax Escalator set a timetable for annual tax increases, rising sharply since 2005 and quadrupling in the subsequent decade; this has driven up the gate fees paid to waste-management companies.

The Tax Escalator incentivised Mechanical and Biological Treatment (MBT), which removes some recyclables, especially dense plastics and metals. MBT can segregate relatively wet waste, e.g. food or garden waste, for sending to an anaerobic digester (AD). MBT systems also can produce a fuel of various kinds. Solid Recovered Fuel (SRF) denotes waste made to a defined specification as compressed pellets, used to maintain feedstock consistency. Refuse Derived Fuel or RDF denotes a lower-grade, more variable quality (Archer et al., 1995).

To help local authorities to fulfil their statutory duty for landfill diversion, since 2006 the UK's Private Finance Initiative (PFI) scheme offered subsidy for a Waste Infrastructure Delivery Programme (WIDP). This explicitly favoured recyclables removal through long-term contracts with waste-management companies. The programme funded many proposals for MBT plants, throughput ranging between 70 and 400 kt/year (House of Commons, 2002). Yet the PFI scheme also subsidised contracts with waste-management companies for large mass-burn incinerators to treat residual MSW, whose throughput ranged between 60 and 300 kt/year (see Fig. 1).

New incinerators have faced landscape-level changes. Early designs prioritised waste-volume reduction to minimise final landfill disposal of bottom ash. In some facilities, more recent designs have featured improvements in resource use. These include: removing more recyclables prior to heat treatment, generating more ‘energy from waste’ (EfW) from the residual MSW, and reusing the bottom ash for construction materials rather than disposal (Breeze, 2014).

Meanwhile the emphasis on incinerators came under attack. Large environmental NGOs advocated greater waste reduction and recycling, while stigmatising waste incineration as a ‘waste of resources’. While sharing this perspective, local opposition groups have pragmatically focused on issues considered by local and planning authorities – especially air pollution, health risks and sitting (Rootes, 2009). In some cases, local opponents successfully demanded greater recycling to stop a new incinerator (Dodds and Hopwood, 2006). The broader arguments have been taken up by more local campaigns over the past decade.

In such ways, the EfW regime also has faced criticism for undermining the waste hierarchy. A new facility depends on combining several elements: a long-term feedstock supply with a sufficient gate fee, a bankable technology and private finance, sometimes backed by state funds. Less tangibly, it needs an adequate public justification to overcome or accommodate opponents.

4. MSW gasifiers supported as a niche innovation

The Table contrasts three broad categories of thermal treatment. The second column indicates promoters' framings of key objectives or advantages, which become more complex in multi-stakeholder discussions.

As an alternative to mass-burn incinerators, gasifiers have been promoted for several advantages (see Table 1). Their commercial adoption has depended on support measures at several stages – e.g., R&D funds, demonstration plants and operational subsidy. Their technoscientific improvement and adoption have also depended on social representations making gasifiers familiar through various anchorings in incineration. Through such measures, the technological development constitutes a niche innovation, as described in this section.

4.1. Promoting gasifiers as a niche innovation

Gasification originated two centuries ago in a process converting peat or coal to a synthetic gas. In the 1990s gasification technology was extended to biomass feedstock for Integrated Gasification Combined Cycles (IGCC) for high-efficiency power production. From 2000 onwards the focus changed to the production of various biofuels (Kirkels, 2014). More recently R&D has been extended to heterogeneous feedstocks, especially MSW for producing a synthetic natural gas.

For a smooth process, MSW feedstock requires pre-treatment with energy input, known as ‘the parasitic load’, thus lowering net energy production. The process also generates tar-forming contaminants in the syngas, posing difficulties that can disrupt the treatment process and reduce energy recovery. As a potential obstacle, ‘gasification of wastes continues to face several technical and economic issues, mainly

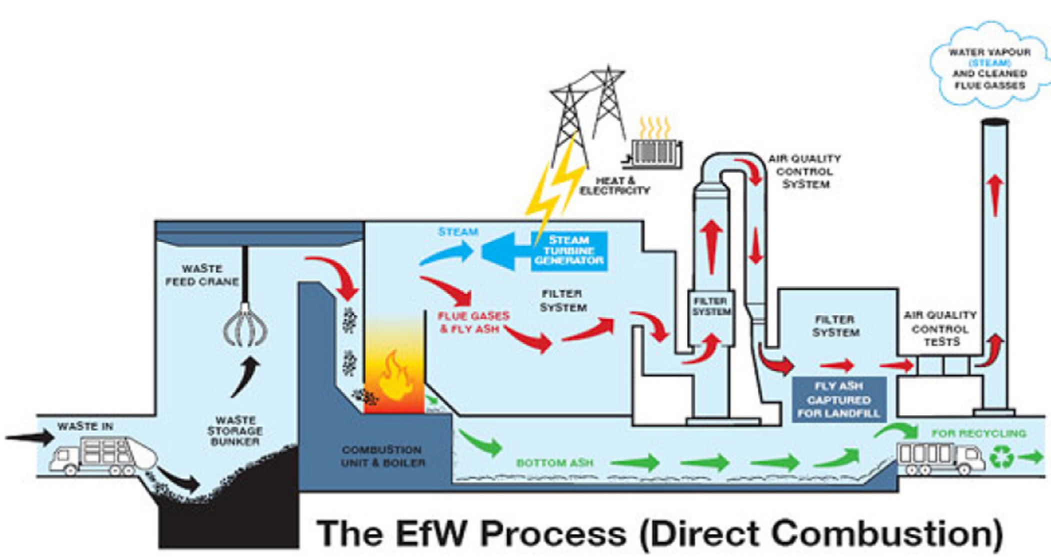

Fig. 1. Energy from Waste (EfW) incineration process, Credit: http://www.arc21.org.uk/.

Table 1
MSW thermal treatment options according to promoters.

