Technology review report

for

AHDB Pork

Carried out by:
Mike Bond, NFU Energy
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Contents

Background

The GrowSave programme's pork sector work aims to identify and publicise the latest technologies that can help pork producers to improve their efficiency, specifically energy efficiency, but also to highlight and promote climate or environmental improvement actions.

In considering the future for the pork industry and agriculture, we need to be considerate of the move towards the concept of the triple P – people, profit, planet. This principle accounts for the stewardship importance that must be adhered to in order to survive in an increasingly environmentally conscious world, where reputational benefits may also become part of the accessibility of funding, securing the right to supply, and form part of the claim for Environmental Land Management payments (ELMs). The major pressures from the Government to move towards the concept of public goods, ELMs, the Clean Air Act, the Agriculture Bill and new welfare codes all provide the rationale for this work to be done.

Some technologies were chosen to be discussed because of their general relevance to the sector, and others are a result of conversations with participants of this review. The review is wide-ranging and contains discussions of techniques, technologies, and principles, in more and less detail depending on appropriateness and availability of evidence. This report is not intended to be a holistic and complete review but more an introduction and direction for further GrowSave activity.

It was clear from the initial discussions held with AHDB, and anecdotally by NFU Energy conversations with producers, that one of the most 'of the moment' technologies being discussed is that of slurry cooling. The principle that this may not be all that some believe it to be, and that there may be facets of the implementation which need a clear explanation, led to the definition of this work.

Brief

- To identify emerging technologies in the pork sector
- To investigate their viability and cost-effectiveness
- To put forward those recommended for implementation
- To identify Steering Committee members to help define ongoing GrowSave delivery

Methodology and references

Beginning with a list of six sector participants provided by AHDB, each was approached by email, with an explanation of the work in hand and a request for a brief phone conversation. All agreed to take part. At this initial discussion, each participant's involvement in the sector was established, and in the case of producers and consultants, they were asked to provide any insights into the areas of technology they considered important and relevant. This often led to further contacts being provided for follow-up. These were also contacted by phone and email, for a description of their offering and what it brings to the sector.

Notably, a face-to-face meeting was held with Peter Schriver from Klimadan (with AHDB in attendance) for a detailed discussion of slurry cooling technology but also for GrowSave to explain and discuss the energy industry and available support for renewables systems in the UK. It was also anticipated that visits would be conducted to producers who had installed this technology in spring 2020. However, the coronavirus (COVID-19) situation has dictated that these visits will need to be made when conditions are easier.

Phone conversations were conducted mostly from February to May 2020. In all, 20 participants, including AHDB, have provided input into this report, some with multiple conversations. These are:

- Pork producers
- Equipment suppliers (e.g. Klimadan, Farmex/Dicam, Greengage Lighting, Alltech E-CO_2, N2 Applied, Unilight)
- Industry professionals

This report summarises the outcomes of these conversations and provides details of the technologies discussed, alongside a technology matrix summarising these and providing recommendations for each.

The technologies discussed can be broadly categorised into three types:

- Energy generation
- Efficient use of energy
- Control/measurement

Our review follows these categories. Although some technologies could be categorised into more than one, they are shown in their main category. There is a final category of 'other technologies', for items discussed in conversation and considered to be relevant indirectly.

Energy generation and market

Perhaps unsurprisingly, all the producers spoken to had either invested in some form of renewable-energy generation over the last few years or had considered it. Some of these technologies are well established by now, others less so. However, the improvements in equipment efficiency, reductions in cost and changing market dynamics make them worthy of discussion and for future work. Before renewable-energy technologies are discussed, we have included a section on energy prices for context and for information.

Energy prices

The use, and therefore cost, of electricity dominates energy consumption in the pork sector – this is for lighting, cooling, often for heating and other ancillary uses.

We have interrogated the Climate Change Agreement data available for pork production. This scheme gathers energy-consumption data versus the tonnes of pig meat produced. The data shows that there are 115 sites registered in the scheme (these will be the highest energy users and those most likely not to have a high proportion of renewable energy). The data presented equates to a 500-sow unit.

The data shows that:

# sites	Average electricity consumption	Proportion of renewable electricity	Average heat consumption	Proportion of renewable heat
115	334,000 kWh	40,000 kWh	90,000 kWh	14,547 kWh
Specific energy consumptions	278 kWh/tonne	33.4 kWh/tonne (12%)	75 kWh/tonne	12 kWh/tonne (16%)

Using the values of average energy consumptions above, producers will have an energy bill around £52,000 per annum, made up predominantly of £45,000 of electricity cost, with the remaining being heating fuels.

While the cost of electricity is underpinned by the cost of generation, largely from gas, it is also highly dominated by the additional charges levied to provide revenue to support renewables generation and taxation. This means that of the current 10–16p/kWh cost for imported electricity, often more than half of this cost is fixed by such charges (non-commodity costs).

The commodity proportion of electricity costs has generally been linked to the primary fuel – gas – used to generate it. When gas increases in cost, so do electricity prices, and vice versa. We are seemingly transitioning to a generation mix where renewable-energy provision plays a much more significant part. This is especially true of large-scale wind and solar and we have seen increasing incidences during early mornings and weekends where spot market price for electricity is close to zero cost and sometimes even negative. Natural decarbonisation of pork production will occur as the electricity grid decarbonises. However, to decarbonise the heat, use will require a much larger shift to lower-emissions heating and heating fuels, such as heat pumps and bio-based alternatives.

Volatility in energy prices is both a concern and an opportunity. While most producers purchase their energy in a fixed-price manner, those with larger supplies (100 kW demand or greater) can play the market and purchase more flexibly. This allows producers to benefit from reducing prices more immediately and employ a consumption and purchasing strategy to reduce costs, without necessarily altering their primary consumption requirements. The employment of battery technologies in times to come may provide additional opportunity for this. A further section discusses battery storage in more detail.

Review outcome

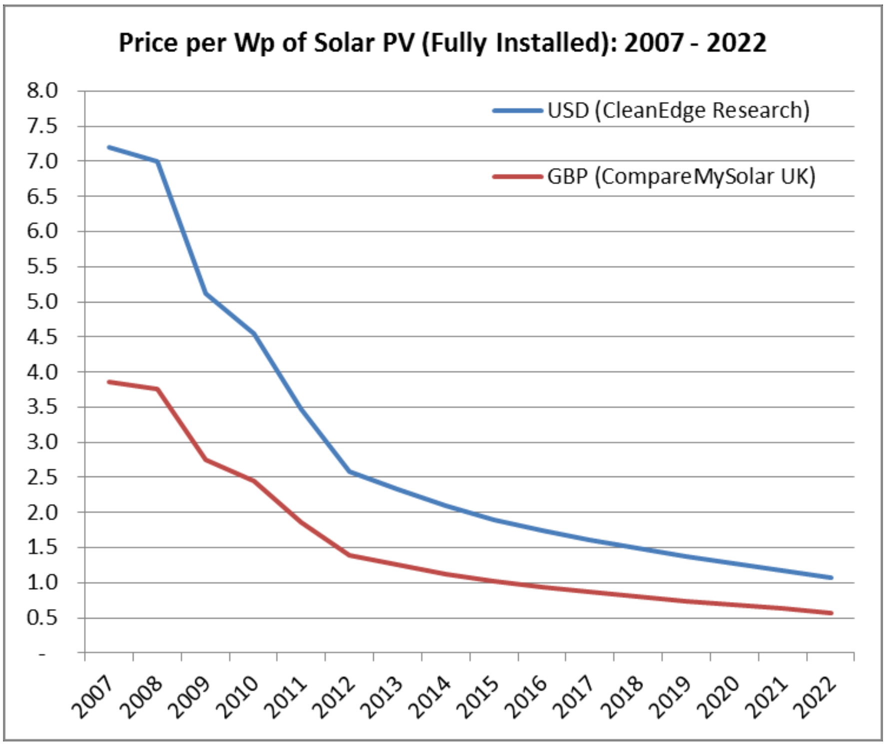
Discussion and provision of materials around strategies to reduce energy cost (especially electricity) will benefit the pork sector, in much the same way as they will benefit other sectors in AHDB. With the market in a continuous state of flux, regular updates on the market dynamics will help producers to make purchasing decisions.

Decarbonisation plays an increasingly important role in producers' decision-making and, therefore, awareness of decarbonising influences and strategies are as important as those for cost.

Solar PV

Probably the best recognised and most established of technologies, Solar PV is undergoing a quiet revolution, where installing panels with improving efficiency and reducing cost is becoming a de-facto part of many buildings and projects.

Solar PV has been supported historically using the feed-in tariff (FiT) mechanism that the Government provided between 2008 and 2018. This mechanism has come to an end now. Consequently, many people believe that Solar PV does not have an economic case. However, the graph below, detailing the change in capital cost of Solar PV over time, clearly shows that the economic situation is not purely dependent on government subsidy and a good case can be made for installing Solar PV without FiT support. When Solar PV energy can be appropriately managed, the paybacks can be as little as six to seven years.



(Ref 01, n.d.)

The graph shows how the trend of installation cost plummeted between 2007 and 2012 and continues to decrease at a more sustainable pace over the next ten years. A fully installed cost of £500/kW would value the electricity produced over a 20-year lifetime at approximately 3p/kWh. Even if producers wish to value this over a much shorter ROI period, say five years, this would be around 12p/kWh, which is often better than daytime electricity price. Therefore, the economics are favourable where systems are designed to match the potential to fully offset site electricity consumption.

As stated, the best economic return for Solar PV is made where the generated power can be used on site when it would otherwise be imported from the grid. This will only happen when loads are of a similar scale and occur during the daytime, especially where there is a heavier reliance in summer, for example in cooling applications. If panels must be mounted with a

NFU Energy 10th Street Stoneleigh Park Kenilworth Warwickshire CV8 2LS
T: 024 7669 6512 F: 024 7669 6360 W: www.nfuenergy.co.uk

non-south-facing aspect, then matching loads to the morning or afternoon period (as appropriate) will be important too.

Idealised installations and load matching cannot always be achieved. Where a temporal mismatch exists, it is widely believed that battery storage (discussed later) will improve matters. However, battery storage, i.e. keeping electrical energy for use later, is not always the most appropriate and cost-effective thing to do. Other ways of using Solar PV energy could be to create loads that only operate when additional energy is available, such as running pumps for moving water or slurry around the site or in some cases creating hydrogen or other forms of useful product that could be used later. The economic case for these systems only exists where the products can be useful to the site or sold to create an additional income, otherwise energy is wasted.

Review outcome

As with materials to help understand the energy market, resources and materials about Solar PV will not solely benefit the pork sector. There is, therefore, an opportunity for a cross-sectoral approach here, with tailored sections to meet the specific needs/concerns of each sector.

For any sector, full benefit from Solar PV will occur when matched electrical demand is present during the daytime. Therefore, descriptions and research into energy matching for loads has a benefit too.

Wind power

Since the change in policy to a less supportive planning system in the early 2010s, onshore wind-generation deployment has been negligible. Local opposition and installation difficulties have provided a further disincentive to deployment.

The RenewableUK wind power database (Ref 02, n.d.) is a useful resource here. It identifies the mix of turbine stock throughout the UK and generally shows that most operational turbines are in the 250 kW-plus sizes. These will provide more energy requirement than the average pork producer will have. Therefore, grid connection and export capability become defining factors where the surplus energy cannot be put to sensible additional uses.

A 250 kW turbine project is likely to cost £500,000–£750,000 and produce energy with a value of £90,000 per annum (where it is wholly substituted), giving an ROI between six and nine years, disregarding any potential incentives.

However, it is likely that onshore (and possibly small-scale) wind generation will undergo a resurgence in the short to medium term. There is improved public perception, set against the requirement for the UK and agriculture to meet net zero CO_2 emissions aspirations, to aid this. Furthermore, the technology can deliver generation that meets demand when Solar PV is not producing. The two are often very complementary, with wind generation more prevalent in winter months. Unlike solar power, however, wind generation is less predictable and can occur at any time of day. Therefore, load shifting through battery storage has the potential to make an even more significant contribution.

The use of complementary energy-generation technologies, such as matching wind power and solar power together, is useful where people want to have a site that can be wholly self-sufficient in energy or exist off the network. Under these circumstances, it is often not possible to completely provide all energy from renewable sources, even where batteries are

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fitted. Therefore, additional backup will be required, such as the installation of a fossil-fuel-powered generator for use in exceptional circumstances.

Review outcome

The challenges of successful deployment are often difficult to navigate. Clear cost benefits and long-term operational issues need to be relayed to producers considering such a scheme, especially where local opinion is weighted against the technology.

Therefore, as the market develops, the messaging surrounding these issues should be produced. This is not considered immediate and will be published via AHDB and GrowSave, among other industry organisations, such as NFU and trade press.

Anaerobic digestion (AD)

This is an established technology that is familiar to many farmers and producers. The process digests crops, agricultural and other biological wastes to produce biogas, which may be burned in an engine to produce electricity, heat or refined for injection into the national gas network. The digestate may still be nitrogen-enriched for use as fertiliser.

Government policy is favourable towards AD plants, specifically where it can be used to produce biomethane for injection into the gas grid to form part of the decarbonising of the heat network in the UK. Announcements in the March 2020 budget, and subsequent launch of a consultation (Green Gas Support Scheme), demonstrate this (Ref 03, n.d.).

The Green Gas Support Scheme has been designed to increase the amount of biomethane that is input into the natural-gas network as part of a decarbonisation programme which will, in turn, include other non-carbon-based gases such as hydrogen. In creating biomethane, the Government will undoubtedly require that the feedstock used for AD plants is from waste, including slurries, such as pig slurry. While pig slurry itself cannot be used solely to feed a new plant and must be part of a feedstock mix, it is clear there is opportunity for improving the value that slurry has where other wastes become limited in supply.

Therefore, the outlook for AD plants and the use of slurries becomes twofold: those providing feedstocks to very large plants and those who are looking to solve their slurry problem themselves with much smaller, even micro-AD plants.

While large-scale AD provides the best balance between install and operational cost against benefits, many producers are interested in micro-AD plants that can manage their wastes and deliver energy predominantly for their local use. Such systems have been developed many times. However, these are rarely truly successful. It is often that the most successful systems are enthusiast-developed and -driven, requiring time and dedication beyond the will of the typical producer.

In the UK, the lack of success in micro-AD can be considered to be in contrast to some of our European partners. Therefore, as an industry, we may look to other countries to provide and showcase their expertise so that we can capitalise on the technology where it fits within the UK pig production.

One of the major resources available to producers in the UK comes from the EU PiG collaborative project (Ref 04, n.d.). The website for the project contains many case studies that reinforce best practice and experiences of other producers in effecting such technology as micro-AD.