Technology and actors	Advantages claimed
Incineration with heat recovery. Bottom ash can be reused (after clean-up) or landfilled.	Low-cost reduction of waste volume. Tolerance of heterogeneous feedstock.
Incumbent actors improve the technology (MLP's P1 pathway).	High energy recovery, even without heat use.
Gasification (two-stage combustion).	Greater reduction of waste-volume, with inert output.
Incumbent waste-management companies contract with new entrants for their novel technology (MLP's P4 pathway).	Scalable, i.e. financially more viable at small scale, using a modular system.
Gasification producing a clean syngas, e.g. via plasmafication: experimental stage	High-quality, clean syngas production flexibly available for various uses.
New entrants raise finance for their own plants.	Greater tolerance of heterogeneous feedstock

related to the highly heterogeneous nature of feeds such as municipal solid wastes' (Arena, 2011: 406).

As related limitation, moreover, early gasifier and pyrolysis designs for MSW treatment gave low priority to energy recovery, thus functionally imitating early incinerators.

> The majority of the technologies aim primarily on improving environmental compliance mainly 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: 55-56).

In treating residual MSW, gasifiers generate a syngas with tar impurities which preclude any external use. The syngas is burned in second chamber, the heat driving a steam turbine, with a thermodynamic result similar to EfW incinerators. So the new technology became known as 'two-stage combustion gasifiers', denoting that all the gas is combusted internally (see Fig. 2).

Despite those limitations, for the past decade proponents have anticipated better energy recovery through further technological improvement (e.g. DEFRA, 2007). They have emphasised the potential benefits: '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', especially through a clean syngas that can substitute for fossil fuel or be used as a chemical feedstock (DECC, 2012: 72), thus bringing facilities higher up the waste hierarchy (DEFRA, 2014). Whenever future technologies become commercially viable, this offers more flexible energy outputs, making 'waste' less burdensome and perhaps even economically valuable. Advocates expect MSW gasifiers eventually to improve energy efficiency, as a reason to invest in two-stage gasification plants and thus to build confidence for future investors (interview, Green Investment Bank, 17.12.2015).

This favourable representation has linked state and industry bodies. The Energy Technologies Institute '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). 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', according to an expert lecture for the Renewable Energy Association (Stone, 2012: 5). A UK industry body also emphasises ATTs' flexibility, which 'enables production of renewable heat and power, fuels, gases such as hydrogen, and/or chemical intermediates' (REA, 2014). Towards such aims, technology development companies design high-temperature plasmafication techniques to clean the syngas; they anchor gasification in natural gas or hydrogen fuel cells (Air Products, 2011; APP, 2013).

In sum, according to favourable social representations (see Table 1), MSW gasification brings these advantages:

- scalable, i.e. financially more feasible for a small-scale plant, which can more readily find users for the heat, thus moving up the waste hierarchy.
- less bottom ash, which can be rendered inert through high-temperature vitrification and thus safe for construction materials; and

If realised in practice, these advantages depend on no systemic change, except the need for feedstock pre-treatment, at least for two-stage combustion gasifiers.

4.2. Overcoming two valleys of death?

Innovations generally have difficulty 'bridging the valley of death between R&D and market introduction' (Geels and Schot, 2010: 80). In the EfW sector, some practitioners have extended the concept to the R&D stage, which has high stakes for performance criteria and their credible demonstration.

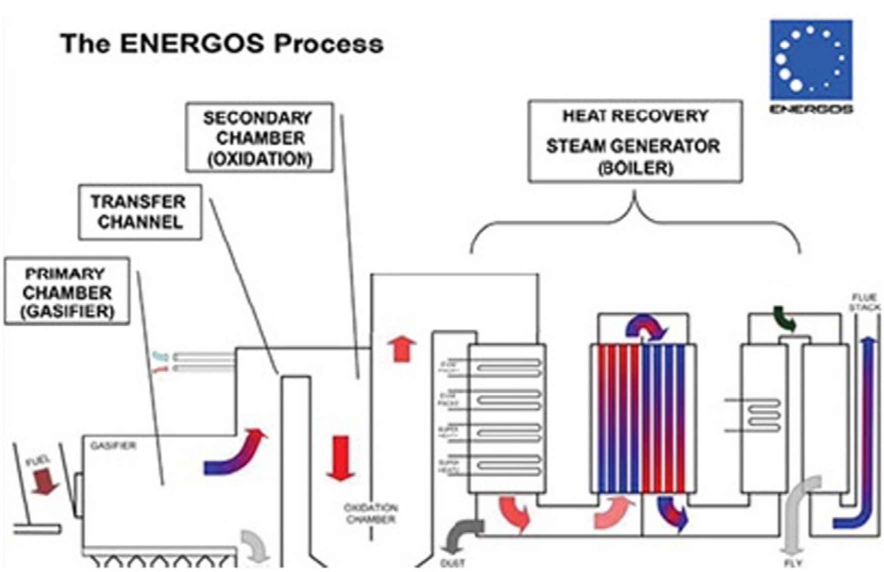

Fig. 2. Two-stage combustion gasifier, Credit: http://www.energos.com/.

> The first valley of death is proving a technology; the second is commercialising it. There is a lot of activity around trying to prove a technology [MSW gasifier], to get between the first and second valleys of death. But few have got through the second, which needs multiple exemplars before a company like ours would take it up (interview, Technical Director, waste-management company, 19.06.2015).

Gasifier development depends on a protected space through several support measures.

To overcome the first 'valley of death', a technology developer must gain confidence in operational reliability. In the early plants, the tar accumulated on the chamber walls, requiring shut-down for clean-up, thus limiting operational efficiency. There have been 'difficulties in getting investors to trust the technology' (interview, REA expert, 11.26.2015). Such uncertainties have high commercial stakes: any malfunction would create a large waste backlog reverting to landfill and incurring financial penalties, especially given the landfill tax escalator. Investor confidence depends partly on due diligence assessments of engineering risk and hence financial risk.