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Review outcome

Further research and data acquisition/analysis are required with regard to micro-AD plants, to fully determine and explain the costs, benefits, and advantages. This technology is well-matched to the pork sector. However, the dairy sector could similarly benefit from this work.

Further work is required, with emphasis on learning outcomes from European neighbours; this could be in the form of dissemination of their materials or study tours showcasing successful plants.

Large-scale AD plants, and how producers may benefit from their deployment, will be dependent on the outcome of the Government consultations and future policy. Blogs, web articles and news features would be suitable to get the basics of the scheme across. Further work would be required to provide applicability to the pork sector.

Battery storage and renewables optimisation

The drawback with renewables, such as solar PV and wind, is the fact that their power may be generated at a time when it is not required, resulting in export to the grid with far lower resulting income (or cost avoidance). Charging electrical storage batteries as a short-term measure to soak up additional generation for consumption later or to export when the price is better is a utopian solution. Similarly, where producers employ an energy purchasing strategy, attempting to avoid expensive periods or to benefit from cheap or negative energy prices, batteries could provide a short-term load or supply.

Although electrical storage batteries are often discussed as being the solution to the variability of renewable generation, the cost of them is still too high of themselves to warrant investment. Most batteries and large battery installations have been deployed in ‘in front of the meter’ grid support services, where they are available to the grid to react very speedily to out-of-specification power provision, such as over- or under-voltage and frequency response. There are limited ‘behind the meter’ installations, which are the preserve of domestic users and enthusiasts. Having said this, the cost of batteries is reducing, and the market dynamics are changing quickly. Therefore, battery storage may soon become viable for price arbitrage (when the mismatch between supply and demand is clear, repeatable, and reliable), or where consumption cannot be avoided at peak tariff periods.

The graph below, taken from a market report by BloombergNEF (Ref 05, n.d.) into the cost of batteries, shows the fall in manufacturing cost. It is expected that by 2023 this will fall further still to under $100/kWh – a point where electric vehicles will start to become comparable in costs to internal-combustion-engine models. The development in EV batteries will have a knock-on effect into static applications.

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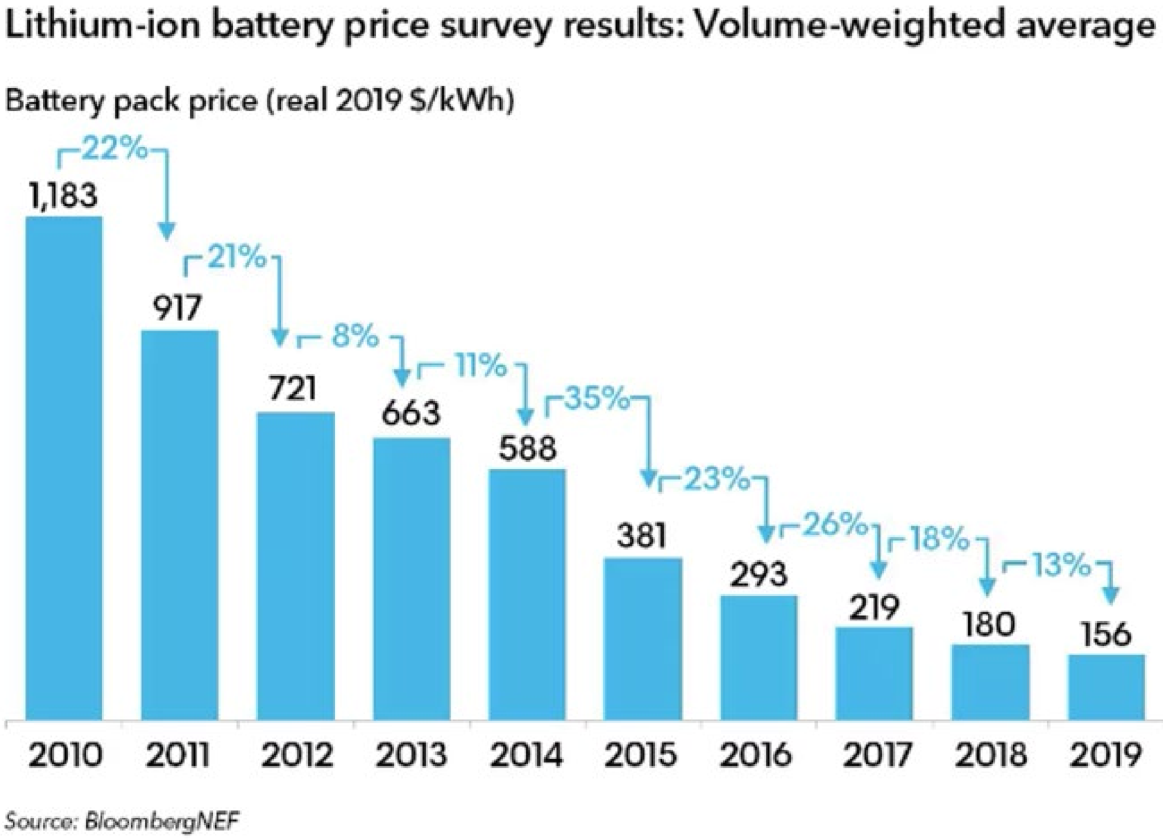

The dominance of lithium-ion technology brings several challenges, as well as benefits (the clearest benefit is cost reduction of batteries, resulting from the automotive industry's developments). However, currently, many of the materials required for battery manufacture are scarce and have an environmental footprint of their own, causing concern for many.

Further developments, especially around flow battery systems where storage capacity is easier to manipulate, mean that static applications of batteries where large quantities of electricity may be stored for longer periods, reducing the temporal mismatch, will likely be more viable.

Large grid-support batteries, such as the recently announced 50 MW/250 MWh liquid air battery that is to receive £10 million of government development funding (Ref 06, n.d.), have very little day-to-day impact on pork producers. However, this highlights the interest in developing other forms of energy storage.

To capitalise on energy storage, it may be necessary to be more creative in our thinking. Additional energy storage forms can sometimes be called a secondary storage.

Other forms of secondary storage include:

- Daily hot water potential for preheating cleaning water
- Interseasonal heat storage for space heating (ground recharging)
- Overcooling produce for limited times
- Glycol cool storage

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- Compressed air for immediate use or regenerative electrical generation

These secondary energy stores have the benefit of being tailored to individual energy requirements and in many cases reduce the energy transfer process (by avoiding placing energy into electricity and back again) and may well be the best solution in the short term.

Review outcome

The interest in the use of battery and energy storage is cross-sector, although tailoring to pork-specific scenarios is required to make the messages relevant. As no material has been produced on this topic to date, this would need a lead sector, which is suggested to be AHDB Pork or Potatoes.

Ongoing research and awareness are needed to ensure up-to-date messaging in such a fast-moving area. Articles and case studies will be needed to support main outcomes and highlight the opportunities in a way that impacts producers.

Energy-efficient technologies

In this section, several energy-efficient technologies are presented. In many applications, these are subject to the requirements of EU reference documents on best available techniques (BREF) (Ref 07, n.d.), as part of the Directive on Integrated Pollution Prevention and Control (IPPC). Where a best available technique (BAT) exists for a certain application, there is further reference to this within the relevant section.

Heat recovery potential

In Northern Europe, ambient air is too cold for pigs for 50% of the year, so heating is often provided in sheds. The need for fresh air ventilation, and subsequent cleaning of exhaust air from pig sheds, presents the opportunity for heat recovery with significant energy savings.

The exchange of heat between indoor air and fresh air, water, or the ground are all allowable BATs. The principle being to recover the heat in exhaust air for reuse in fresh intake, displacing reliance on energy-intensive heating systems.

Technology supplier Inno+ has further developed the traditional ventilation system, of shed-side louvred air inlets and a central extraction system, by turning the legislative requirement for air cleaning into an advantage for the operator. The water-based air scrubber systems that remove pollutants from the exhaust airflow also collect all the heat present in the air, meaning that the wash water leaves warmer than it entered. The Inno+ Triple EEE system (Ref 08, n.d.) collects this heat by pumping warm, dirty wash water to a heat exchanger, where heat is transferred to a clean-water circuit at around 10°C and circulated to exchangers located at each air intake louvre, returning the heat to the shed and reducing the reliance on make-up heat systems. It is claimed that 1 kW spent on pumping water is rewarded with up to 77 kW of recovered heat.

By adding a heat pump to this system, the heat may be boosted to a more useful 45°C for a higher transfer rate at the air inlets, at a COP of around 4 (i.e. a 400% efficient system). This is also a BAT. It is claimed that intake airflows no longer cause draught discomfort, and therefore improved indoor climate (branded by Inno+ as ‘fourth generation’ or 4G Climate (Ref 09, n.d.)) is acknowledged to bring animal health improvements.

Although most cost-effective when incorporated into new buildings, retrofit of the technology is possible where exhaust air is handled via a single exit point. It may be adapted for other ventilation strategies. When paybacks of under five years are possible, this is an option for existing pig sheds with intended lifespans of up to 20 years.

Water scrubbers are one method of removing dust, NH_3 and odour from extracted air but may require combination with other technologies (such as acid scrubbers or biofilters) to meet the requirements of BAT for ammonia reduction.

Heat pumps

Often considered as a renewable technology (and where ground, air or water is used as a heat source, this can be correct), heat pumps are set to be a cornerstone of the heat generation and efficiency strategy towards meeting net zero aspirations, as well as providing financial benefits for producers and farmers.

Simply put, heat pumps can use a small amount of electricity to boost reject heat or a low-temperature heat source to a more useful temperature. This is especially useful where reject heat from other processes or being required to be removed from buildings can be employed as the source. This can, therefore, make them an efficient technology, providing simultaneous cooling and heating, as well as a substitute source for more traditional heating fuels.

The applications of heat pumps in the pork sector encompass that of slurry cooling (discussed comprehensively below), as well as other heat harvesting (including air washers, see above) or heat requirement situations. As these are complicated principles and the equipment is poorly understood, clear resources are needed about how these will work, where they may be useful, and what is the best way to establish them on farm.

Review outcome

Some work on heat pumps has been done and literature/training materials produced for AHDB Horticulture, which could be used as a starting point for this work. The work would have cross-sectoral appeal for AHDB Dairy, which has similar challenges around milk cooling and water heating.

Sources of heat for boost by heat pumps can be various, as described in the heat recovery section, therefore these themes need full sense checking and potential explanations for them to be relevant to producers. Near-market R&D and case-study material will be invaluable here.

Slurry cooling

In considering the application of slurry-cooling technology, producers must be considerate of their reasons for doing so and the status of their environmental permit. Should there be no environmental permit in place, then the options for installation and operation are greater. Where permit compliance is, or may later be, required, due to planned expansion, then the best available techniques must be followed to meet IPPC and planning guidance.

Slurry-cooling systems are not, per se, new technology, but merely an application for heat pumps. Slurry cooling originated in Norway thirty years ago and was further developed in Denmark (where the pig population is higher than in the UK and where, historically, heating relied more on cheap gas than on insulation). The technique extracts heat from the slurry and the ground and produces low-grade heat that may be used for local heating applications. It is relatively new to the UK and is less commonly applied here. That may be about to change.

Slurry cooling may be implemented into a new build, or as a retrofit measure. When incorporated into new facilities, cooling pipes are embedded into the concrete slurry pit to remove heat at source, or suction channels may be used to remove the slurry to a holding tank where cooling takes place, subject to permit adherence requirements. When installed as part of a new build, costs will be kept lower than installing the system as a retrofit, as items are incorporated into the main build.

As a retrofit measure, slurry cooling may be less effective and more expensive. Cooling pipes may be wrapped around, or even immersed into, a slurry storage tank; in pig buildings, they may be fixed to the slurry pit floor and screeded, reducing capacity slightly. There is an option to pin to the pit floor and leave exposed; however, this is less efficient than screeding the pipes and should only be considered in the shallowest of slurry pits. In a deeper tank, stratification prevents heat from being recovered from the upper layers, which remain warm. Cooling a tank is only appropriate if the anaerobic breakdown is not required, as cooling may slow the process. The deployment in storage tanks may provide an opportunity for use in the dairy sector. Where slurry is being stored at ambient temperature for spreading, the technology ensures that the heat is recovered rather than lost.

The best available technique for retrofit applications involves the use of surface-cooling fins which float on the slurry surface. Cold water (mains or borehole water) is circulated through these at 12°C to cool the slurry surface uniformly to <15°C. The fins are connected in series locally, then grouped in parallel (known as a Tichelmann system), to allow the most effective recovery of heat, able to respond to occupancy of individual areas.

The amount of heat recoverable is highly dependent on the point at which it is extracted, the degree of cooling applied, ground exposure and the volume of slurry available to be cooled. A pig may produce between 3–11 litres of slurry per day at around 39°C, and if 7 litres of slurry is cooled by 25°C, only 0.25 kWh of heat is recovered, or 125 kWh per day for a 500-sow unit (including the contribution of the compressor). For this reason, systems may be combined with a ground-source heat loop to boost their output. This practice also brings eligibility for Renewable Heat Incentive (RHI) payments (although that scheme is due to close in 2021).

Once removed from the slurry, heat may simply be rejected, but to comply with the requirements of BAT, it should be put to use locally, to avoid the need to pump large volumes of water over any distance. For example, the low-temperature heat may be used to displace conventional energy for nearby heating services. Heat with a flow temperature up to 45°C is readily achieved and may be used for space heating in the farrowing pads (creep pads) and the weaner rooms. Here, the temperatures required are within the range at which a heat pump can operate efficiently. However, higher-grade heat, up to 60°C, can be achieved (with a reduction in system efficiency) and may be used in more applications, such as to preheat cold water in a wash-water calorifier, where some electric top-up would be required to achieve the final temperature of 90°C. The cost-benefit is greatest when electric heating can be displaced using the heat rejected from a heat pump, which comprises up to 74% recovered heat and as little as 26% from an electrical input. (The coefficient of performance of a heat pump, or the ratio of heat output to electrical consumption, is typically 3.8. This falls if higher output temperatures are required.)

However, there are other benefits from cooling the slurry which are more widely acknowledged and understood and appear to be the primary motivation for using the technique. The emission of harmful ammonia from the slurry is a highly temperature-dependent process; cooling may reduce emissions, as shown in the table below (taken from BREF).

Economics

Table 4.78 shows the reported extra investment and annual costs from the Netherlands, together with the expected achievable ammonia emissions reduction (compared to an FSF system).