In the late 1990s state support was directed at several new technologies, especially gasification and pyrolysis of homogeneous biomass, with expectations for short-term commercial scale-up. In particular the ARBRE (Arable Biomass Renewable Energy) demonstration project was an integrated gasification-combined cycle system to generate electricity from dedicated energy crops. Such scale-up efforts were premature (Piterou et al., 2008: 2050). The UK focus on advanced technologies failed, at the expense of support to more mature technologies which would have helped the biomass energy sector to grow and expand (van der Horst and Vermeylen, 2011: 712; also Kirkels, 2014). Technical failures undermined investor confidence in such trajectories.

For novel alternatives, DEFRA's New Technology Demonstrator Programme (NTDP) aimed 'to prove the economic, social and environmental viability (or not) of each selected technology'. Of the 9 projects funded by the NTDP, two were gasifiers for treating MSW. In particular, Energos' pilot plant was retrofitted into an old incinerator in the Isle of Wight. The demo plant was designed to fulfil a key rule of the socio-technical regime: any novel technology must be 'proven' through standard engineering criteria – 8000 operating hours over several years.

Before the plant started operation, a crucial issue was its eligibility for funds under the Renewables Obligation. Discussions with Ofgem led to agreement that the technology design had a sufficiently low-oxygen process to be a true 'gasifier' (interview, DEFRA, 14.04.2016). Energos' gasifier became the first ATT to be accredited for such subsidy. The demonstration plant combined all those elements – essential for avoiding a 'valley of death' barrier from R&D to commercial use. Eventually this technology was adopted for contracts with several local authorities (see below).

The UK government had been anticipating better energy recovery from future gasifiers, as a rationale for all current designs to gain subsidy through the Renewables Obligation (RO): '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). The highest subsidy level, a 2.0 Renewable Obligation Certificate (ROC), was awarded to all these technologies, including gasifiers with waste feedstock. The subsidy applies also if waste is processed by ATTs such as anaerobic digestion, gasification or pyrolysis; 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 (DECC, 2014; Ofgem, 2015).

Having provided a crucial incentive, operational subsidy became less predictably available to new MSW gasifiers since the Renewables Obligation scheme was replaced by Contracts for Difference (CfD), which holds auctions for the lowest electricity price. ATTs are put into competition with offshore wind within the broad category, 'less established technologies'. The overall criteria 'will disadvantage the SMEs that are prevalent in the renewable power sector, and will favour the vertically integrated utilities that are much better equipped to launch successful auction bids under these arrangements', warns the Renewable Energy Association (REA, 2014).

The CfD scheme carries the mottos, 'least cost to consumers' and 'good value for money' (DECC, 2013), widely seen as a pretext for defunding renewable energy (interview, REA, 30.10.2015). This shift corresponds with the UK government's weaker support for renewable energy, alongside a greater commitment to natural gas and nuclear power (Geels et al., 2016: 911). For all these reasons, ATTs' future economic viability depends on increasing the energy income from gasification plants.

5. Incineration controversy destabilising the EfW regime

Proposals for new heat-treatment plants have generally attracted controversy. UK planning applications for ATT plants have drawn similar objections as conventional incineration, especially as regards amenity issues such as odour, dust, noise, traffic, litter etc. (e.g. DEFRA, 2013b: 32; EA, 2014; Llanelli Star, 2014; Marton cum Grafton, 2011). This landscape-level conflict destabilised the earlier rules of the socio-technical regime. This multi-faceted debate can be illuminated by social representations theory: each standpoint anchors gasification differently vis à vis incinerators, or vice versa.

Gasifiers have been made familiar through various social representations, deployed for different policy-market agendas. Through contrary anchorings, opponents pejoratively represent all heat-treatment plants as incinerators, e.g. as imposing their negative features, while incinerator advocates favourably represent them as ATTs thanks to recent improvements. By contrast, according to differential anchorings in incinerators, gasifiers improve the anchor's negative features – by keeping waste-flows local and minimising bottom-ash disposal (as in Table 1), while also matching its positive features, especially its reliable operation and financial bankability.

A decade ago the latter two criteria set goals for improving and demonstrating gasifiers. Optimistic expectations helped to mobilise resources, especially policy support and R&D investment, which could fulfil the criteria – most successfully for Energos' gasifier. Moreover (see Table 1), truly 'advanced' plasma-gasifiers carry greater expectations which justify state support for two-stage combustion gasifiers. Whenever encountering technical difficulties, expectations are readily shifted to newer technologies (Levidow and Upham, 2016).

While expectations are future-oriented, social representations may have any time-orientation, with conflicting cognitive frames. This section links social representations with regime-rules as theorised by the MLP. It analyses unstable, changing rules regarding health hazards and the waste hierarchy in turn. For both issues, there is future uncertainty about selection pressures for competing technological options.

5.1. Controlling health hazards?

Incineration reduces the waste volume that needs disposal but generates a hazardous fly ash, whose elimination depends on end-of-pipe flue-gas cleaning (Pena et al., 2006). Public opposition against incinerators has focused especially on health hazards. As a key rule of the socio-technical regime, the EU's PM10 standard limits toxic emissions, especially dioxins and furans (EC, 2000). But there have been many breaches by incinerators.

Public protest has stimulated technological change for improvements in flue-gas cleaning to comply with legal requirements. Some new incineration plants adopt a technology which could fulfil more stringent standards, anticipating future changes (JRC, 2011: 8). According to some incineration companies, new designs avoid hazardous emissions, even the need for stacks to eliminate them (Sigg, 2014), though this seems doubtful.

Health hazards from toxic emissions have remained contentious. According to the UK Health Protection Agency, referring to the gaseous emissions after such cleaning: ‘any possible health effects are likely to be very small, if detectable’ (HPA, 2009). The uncertainty was cautiously reversed by its Scottish counterpart: ‘small but important effects might be virtually impossible to detect’, citing a US regulatory agency. For MSW incineration the overall body of evidence ‘is inconsistent and inconclusive’ (SEPA, 2009: 66-67).

Responding to public protest, the Agency began a review of health hazards. Some experts advocated or anticipated more stringent emission limit values (ELV). Although an HPA report was originally planned for 2014, the timetable was postponed twice, provoking public suspicion (AQN, 2014). According to some proponents of gasifiers, they could more easily accommodate tighter standards for NOx, yet this technology has sometimes exceeded statutory emission limits (Sloley, 2010; Environmentalist, 2013; SEPA, 2012).

5.2. Moving up the waste hierarchy?

The waste hierarchy has been officially ‘a guiding principle’ for new treatment facilities (DEFRA, 2007: 2). ‘Government policy is driven by the desire to drive waste up the hierarchy’, e.g. through EfW plants, asserts the government (DEFRA, 2014: 67). However, long-term contracts for large incinerators do the contrary, argue campaign groups and some experts. The PFI programme and its specific plants came under attack from environmental NGOs.

> There is growing concern that the PFI process encourages local authorities to procure large, inflexible facilities such as incinerators, rather than implementing schemes to maximise recycling and provide small-scale, flexible technologies to deal with the waste left after recycling and composting (FoE, 2008: 1).

Indeed, according to local protest groups, incinerators generate pressures to ‘feed the beast’. In other words, they perpetuate a long-distance, large-volume feedstock supply to ensure that the plant recoups its investment and remains financially viable. On these grounds, new plants deter greater recycling (Connett, 2013; Gloucestershire, 2013; Seltenrich, 2013).

An NGO linking such local groups, UK Without Incineration Network (UKWIN), has opposed all thermal-treatment plants for contradicting the waste hierarchy. ‘People should focus on the exit strategy for incineration, not whether one form of incineration should be preferred over another’ (UKWIN, 2010). Representing 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).

> 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).

Put more starkly, gasification is ‘incineration in disguise’, argues the Global Alliance for Incinerator Alternatives (GAIA), which encompasses UKWIN. Regardless of the specific technology, ‘Incineration is part of the linear economy’, thus impeding a circular economy, argues opponents (UKWIN, 2016b; see Fig. 3).

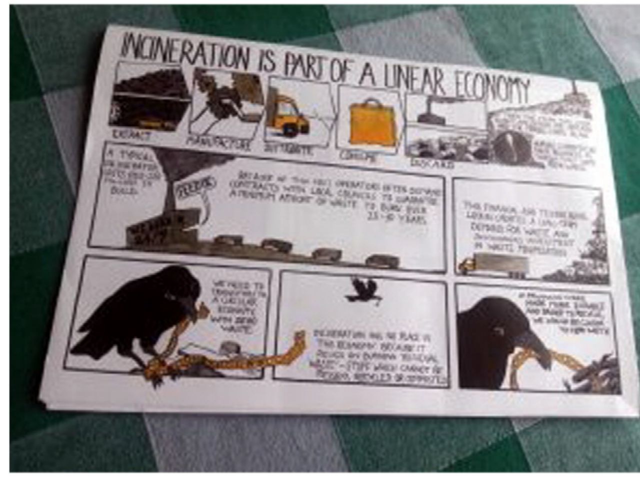

Fig. 3. ‘Incineration is part of a linear economy’, from *Everything Goes Somewhere*, Credit: UKWIN (2016b), http://ukwin.org.uk/resources/zero-waste-pamphlet/.

Industry rejects the criticism: ‘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’, argues the Renewable Energy Association (REA, 2011), which advocates state support for ATTs. Indeed, waste localisation became a more prominent argument for MSW gasifiers, e.g. by Energos (MPS, 2007). These were initially small-scale plants, anyway necessary to obtain external finance and investment decisions for a novel technology, especially before it is widely seen as ‘proven’. Gasifiers are commercially scalable: they ‘can operate at higher efficiency on a smaller scale than traditional incineration plants’ (Spice, 2013).

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).

On this basis, small-scale gasifiers can avoid the ‘feed the beast’ driver of mass-burn incineration, while also more readily finding nearby users for the heat, argue proponents.

The UK government likewise portrays incineration as potentially compatible with recycling. Crucial are ‘suitably flexible facilities and contracts – i.e. that do not “lock in” an unreasonably high proportion of waste, should waste prevention, reuse and recycling performance substantially increase’ (DEFRA: 2013a: 5).

> 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, 2014: 3).

The focus on flexibility evades the issue of incentives for high-calorific value feedstock for heat-treatment plants.

State incentives for MSW Advanced Thermal Treatments (ATTs) are criticised not only by NGOs, but also by technology rivals within the EfW regime. Incineration promoters emphasise the benefits of associated energy recovery, which gains no inherent advantage from ATTs (CIWM, 2013). According to one company, its ‘mass burn’ incineration 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 (Sigg, 2014). On similar grounds, a company manager 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).

Thus any distinction between the two categories – Advanced Thermal Treatments (ATTs) and incineration – is ambiguous, even contentious, despite the technical distinction between them. Each policy standpoint anchors gasifiers in incinerators in different ways – or else vice versa to promote the latter. Together these different social representations leave instability in selection pressures for technological choices in investment decisions, as shown in the next section.

6. Technological competition amidst unstable regime rules

In decisions on new facilities for MSW treatment, gasifiers compete with incinerators as the incumbent technology of the EfW socio-technical regime. Its rules involve conflicting cognitive frames relating the material and ideational aspects; outcomes are reflected in specific decisions on technological preferences and complementary waste treatment technologies. This section analyses the selection pressures of the EfW regime, particularly how the technologies' differing social representations relate to their institutional context.

The greatest opportunity for new waste-management contracts arose during the height of the government's PFI programme, heavily subsidising local authorities between approximately 2006 and 2010. Afterwards the programme began to decline, as the government judged that many areas had sufficient incineration capacity from current or recently commissioned plants (Let's Recycle, 2011). In recent years, there have been fewer commercial opportunities for any thermal-treatment plant, alongside greater technological competition.

As a niche innovation, MSW gasifiers were not yet sufficiently developed, or had not gained sufficient demonstration as operationally reliable, at least in the UK until around 2010. Experts cite a temporal mismatch: the PFI programme was declining, just when investors were gaining confidence in gasifiers as proven and bankable. According to an expert in a state body dealing with waste issues:

> Gasifiers had a short window of opportunity when some became proven around 2010, just before PFI funds were soon withdrawn or reduced. In that period, many local authorities lacked sufficient confidence in gasifiers (interview, waste agency, 17.12.2015).