Table 4.78: Costs for the implementation of cooling fins for different animal categories and expected ammonia emissions reduction, in the Netherlands

Animal category	Cooling fins' surface/slurry surface	NH_3 emissions reduction		Extra investment cost (1)	Extra annual costs (2)
	%	%	kg/ap/yr	EUR/ap	EUR/ap/yr
Gestating sows – partly slatted floor	115 for individual housing, 135 for group housing	50	2.2	110	20
Farrowing sows	150	70	2.4	240	40
Weaners – fully slatted floor	150	75	0.15	19	3
Weaners – partly slatted floor	150	75	0.15	14	2
Fattening pigs – concrete slats, partly slatted floor	200	50	1.0	27	5
Fattening pigs – metal slats, partly slatted floor	170	50	1.4	35	6
Fattening pigs – metal slats, partly slatted floor	200	60	1.2	NI	NI

(1) The extra investment costs are calculated relative to a fully slatted floor with a deep pit.
(2) Annual costs include depreciation, interest, maintenance and other operating costs such as energy, extra manure storage, manure management costs, and the costs of any additives.

NB: NI = no information provided.

Source: [43, COM 2003] [168, Netherlands 2010] [169, Netherlands 2010] [589, Netherlands 2010] [640, Netherlands 2013]

This can assist producers with environmental compliance, which may be of even higher importance in the future. There may be savings on groundwater monitoring too, which all adds to a virtuous cycle of investment.

Interest in this technology will depend on producers requiring the waste heat that is made available, which can contribute to (but does not dominate) the economic case for implementation. A thermodynamic model is required for each instance, to evaluate equipment suppliers' claims, and a monitoring system will demonstrate the system's effectiveness in use. The AHDB slurry cooling guide (Ref 10, n.d.) is a useful reference document for producers that explains how these systems could be designed and implemented.

Potential drawbacks include the increased electrical demand (except in applications where electric heating is being displaced or where surplus electricity from renewable energy can be usefully applied). This may bring severe cost penalties if operated at sites where the time-of-day tariffs apply, during afternoon 'Red Band' periods. Additionally, the heat pump contains refrigerant, a substance requiring licensed installation, and will require routine servicing.

The technology is being introduced in the UK by Klimadan of Denmark (Ref 11, n.d.), whose systems claim 30% ammonia reduction, especially in summer, as well as odour elimination. It is increasingly a feature of new piggeries. The first installation, a small-scale one, claims to heat one-third of the new building from heat recovered by a pipe network of 60 m x 22 m.

There is a general interest in slurry cooling, although most appear to be aware more of its ammonia-reduction benefits as a measure to meet planning and permitting requirements. Its deployment for energy reductions/savings is more marginal as a justification. A need must exist for the heat at the temperatures which it is supplied.

Of the producers we spoke to:

- One is installing Klimadan (as detailed above) and expects the benefits will be multiple and that ammonia suppression/reduction is a more important benefit than the recovered heat. The system cost was felt to be lower than other options
- Another Klimadan adopter has included slurry cooling in new-build barns, including a slatted weaner shed, using 2 km of pipe buried in the concrete base of the slurry channel, covering a total of 1,870 m^2. The system will draw heat from the ground as well as from slurry and provides 53 kW peak output. This will be used in the eight fully insulated barn zones, which require ambient temperatures of up to 28°C, and in office areas and to heat domestic hot water (DHW), although this is not yet implemented. Backup electric immersions are fitted. These were useful until the system was fully installed and commissioned. An important point to note here is that successful deployment requires clear installation instructions and attention to detail in construction
- One considers that the heat available is small, ammonia suppression is the main benefit and cautions against increasing electricity demand at peak periods
- One considered slurry cooling but decided not to proceed following evaluation of the available heat load
- One had no experience

Review outcome

Due to the high interest level in this technology and its potentially high recovered energy benefits, good resources and materials are required to explain and promote the use of the technology in an appropriate manner. There is a small crossover into the dairy sector surrounding the use of the technology in storage tanks. However, the pork sector material should be suitable for this purpose.

Learning outcomes from early adopters could be used as the basis for materials. This could be disseminated through case studies, filmed tours, testimonials or webinars.

NFU Energy 10th Street Stoneleigh Park Kenilworth Warwickshire CV8 2LS
T: 024 7669 6512 F: 024 7669 6360 W: www.nfuenergy.co.uk

Lighting

In considering lighting and improvement or energy-efficiencies, producers should adhere to their requirements under the environmental permits applicable to their sites – section 2.3.3.2 of the BREF is clear in this outline. Similarly, all welfare codes and standards for production must also be met.

Improvements in LED lighting technology have brought new benefits to agriculture generally, through aspects such as yield improvement, behavioural control, and reduced fire risk, as well as the well-understood benefits of energy savings and longer lifespan.

By providing artificial daylight for 16 hours per day, simulating the summer period and breeding season, the dairy sector has achieved noticeable improvements in milk yield. Although for pigs the benefits are lower, some underlying mechanisms, the oestrus cycle, sow lactation and growth, still apply. To what extent is the subject of research, which is limited to date. Further research is needed to assess parallels with dry cow lighting regimes and their impact on fertility in sows. The pork sector can demonstrate accelerated growth and reduced cycle time, with the attendant reduction in the feed. However, any effect from prolonged daylight on fattening may be outweighed by undesired effects.

Whereas traditional lighting had two options, on or off, modern lighting systems can be dimmed, spectrally adjusted, controlled via connected devices, and integrated with other services. These additional functions may be specified as required to implement available guidance on issues such as growth stimulation and behavioural control. By tailoring the LEDs' spectral output to match the response of a pig's eye, it may be possible to reduce energy formerly wasted producing unwanted wavelengths. Full-spectrum 'white' light may only be required in lower levels. Guidance is available from AHDB in the form of the Lighting in pigs guide (Ref 12, n.d.) and the Controlled environments for livestock handbook (Ref 13, n.d.); further research and trials into the subject are required.

Controllable lighting brings benefits, such as the ability to switch off or reduce levels in response to Triad events in the electricity market, avoiding punitive charges, albeit the application of this must be considerate of all welfare codes and standards. Battery technology may provide opportunity here.

LED fittings are also perceived to present less of a fire risk in straw-based pig buildings/housing than their predecessors – fluorescent and discharge sources with hot-running wire-wound ballasts.

Finally, some supermarkets already request higher animal welfare standards, such as Red Tractor (Ref 14, n.d.), which may include lighting requirements (natural or artificial) – this is already affecting the poultry sector.

There is good interest in, and awareness of, lighting technology, with all respondents knowledgeable to some degree. Producers have trialled different approaches, but all seem to centre around a 16-hour day, which is known to extend the breeding season.

We spoke to two specialist suppliers in the market:

- **Unilight**: Claims a Danish study recorded a growth increase of 3–5% or one week, with improved lactation, piglet growth and weaning weight. The target is 200 lux at the 460 nm blue wavelength. Any light source may provide this, but LED is cheaper to operate (Ref 15, n.d.)

- **Greengage Lighting**: Its ALIS (Agricultural Lighting Induction System) reduces fire risk and gives installation freedom with high-frequency power carried on contactless cabling, which runs the length of the building and to which lighting and a variety of intelligent sensors can be attached or relocated. Barn lamps have a lifetime of 100,000 (k) hours (17 years at 16 hours/day) and can be dimmed and colour-shifted for behavioural control in pig and poultry applications. Sensors can report on CO_2, ammonia, lux and temperature, as well as relaying video and sound; an animal welfare index is computed by an app. A two-cycle trial is underway (May 2020) to test links between spectrum and behavioural control, with a sensor detecting aggression and triggering a colour change, with warm white, red and blue available (Ref 16, n.d.)