Contributing to the mis-match, operational subsidy had an uncertain future, especially for two-stage combustion gasifiers (DECC, 2012). According to an expert advisor of the Renewable Energy Association.

> The double-ROCs subsidy available from 2009 could have stimulated the ATT sector through gasifiers for MSW treatment. But there was future uncertainty about the technology's ROCs rating, which might have been reduced in the 2012 RO review. So an opportunity was lost during the interim period (interview, REA expert, 26.11.2015).

Given the earlier pressures to go up the waste hierarchy, the EfW regime became unstable long before MSW gasifiers became demonstrably reliable. Incinerator improvements can be seen as a P1 adaptation-transformation pathway. From 2013 onwards, gasifiers can be seen as a P4 reconfiguration pathway, whereby an incumbent waste-management company contracts with a novel technology provider; the gasifier provides a component replacement to address local problems, e.g. local authorities' difficulties in justifying a new heat-treatment facility. In each case, the gasifier has been integrated with an on-site MBT plant which brings waste up the hierarchy and pre-treats the gasifiers' feedstock. Otherwise gasifiers depend on no major change in input-output parameters. The technology may look like a regime shift vis à vis incinerators, yet it is arguably an incremental change vis à vis the wider waste-management system (cf. Geels and Schot, 2007: 400).

Socio-political agents' roles, their multi-stakeholder interactions and consequent selection pressures are analysed next.

6.1. Industry's cautious perspective

Central to decision-making are waste-management companies, which generally bear the risks of any novel technology. They seek to accommodate the tender criteria of a local authority and then to obtain finance for a successful tender. Or else they plan their own Commercial & Industrial plant (C&I), also known as 'merchant', i.e. with private-sector contracts. Waste-management companies have diverse perspectives on gasifiers, according to our survey including Biffa, AmeyCespa, Sita, Viridor, etc.

They have maintained a cautious perspective towards gasifiers as an option to be considered and sometimes adopted for the company's advantage in a specific context. For example,

> We have a role to play in picking the right tool for the job, not through a technology-sexy approach, i.e. not always through gasification. We have one gasifier built and one being built…. But ATTs are more risky in the sense that there is less knowledge about their operation (interview, Technical Director, waste-mgt company, 19.06.2015).

Looking beyond a specific plant, waste companies would like to gain practical familiarity with any technoscientific development which may have future commercial advantages, yet avoid any first-mover disadvantage from technical failures.

Waste-management companies play a persuasion role vis à vis local authorities as regards appropriate technological choices. These are sometimes expressed by analogy with motor vehicles:

> To influence future developments, the best way is to make people aware that these tools are available and what are [or not] the most appropriate ones… We try to persuade the customer that a Ferrari is not the best choice for a farmer, though may be for a racetrack (ibid).

Here a racetrack denotes a context exceptionally warranting a gasifier.

Local authorities vary in their capacities, priorities and criteria to evaluate technological options. 'Local authorities recognise the economic value of waste and so drive a hard bargain for a lower gate fee. But some don't much evaluate the waste-treatment method, lacking the expertise to do so', according to staff at the Renewable Energy Association (interview, REA, 30.10.2015). 'Gasification technology has diverse processes; local authorities cannot simply buy one in a shop, and they tend to be risk averse' (interview, waste agency, 17.12.2015). The Welsh government applied several criteria to evaluate technological options, eventually finding no general environmental advantage of gasifiers vis à vis incinerators (interview, environmental officer, 07.12.2015). Amidst the technical complexities of various options, local authorities set performance criteria and then compare tenders accordingly (see next sub-section).

As the UK's market leader, Energos' gasifier has been included in contracts with several local authorities, e.g. Milton Keynes, Glasgow and Derby, generally through a waste-management company. According to a Technical Director: 'Although Energos' gasifier has lower energy-efficiency, it has lower capex and is seen as more reliable than other gasifiers through operational experience.' At the same time, he saw its technological design as closer to an incinerator than a 'true gasifier' (interview, Technical Director, waste-mgt company, 17.08.2015). Likewise most experts see this technology as 'not really a gasifier' (interview, DEFRA, 14.04.2016), especially because the syngas is burned on-site.

Less tangibly, a local authority has distinguished a gasifier from incineration, e.g. when pre-specifying an ATT (e.g. Milton Keynes in 2012) or when eventually opting for a technology 'better and cleaner' than incinerators (e.g. Glasgow in 2013). Promoters have represented a gasifier as 'not an incinerator', according to various criteria, within a broader strategy to gain support and avoid public opposition. Yet this general distinction between technologies is criticised by opponents and advocates of incineration in contrary ways (Section 4).

By 2016 the UK context was becoming more adverse for gasifiers. Subsidy became less predictably available under the Contracts for Difference scheme. At a stage where gasifiers were meant to be generating energy, some did not – or even breached statutory limits on hazardous emissions (Environmentalist, 2013; SEPA, 2012). And technical difficulties arose in constructing several new plants (e.g. Air Products, 2016; UKWIN, 2016a). As a plausible reason, the technology was scaled up too quickly, thus aggravating the difficulties in treating heterogeneous variable waste (Peake, 2016). Building four gasification plants simultaneously, the UK's market leader went into administration after cashflow problems and disputes with its contractors, involving failure to obtain completion certificates for staged works (Energos, 2016). In at least one case, the waste management company terminated its contract with an intermediary company responsible for coordinating the construction work (Morby, 2016).

After a succession of such difficulties in the UK, an EfW conference advertised a session as follows:

> Has gasification had its chance? It's been a bad 12 months for gasification, with high-profile exits from the sector and delays in plants coming online. With grate-based waste combustion the most established technology, with demonstrable long-term commercial viability, why choose gasification? And how do the economics stack up? (WtE, 2016).

Echoing industry's doubts, these sceptical questions put gasification on the defensive vis a vis the incumbent regime.

6.2. Selection pressures contingent on cognitive frames

Gasifier technologies have competed with each other and with incinerators according to various selection pressures, i.e. criteria that must be fulfilled. These can be analysed as unstable or more stringent rules – linking normative, cognitive, institutional, regulatory and technological. At first sight the rules below may seem 'rational' criteria for technological, market and/or environmental advantage.

Yet their meaning varies according to actors' social representations, expectations for future technoscientific improvement, cognitive frameworks etc. Conversely, experts emphasise the multiple contingencies in comparing options: 'The "best" technology for recovering energy from residual waste will depend on local, technical and financial circumstances' (CIWM, 2016: 5).

The selection pressures below shows how regime rules can vary with different cognitive frames, analysed as social representations, while also indicating how regime-rules become unstable or more stringent. Each criterion below starts with a headline summary, especially referring to gasifiers. Energy recovery has its own sub-section.

6.2.1. Reliable? The evidence base draws on a wide geographical experience but remains open to different interpretations

Each technology design must demonstrate operational reliability and energy recovery: Gasifiers remain sensitive to feedstock-composition control and pre-treatment, a risky contingency for the contractual obligation to remove MSW. For example, most gasifiers have difficulty with large-sized particles in the feedstock (interview, Technical Director, waste-management company, 09.06.2015).

> The technology is immature, with problems of reliable, durable operation over a long period… Also problems of low resilience to variable feedstock… The main requirement is to take away the waste day after day, with penalties if you don't. So this leads operators to choose reliable technologies to service the need, thus minimising the risk of not delivering the contractual obligations (interview, Technical Director, waste-mgt company, 19.06.2015).

Some companies eventually saw Energos' gasifier as adequately reliable for inclusion in their tender to local authorities:

> The 'risk to delivery' criterion can drive a local authority further away from ATTs, especially if they are unproven. But Energos' gasifier was already proven as reliable from experience elsewhere and so dealt with the issue… (interview, Technical Director, waste- management company, 20.06.2015).

Thus evidence from other European countries, especially Energos' home base in Norway, supplemented its UK demo plant. But this was still seen as unreliable: the Isle of Wight Council eventually sought 'to reduce reliance on the gasification plant, which has in the past proven to be unreliable' (IoW, 2012; also Sloley, 2011).

For its 2014 decision on a new facility, Leeds City Council chose an incinerator as a more reliable option than Energos' gasifier. 'ATTs are the future if they can extract more value from waste, but few such technologies are proven' (interview, Technical Director, waste- management company, 18.03.2015). In these ways, the mixed evidence remains open to different social representations.

6.2.2. Bankable? Private finance depends on prior technological demonstration — itself a policy aim which can justify finance

Finance for ATTs often remains difficult. Potential investors or creditors foresee a high risk of technology failure, mainly regarding operational reliability. A track record must be demonstrated according to standard engineering criteria (see Section 4). From an inside view, Scotland's environment agency has monitored such developments:

> Most proposals that SEPA now receive are gasification or pyrolysis, mainly due to cost: they are cheaper than more traditional types of thermal treatment. However, many proposals do not reach development stage because finance for novel advanced combustion technologies is difficult to procure. Anecdotal evidence suggests that financers seek to minimise commercial risks; new technology carries a high risk (interview, SEPA, 22.12.2015).

To help raise confidence, the Green Investment Bank identifies technically 'proven' MSW gasifiers, as a basis to invest in new plants. Its role initiates or completes the finance – partly to facilitate the plant, and partly to stimulate further incremental steps towards future gasifiers.

> So our investment has a demonstration effect on the market. By supporting this technology at a slightly less efficient stage, it enables the more efficient stage. It's innovation by steps, rather than quantum leaps each time (interview, GIB, 23.12.2015).

On these grounds, beyond the financial return on a specific investment, the GIB co-funded four UK gasification technologies at a total of five sites, some for MSW feedstock. Thus weak bankability can be grounds either to avoid or strengthen investment in a gasifier, depending on an agent's representation of future technological prospects.

6.2.3. Technics familiar? Resemblance to incinerators can facilitate finance but less-efficient designs

Beyond engineering data, gasifiers whose design most resembles incinerators are often seen as more familiar and thus more reliable:

> The ATTs being built are mainly low-end gasifiers because they are lower risk… In particular, Energos' gasifier is as close as you can get to a traditional 'combustion plant' (interview, Technical Director, waste- management company, 20.06.2015).

By contrast, its competitors' technological designs 'are horrendously complex', says Energos (Let's Recycle, 2016).

Moreover, dependence on ROCs subsidy can protect and thus incentivise less-efficient gasifier designs (interview, ETI, 05.01.2015). Government R&D funds favour design closer to incinerators, according to a technology developer which claims to produce a high-quality syngas for use in gas engines (interview, 05.03.2015). Conversely, the prevalent criteria disfavour some novel designs which may have better prospects to enhance energy efficiency and flexibility (interviews, several waste-mgt companies, 2015). Hence the technical design may have tensions between cognitive familiarity versus energy efficiency and potential improvement.

6.2.4. Scalable? Wherever required, a small-scale plant is financially more feasible for gasifiers than incinerators

Gasifiers are represented as financially scalable, i.e. viable at small scale, wherever this may be sought; size is flexible using a modular system. Some local authorities have chosen company bids with gasifiers in contexts favouring a small-sized plant, for various reasons, e.g. specifying an ATT, localising waste management or using current waste-infrastructure. In the Glasgow contract including Energos' technology, several gasifiers were combined in modular fashion for greater capacity. After local authorities reach adequate capacity for MSW treatment, the main opportunity will lie in commercial and industrial (C&I) plants; these generally need a small-size facility for the available feedstock and so potentially favouring gasifiers over incinerators (interview, Technical Director, waste- management company, 19.06.2015). Nevertheless these lose the financial advantage of a large-scale plant. Thus scalability has diverse social representations, partly linked with prospects for energy recovery and use.