Review outcome

Much has been written about lighting for the pork sector. Regular short updates disseminating the existing material and regarding the improvements or novel applications of the technologies would seem the most appropriate means of continuing the messaging in this area.

There are, and will be in the future, changes in legislation requiring minimum standards for lighting, which would be better presented to the sector in lengthier and more detailed knowledge to be prepared.

Control and data

Energy efficiency

Unsurprisingly, and somewhat disappointingly, few of the producers we spoke to mentioned energy efficiency as a technology area, albeit the undercurrent of this runs through applications of new and renewable technologies. It is widely accepted that energy efficiency provides the fastest paybacks and is the easiest route to reducing carbon emissions. However, it is often considered the least exciting.

In understanding where the potential lies for energy-efficiency improvements, we need to consider three predominant areas. These are lighting load, heating load, and motive load. As lighting is discussed in greater detail above, the following sections include motive load and heating load, followed by control considerations, as a holistic means of reducing energy consumption.

Motive load

Wherever an electric motor is deployed, whether in the form of a fan or a pump, energy is usually being wasted, as motors are rarely sized to match the mechanical load they serve. Furthermore, motors may not operate at the ideal speed for the service they provide – any excess speed representing a waste.

In recent years, motor technology has improved, with synchronous AC motors improving in efficiency class from IE2 through IE3 to IE4 and even, for some applications, IE5 – each step representing an increment in efficiency, from 88% into the mid-90%. While it is not economically beneficial to upgrade a working motor purely for energy saving, it is certainly worth specifying the highest possible efficiency when replacing one. At this juncture, only the extra cost of the more efficient product needs to be justified by its saving.

Motor speed is now readily controllable through the insertion into its electrical supply of an inverter or variable-speed drive. These electronic devices regulate speed by supplying the motor with variable-frequency power, from full speed 50 Hz down to 20 Hz. Motors obey a law of physics known as the Cube Law, which states that power consumed is proportional to the cube of speed – which means that at 90% of full speed, only $(90\%)^3$ = 73% of full power is drawn; and at half-speed this falls to just 13%. Clearly, speed control is worthwhile, where it can be introduced. Speed can be adjusted manually, or automatically in response to a controller monitoring the parameter that the motor is governing, for instance air quality where a ventilation fan is concerned.

Finally, the latest motor technology combines all these advantages into one. The electronically commuted (EC) motor is inherently efficient and speed-controllable through integrated electronics – no need for a separate inverter. When linked directly to the load without the need for a belt, for example a fan where the motor is mounted at the hub, friction losses are also eliminated for the best possible performance.

These technologies are becoming commonplace in new equipment. Pig shed ventilation is a good example. One producer involved in the review has introduced EC ventilation fans which operate at variable speed with automatic control based on temperature and air quality; energy savings of over 50% have been made.

Heating load

Turning attention to the provision of heating, where renewable or recovered heat is not available and it must be provided from a grid supply, efficiency is again important as heat can represent large quantities of energy. Providing it from electricity, the most expensive fuel and still having the highest carbon footprint, should be avoided where possible. If gas is not available, heat pumps (air source or ground source) may be more economical, as well as eligible for incentive schemes, such as the Renewable Heat Incentive (although this will close in 2021). Heating systems also benefit from close control and insulation, to ensure that only the heat required is produced, and that it is delivered to the point where it is needed without loss in distribution – from a hot-water storage cylinder to a heated barn.

Another means of reducing carbon emissions from heating is to reduce the heating requirement. Traditionally, insulation is well understood, and it remains an important part of energy efficiency. Insulation encompasses that used for reducing building heat, as well as ensuring heat transfer from primary sources is efficient and provides accurate and good temperatures.

Typically, insulation materials are not very different from several years ago. However, the main changes are very much about how these materials are applied and the economic levels at which these should be deployed. The law of diminishing returns is an important principle in respect of insulation. Each additional layer of insulation has less of an impact than the one that was applied previously. However, there are good standards and guidelines for insulation levels in buildings, as well as on pipework and heat supply infrastructure, which are being continually updated as costs of energy increase and the importance of energy efficiency is popularised.

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Taking good care in construction, using good-quality materials and applying the correct coatings for surfaces will have an impact on their primary reason for being there (ability to washdown for example) but also ensure good energy efficiency. This is especially important for reducing heat loss through natural and uncontrolled air exchange versus well-sealed buildings and controlled ventilation based on set requirements.

Control

Replacing technology with more energy-efficient versions and providing the same outcome certainly reduces energy consumption. However, this can be quite capital-cost-heavy and often it is inappropriate to replace technology until the control has been resolved. Control systems have been revolutionised by the availability of cheap electronics and sensors, for example. This means that control can be done at an individual-pig-mat level, where previously the best form of control would have been at a whole-house level. This enables the tailoring of the environment to match the individual animal's requirements at the time.

The application of good control requires good data acquisition and the intelligent analysis and application of that data (see following sections). Time spent altering control settings and tailoring them to get the best outcome is rarely wasted and the availability of cheap wireless sensors, powerful computers and widely available tools and manipulation lends itself well to providing great opportunities for energy efficiency from control in the future.

Review outcome

The pork sector would undoubtedly benefit from ideas, materials and promotion of efficient techniques to reduce energy consumption, especially where these have limited or no impact on day-to-day production.

A programme of efficiency identification and promotion would be invaluable here, perhaps with 'monitor' producers used to highlight areas and showcase improvements.

Data acquisition

Some of the sector participants we spoke to are involved in the gathering of data and its use to monitor the energy consumption and benchmark a farm operation. This is an important part of improvement techniques, as knowing where you started from gives confidence to the results and ongoing measures.

In respect of energy efficiency and control, data acquisition should not be limited to the obvious areas, such as energy consumption, temperature, on/off times, etc. To get best value, data should be gathered and reported against all sensible metrics, such as feed requirements, fertility, weight gains, mortality, etc. In this way, the full impacts of the changes that are made can be assessed and the right decisions made. Much of this is important in traceability and welfare, although the protection of this data such that it is used for the improvement of the producer and the industry is crucial. Internet-connected systems abound (such as 30 MHz) and internet collaborative platforms (which are both popular in horticulture), such as LetsGrow, can be deployed to get a 'big data' effect.

Two such companies in the pork sector are AgroVision (Ref 17, n.d.), which provides national benchmarking data to producers via AHDB, and AgriSyst (Ref 18, n.d.), which is working in a three-year project with AHDB on ways to better visualise data – this data is available in real time and through push reports. Using this data for predictive analytics is expected to change how producers manage their enterprise and gain maximum efficiencies in all aspects of production.

One of the deployed technologies comes from Farmex (Ref 19, n.d.), which produces environmental controls for pig production facilities. Their Dicam process controller unit is installed on over 100 farms in the UK. Featuring remote access and data capture, Dicam² (launched 2020) (Ref 20, n.d.) will network wirelessly and give full app control, rendering control panels unnecessary. Unlike other systems which rely on cloud-based algorithms, Dicam² retains the intelligence on site, allowing it to continue when communications fail.

As a data-capture unit, producers will be able to specify what they wish to measure and monitor to tailor the systems for their requirements. By integrating the system with wireless sensors, it would be possible to put other site data, for example from renewables or refrigeration plant, to better use.

Avoiding the need to install cabling to remote locations, wireless sensors bring down the cost of the gathering of environmental data for information, monitoring and alarms, and to feed into the benchmarking process.