6.2.5. Competitive? A lower gate fee makes a facility economically more competitive

Resulting from the Landfill Tax Escalator, feedstock gate fees paid to thermal-treatment plants have risen greatly. Thanks to the operational subsidy, moreover, the energy comprises 60–70% of income for a gasifier, by contrast with only 25% for an EfW incinerator. Also a gasifer is usually cheaper to build. For both reasons, a gasifier plant can afford to charge a lower gate fee, to be economically more competitive in the waste market or for bids to local authorities. But this potential advantage hasn't always materialised:

> In theory, greater income for the energy [including ROCs] should allow a plant to charge a lower gate fee. But we haven't yet seen it, perhaps suggesting that the technologies aren't mature enough to do that (interview, Technical Director, waste- management company, 19.06.2015).

This mattered less for Milton Keynes Council under its new business model as part-owner of the gasifier plant. Its spare capacity will treat waste from local companies, whose gate fees will go partly to the Council. Thus criteria for a 'competitive' gate fee depend partly on the business model and trade-offs with environmental criteria. Prospects for a lower gate fee may be constrained by the shift to Contracts for Difference.

6.2.6. Emissions controlled? An in-built combustion of toxic substances can offer better control

Gasifiers' proponents claim a greater in-built combustion of hazardous gases than incinerators. As well as public reassurance, this difference matters if future emissions standards become more stringent, as had been anticipated around the government review. This advantage over incinerators was cited by some local authorities, e.g. Glasgow's 2013 decision to favour a gasifier. But some gasifiers have breached statutory limits, e.g. the Energos demonstration plant (Sloley, 2010). 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). So for emissions control the potential advantage is contingent on a specific plant, commercial-stage tests and cognitive frame.

6.3. Energy recovery: multiple criteria

For representing a technology as an improvement or as preferable, the distinction between recovery versus disposal matters. This in turn has multiple aspects, involving trade-offs with other benefits. Diverse selection pressures can be favoured for a technology choice within a larger waste-management facility.

The 'recovery vs disposal' criteria are set by EU law. 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), i.e. all counting as waste disposal. EC waste-incineration guidance likewise exempts plants 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. Opponents can more easily discredit a 'disposal' facility.

Further criteria come from EU policy, especially since the 'waste hierarchy' was given a statutory basis. The 2008 EC Waste Framework Directive (WFD) requires that a recovery route should be given preference over disposal, the latter analogous to landfill. There was political impetus to clarify this distinction through a standard EU-wide formula.

For a waste combustion plant to be a recovery operation, it must generate sufficient energy to fulfil the 65% recovery 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 per se. If below the threshold, a plant is classified as disposal (EC, 2008). R1 status is a mandatory condition for a plant to import waste feedstock from across national borders, though this incentive has no relevance to the UK, whose waste system only exports refuse-derived fuel (RDF).

New proposed plants must undergo an evaluation for waste recovery versus disposal. The relevant competent authority 'will assess whether or not a municipal solid waste combustion facility meets or exceeds the threshold and can be considered a recovery operation'. This distinction matters for 'the proximity principle', i.e. localising waste management (DEFRA, 2014: 24). It is also a criterion for some national and local authorities to support a new EfW facility, e.g. through planning permission or subsidy. A plant must have R1 status and CHP-compatibility to be eligible for Wales' subsidy of gate fees (Welsh Government, 2012: 228). In St Helens a proposed gasification plant was refused, partly on grounds that it did not fulfil the R1 criteria (Planning Inspectorate, 2015; UKWIN, 2015).

Indeed, current gasifiers cannot easily fulfil the R1 criteria, for several reasons. Energy recovery generally depends on two main aspects – net power production and heat use, as follows.

Net power generation: Crucial for reliable operation of gasifiers, their feedstock pre-treatment imposes a parasitic load, lowering net energy output. For this reason, proposed gasifiers have difficulty to fulfil their requirements on start-up, i.e. 20% electricity-generation efficiency relative to calorific value, by contrast with incinerators' average 25% (interview, SEPA, 22.12.2015). The 20% figure in turn limits the R1 rating: current gasification plants can achieve only 50% recovery, while combustion-based EfW plants achieve at least 60% (Welsh Government, 2012: 227). The most reliable gasifiers are the least efficient; their design is relatively closer to incinerators than more 'advanced' gasifiers (interviews, Technical Directors, waste-mgt companies, 19 + 20.06.2015).

Heat use: By 2012 only 3 of 25 UK incinerator plants were exporting heat (Nixon et al., 2013), mainly because a district heating system cannot be easily retrofitted. Nevertheless many electricity-only EfW plants have gained R1 classification; many more would do so if they submitted an application, though there has been little incentive for operators to do so (Kaminski, 2015; Goulding, 2016). By contrast, a small-sized plant such as a gasifier can more credibly claim to find local users for the surplus heat. Yet the incentive structure from ROCs favours designs maximising electricity production at the expense of heat, which gain a much lower subsidy (interview, Technical Director, waste-management company, 15.05.2015). Contracts for Difference require that plants be CHP-ready but not necessarily that they use the surplus heat; thus energy recovery via heat use gains little tangible reward.

7. Conclusions

As outlined earlier, the MLP helps to identify specific roles played by socio-political agents in promoting specific rule changes and transition pathways. Through endogenous enactment, actions supportive of potential alternative pathways are continuously enacted and contested by diverse agents (Geels et al., 2016). The theory invites clarity on these generic questions: How does socio-political agency generate landscape-level changes, regime instability and technological competition? How does a niche innovation compete with the incumbent regime in ways accommodating, stretching or changing its cognitive rules, especially regarding environmental sustainability issues? How do such rules undergo change, along lines which become more widely shared? This case study brings insights to those theoretical questions, especially the latter one.

Agents' strategies around cognitive frames can be analysed as social representations, bringing together various rules – regulatory, institutional, market, etc. – into shared or competing views of what is feasible and desirable. For this theoretical perspective, the Conclusion first recapitulates the case study and then suggests broader implications.

As a relatively low-cost alternative to landfill, mass-burn incineration became a prevalent means for managing municipal solid waste (MSW), at least by 2010 in the UK. Within this incumbent socio-technical regime, the rules initially favoured waste-volume reduction and then electricity production, thus becoming an energy-from-waste (EfW) regime. Incineration was increasingly criticised on numerous grounds – e.g. for emitting harmful gases, for producing substantial quantities of hazardous bottom ash, for favouring waste disposal over recovery, for demanding large-scale waste transport to 'feed the beast', and thus for contradicting the waste hierarchy.

As a landscape-level change, controversy over incineration destabilised the EfW regime's rules, shifting them towards greater environmental sustainability, beyond the earlier criteria of incinerator design. There were greater selection pressures for moving up the waste hierarchy, e.g. via greater removal of recyclables and biodegradables, as well as improving incinerators for better energy recovery. Meanwhile 'advanced' thermal treatments (ATTs) gained state support for overcoming the dual 'valleys of death', i.e. via R&D demonstration projects and then operational subsidy.

This support has provided niche protection for novel technologies which could not otherwise compete with incineration. As a key rationale, future technoscientific development could achieve better energy recovery from waste, despite limitations of the currently available technology. In these ways, the incinerator controversy opened up opportunities for gasifiers as a niche innovation within the EfW regime, yet gasifiers have become an extra focus for conflict over the regime's rules and its wider role in the waste hierarchy.

The technological competition processes have been analysed here by linking the multi-level perspective (MLP) with social representations theory, whereby socio-political agents seek to render a novel technology familiar through different cognitive frames. They compare thermal-treatment technologies by anchoring them in ways serving different agendas. Some environmental NGOs and local groups pejoratively anchor all thermal treatments in 'incineration'. By contrast, state and industry bodies anchor gasifiers as matching incineration's positive features (reliable operation and bankability), while avoiding or improving its negative features (small-scale localisation versus 'feeding the beast'). Reversing the comparison, the incineration industry represents its technology as already 'advanced'. These conflicting cognitive frames illuminate how regime actors seek to influence landscape-level changes as well as regime-level selection pressures (cf. Jørgensen, 2012; Geels et al., 2016).

Amongst local authorities and relevant companies, different gasifiers compete with each other and with incinerators around multiple selection pressures. No optimal techno-economic efficiency can explain investment decisions (cf. Genus and Coles, 2008), so an explanation needs a cognitive perspective. Thermal-treatment options are evaluated on various criteria – e.g. as reliable, familiar, bankable, competitive, scalable, safe, efficient, etc. – whose norms have become less stable or more stringent. Any gasifier design entails trade-offs, e.g. between energy efficiency versus operational reliability, given the latter's dependence on energy-intensive pre-treatment. As a flexible policy framework, the waste hierarchy has diverse criteria, e.g. waste-volume reduction, resource recovery versus disposal, energy efficiency, etc. Each criterion involves divergent interpretations, trade-offs and cognitive frames.

This theoretical linkage helps to analyse how technological options relate to change in the wider EfW regime, as theorised by the MLP's ideal-type transition pathways (cf. Geels and Schot, 2007, 2010; see again Section 4, Table 1). From 2006 onwards, incumbent companies gained opportunities from the UK government's PFI programme and the industry's rising gate fees. Following a P1 transformation-adaptation pathway, they made incremental improvements in EfW incinerators, sometimes combined with on-site MBT plants, thus somewhat moving up the waste hierarchy towards greater resource recovery.

As a niche innovation, MSW gasifiers were not yet sufficiently developed, or had not gained sufficient demonstration as operationally reliable, to compete with incinerators. By around 2011 gasifiers found a new opportunity as new PFI funds declined, ROCs operational subsidy was still available and anti-incineration protest continued. Gasifiers' social representations became more favourable, especially as regards earlier doubts about reliable operation and bankability.

Some incumbent waste-management companies have contracted with new entrants, e.g. to provide a gasifier to accommodate the environmentally more stringent criteria of local authorities and/or to gain the commercial advantage of small-scale C&I waste plants, while potentially avoiding negative association with incinerators. Operational subsidy helps a gasifier to cross-subsidise an on-site MBT plant. Within a P4 reconfiguration pathway, gasifiers provide a component replacement which potentially alleviates local problems, while facilitating a modest architectural change (cf. Geels et al., 2016).

As operational subsidy for new gasifiers becomes less predictable, however, they have uncertain prospects for competing against incinerators, which remain the default mode as a P1 adaptation-transformation pathway. Among other obstacles, gasifiers' performance difficulties have limited the widespread positive social representations that would be necessary for major commercial adoption. There may be a long-term symbiotic co-existence between P1 and P4 pathways. Or rather, this ideal-type taxonomy provides a heuristic device to identify more complex relationships among technological options.

MSW gasifiers may look like a regime shift vis à vis incinerators as multiple options for EfW, but the new technology is merely an incremental change vis à vis the wider waste-management system (cf. Geels & Schot, 2007: 400). To the extent that they are successfully distinguished from incinerators, moreover, gasifiers may make a new thermal-treatment plant more defensible in a context where otherwise it would be politically contentious. Through incremental changes, gasifiers can serve to reinforce the EfW regime.

In this case study, a theoretical gap in the MLP was addressed through a link with social representation theory. This has illuminated how socio-political agents make a novel technology familiar, favourably and/or pejoratively, through cognitive framings which variously accommodate, destabilise or change the regime's rules. Niche innovations have brought more modest regime changes than in most studies of socio-technical transitions. Social representations theory offers an insiders' perspective on the endogenous interactions and influences that change socio-technical systems. So the theoretical linkage with the MLP reveal dynamics which may have general relevance to incremental change.

Acknowledgements

This work was supported by grant from the Engineering and Physical Sciences Research Council (EPSRC) Supergen programme during 2013–17, project no. EP/K036793/1, 'Increasing energy yield from the integration of anaerobic digestion and pyrolysis', http://www.supergen-bioenergy.net/research-projects/increasing-the-energy-yield-from-the-integrations-of-anaerobic-digestion-and-pyrolysis/.

For helpful editorial comments, we would like to thank Stephen Burnley (Open University), Frank Geels (University of Manchester), Geraint Evans (Energy Technologies Institute) and Niranjan Patel (DEFRA). The authors alone are responsible for the content.

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