Data analysis

Modelling data and understanding the results can be a difficult task, especially where outcomes are not necessarily known or well understood. This can be done using spreadsheets or, more commonly, by application of proprietary systems, such as that provided by Alltech E-CO_2. (Ref 21, n.d.).

Alltech E-CO_2, a subsidiary of animal health and nutrition experts Alltech, specialises in modelling and reporting, in simple and easily interrogated ways, the footprint of farming operations to assess and address emissions. The footprinted components are feed, fuel, fertiliser, energy, transport and (indirectly) health. The value of having benchmarked data against other similar operations is seen in this platform too.

The feed is the largest component; other factors, e.g. fertility, can indirectly reduce the feed by speeding up the cycle, generating higher productivity. Feed concentrates have a higher footprint as they require reduction, transport and mixing; forage is lower-impact (probably more relevant to the dairy sector); use of by-products also reduces FP. Efficiency can be improved by increasing output per feed, or by reducing feed for the same output. Finishing units add to footprint, so the heavier the arrivals, the fewer emissions arise there.

Alltech E-CO_2 should be useful to model the footprint benefits of the other technologies evaluated in this report. For example, they have already evaluated the effects of blue spectrum lighting for Unilight.

Other tools, such as AHDB’s Farmbench (Ref 22, n.d.), can also be used and highlighted in this work, although this is more a financial and business performance tool than an improvement and management system.

Review outcome

As some of the most exciting developments of the connected world, these systems enable the good gathering of information and presentation of results. Applying this to exemplar or monitor farms will provide good case-study material, showing how such systems can be used to improve efficiency and make improved business decisions.

This material, alongside the use and promotion of suitable systems and highlighting improvements in acquisition techniques, would form the basis of technical updates and other materials.

Others

The following areas were raised during conversations; these may be areas for further research and are included here for completeness, although without any specific recommendations for action currently.

Nitrogen fixing

This emerging technique, by N2 Applied of Norway (Ref 23, n.d.), uses a plasma reactor to 'fix' nitrogen from the air, which is then combined with slurry to form a stable organic fertiliser. It must be said that slurry is generally valueless and, where possible, any ability to recognise a value as a nutrient enhancer or other resource at economic cost will be widely welcomed.

Air is forced through the reactor, where positive and negative fields break the triple bond between N_2 and O_2, pulling the atoms apart. The resulting reactive NOx gas is then combined with slurry (or digestate from AD) in an absorber, to form ammonium nitrate, an enhanced biofertiliser with up to three times the nitrogen content of slurry, with no smell and reduced pH – the benefits being 90% reduced ammonia emissions and lower soil acidification.

The drawback to this has been extremely high energy usage, but the latest prototypes have achieved >50% reductions. Of the six prototypes in the EU, one is in the UK, in Stirling. A further 10 trials will be deployed in 2020, to the dairy, pork and biogas sectors. The limited data revealed that a 52 kW electricity supply is needed and the containerised plant can service a herd of 200 cows.

Application in the pork sector is yet to be quantified.

Electrolysis of pig slurry

Electrolysis of ammonia has been proposed by electrochemical engineers in Ohio (Ref 23, n.d.) as an energy-efficient way of destroying the NH_3 bond to release nitrogen and hydrogen. This technique uses less energy than N_2 fixing and may readily be applied to agricultural sources of ammonia. The process converts ammonia into 82.5% N_2 and 17.5% H_2. It consumes 1.55 kWh of electrical energy for each kg of hydrogen released; in combination with a fuel cell, the heat required would be available from the process of converting 1 kg of hydrogen into 33 kWh of electrical energy.

The technique was born from the realisation that diesel transport costs were becoming significant in the slurry disposal process, and yet the slurry could itself replace that fuel or part of it.

Research has been conducted in airtight pig units capable of measuring every input and output, allowing factors to be varied and the resulting variances in carbon balance measured. Severn Trent Water and sewage experts from Coventry University explained that by flushing slurry (as referred to in BAT [1] section 4.7.1.9), the ammonia would be carried away in the liquid, leaving the solids to be sent to anaerobic digestion, where they would give a 30% higher biogas yield than unseparated slurry. Meanwhile, the ammonia-rich liquid could be warmed and electrolysed, releasing hydrogen with a value Defra calculated at £20 per finished pig.

Practical implementation requires a 9-inch pit beneath the pigs, which can be flushed with rainwater every two days. An inclined sluice performs the separation. Lagoons are required for rainwater and flushed produce. Care is needed to prevent formation of dangerous H_2S. Warming condenses the liquid to a low pH; soya oil is added to improve the electrolysis process. Slurry solids are digested to biogas, the digestate being dried to form fertiliser pellets. The heat and electricity required are raised in a CHP from the biogas, with some to spare.

The viability of the technology relies on a market for hydrogen as a fuel. It may be of use to some producers on their premises, through diesel-engine conversion kits. This also avoids the need to sell the fuel, with associated losses to handlers or through taxation. Several farms are incorporating the technology in their new-build designs.

New building structures

Improvements in pig housing and UK pig building stock should benefit from lessons learned in other industries. A principle that holds true is that buildings should be appropriately insulated, have adequate controlled ventilation and be designed to minimise impact on the animals. In considering new technologies, these principles are key. The Controlled environments for livestock book is an important resource here.

One participant, the Agri-EPI Centre (Ref 24, n.d.), reported a trial at Dairy Development Centre, Shepton Mallet, into a triple-layered fibre roofing material that transmits up to 20% of daylight and gives exceptional strength and repairability. The weight per unit area is 10% that of traditional roofing materials, which can reduce the steel requirement at a new build.

This is an example of a learning outcome from another agricultural sector which could be applied to pig production. However, its appropriateness should be reviewed thoroughly.

Automated systems

While not immediately applicable as energy reduction or control techniques, the use of automated systems is an important part of technological advance for the pork sector and will have implications, largely in increasing use, in energy consumption. Such devices will normally fall into three broad categories: labour saving, time saving and improvements in accuracy.

Both AHDB and EU PiG have case studies and documentation worthy of investigation in many of these areas and this body of resource will increase.

Feed

One participant described success with an installation of Schauer's Spotmix (Ref 25, n.d.) feeding system, which pre-mixes dried feed and delivers it to troughs via air tubes. The final mixing with cold or warm water is carried out at the trough, where the ration for each pig may be adjusted to correct any growth inequalities in the litter. Other market leaders include Nedap feeding systems, which has a whole host of technologies that tailor feeding to the individual animal through the implementation of feeding plans, animal identification and monitoring (Ref 26, n.d.).

Roxell, another systems supplier, provides similarly tailored systems for optimal feeding and drinking which aim to reduce waiting time by individuals and provide correct nutrition as required (Ref 27, n.d.).

Animal condition and handling

Labour efficiency and accuracy can be improved by employing automated weighing and sorting systems, such as Hölscher and Leuschner's optiSORT (Ref 28, n.d.) and Fancom's eYeGrow (Ref 29, n.d.), both of which employ techniques to deliver accuracy and minimise stress on the pigs.

Bedding and scraping systems

Sorting straw, clearing muck, and generally ensuring a clean, positive bedding environment can also be automated, primarily to reduce labour and time inputs, but also to ensure welfare. Learning lessons or complementary technology from dairy farming provides opportunity here and companies such as JH Agro (Ref 29, n.d.) aim to tailor the bedding distribution and amounts to improve conditions and slurry quality.

Summary of findings in easy to identify matrix

Technology	Challenge	Review outcome	AHDB pork sector potential	Gaps in producer's knowledge	Potential GrowSave work
Energy prices	How to benefit from a constantly evolving market or protect from harmful effects of price volatility, as well as decarbonise.	Discussion and provision of materials around strategies to reduce energy cost (especially electricity) will benefit the pork sector, in much the same way as they will benefit other sectors in AHDB. With the market in a continuous state of flux, regular updates on the market dynamics will help producers to make purchasing decisions. Decarbonisation plays an increasingly important part of producers' decision-making and, therefore, awareness of decarbonising influences and strategies is as important as those for cost.	High	How the market changes from week to week.	Regular market updates supported by information demonstrating effects of changes to grid make-up.
Solar PV	How to benefit from an established energy-generation technology.	Solar PV will not solely benefit the pork sector. There is, therefore, an opportunity for a cross-sectoral approach here, with tailored sections to meet the specific needs/concerns of each sector. For any sector, full benefit from solar PV will occur when matched electrical demand is present during the daytime. Therefore, descriptions and research into energy matching for loads has benefit too.	High	Changes in support mechanisms and what may be available to make the economics work is limited.	Cost-benefit calculators and factsheets updated to reflect changing costs, potential for load matching and economic support.
Wind power	This has been unattractive for some time but may be about to re-emerge as a generation technology worthy of consideration.	The challenges of successful deployment are often difficult to navigate. Clear cost benefits and long-term operational issues need to be relayed to producers considering such a scheme, especially where local opinion is weighted against the technology. Therefore, as the market develops, the messaging surrounding these issues should be produced. This is not considered immediate and will be published via AHDB and GrowSave, among other industry organisations, such as NFU and trade press.	Low–emerging	Has marketplace changed/will it change to improve ease of deployment of small-scale wind?	Web pages/news and as per PV above.
Anaerobic digestion	Energy production from slurry and other products. Large-scale plants likely to have greater support, while making micro-AD plants work is tricky.	Further research and data acquisition/analysis are required for micro-AD plants to fully determine and explain the costs, benefits and advantages. This technology is well matched to the pork sector. However, the dairy sector could similarly benefit from this work. Further work is required, with emphasis on learning outcomes from European neighbours – this could be in the	Medium – requires large infrastructure and economic rationale	When is it worthwhile, what are new emerging opportunities based around incentive schemes or government policy?	Blogs, web articles and news features would be suitable to get the basics of the scheme across – further work would be required to provide applicability to the pork sector.

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		form of dissemination of their materials or study tours showcasing successful plants. Large-scale AD plants, and how producers may benefit from their deployment, will be dependent on the outcome of the Government consultations and future policy. Blogs, web articles and news features would be suitable to get the basics of the scheme across. Further work would be required to provide applicability to the Pork Sector.			
Battery storage	Batteries can be used as a means of load shifting to improve renewables optimisation or improving average electricity price by buying cheap and avoiding peak import.	The interest in the use of battery and energy storage is cross-sector, although tailoring to pork-specific scenarios is required to make the messages relevant. As no material has been produced on this topic to date, this would need a lead sector, which is suggested to be AHDB Pork or Potatoes. Ongoing research and awareness are needed to ensure up-to-date messaging in such a fast-moving area. Articles and case studies will be needed to support main outcomes and highlight the opportunities in a way that impacts producers.	Medium–emerging	Cost vs. benefit of batteries changing dynamically, not yet suited for many suggested applications – need to keep an eye.	Factsheet explaining mechanics and other potential energy storage solutions, with cost-benefit analysis to demonstrate where it might make sense.
Heat recover + Heat pumps	A governmental cornerstone of decarbonising the heat network in the UK – how does it best fit with producers and what heat could be harvested – requires ingenuity.	Some work on heat pumps has been done and literature/training materials produced for AHDB Horticulture, which could be used as a starting point for this work. The work would have cross-sectoral appeal for AHDB Dairy, which has similar challenges around milk cooling and water heating. Sources of heat for boost by heat pumps can be various, as described in the heat recovery section, therefore these themes need full sense checking and potential explanations for them to be relevant to producers. Near-market R&D and case-study material will be invaluable here.	High	Understanding heat pumps (how they work and their application) is often difficult. Determining their sources and how they are best used to maximise efficiency even more so.	Adaptation of horticultural materials with sector-specific examples of deployment or opportunities. Specific tailored research into currently available techniques and potential sources of heat.
Slurry cooling	Heat pump harvests heat from slurry channels for alternate use, or simply cools slurry for the reduction in ammonia.	Due to the high interest level in this technology and its somewhat overstated energy benefits, good resources and materials are required to explain and promote the use of the technology in an appropriate manner. There is a small crossover into the dairy sector surrounding the use of the technology in storage tanks. However, the pork sector material should be suitable for this purpose.	High – not necessarily energy-driven rationale	Applicability, is heat significant, description of benefits, ease of retrofit? How good are these systems?	Thermodynamic modelling, monitoring of the real-life system. Learning outcomes from early adopters could be used as the basis for materials. This could be disseminated through case studies, filmed tours, testimonials or webinars.
Lighting	Improving efficiencies of equipment and ideas on their deployment can change the rationale for lighting for improved production.	Much has been written about lighting for the pork sector. Regular short updates disseminating the existing material and regarding the improvements or novel applications of the technologies would seem the most appropriate means of continuing the messaging in this area. There are, and will be in the future, changes in legislation requiring minimum standards for lighting which would be	Medium	Good information out there – detailed report written.	Use existing material and condense into easily understood info; disseminate changes as they happen, alongside implications for energy consumption and efficiency.

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		better presented to the sector in lengthier and more detailed knowledge to be prepared.			
Energy efficiency	Pan-business improvement through reducing primary consumption, for no changes in production or business risk.	The pork sector would undoubtedly benefit from ideas, materials, and promotion of efficient techniques to reduce energy consumption, especially where these have limited or no impact on day-to-day production.	High – best to deploy efficiencies as step 1 to improvement	Constantly changing marketplace, with more efficient equipment. More efficient techniques require understanding of how to implement them.	A programme of efficiency identification and promotion would be invaluable here, perhaps with monitor farm producers used to highlight areas and showcase improvements.
Data acquisition and analysis	Gathering data for monitoring and targeting purposes can be tricky on expansive corrosive sites. Good data is key to making good decisions. Data gathering is important, data analysis more so in understanding improvements or areas needing improvement. Proprietary systems may be better than spreadsheets.	As some of the most exciting developments of the connected world, these systems enable the good gathering of information and presentation of results. Applying this to exemplar or monitor farms will provide good case-study material, showing how such systems can be used to improve efficiency and make improved business decisions.	High	Cost and understanding on how these systems should be built or used. What to look for, how to conduct the analysis and what do the results mean?	Use and promotion of suitable systems and highlighting improvements in acquisition techniques would form the basis of technical updates and other materials.

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Conclusion and recommendations

Technologies

- There are a good number of technologies that would be candidates for further work
- Many technologies require educational content and description of applicability or improvements, rather than being new to market
- Slurry cooling appears to be a theme of current interest worth exploiting
- The Steering Committee should help define future work from the review carried out

Steering Committee

There is general interest among participants in joining the Steering Committee. In general, it was felt most appropriate to invite participants and consultants to join, for their first-hand experience, rather than equipment suppliers, who would mainly be interested in promoting their products.

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NFU Energy 10th Street Stoneleigh Park Kenilworth Warwickshire CV8 2LS
T: 024 7669 6512 F: 024 7669 6360 W: www.nfuenergy.co.uk