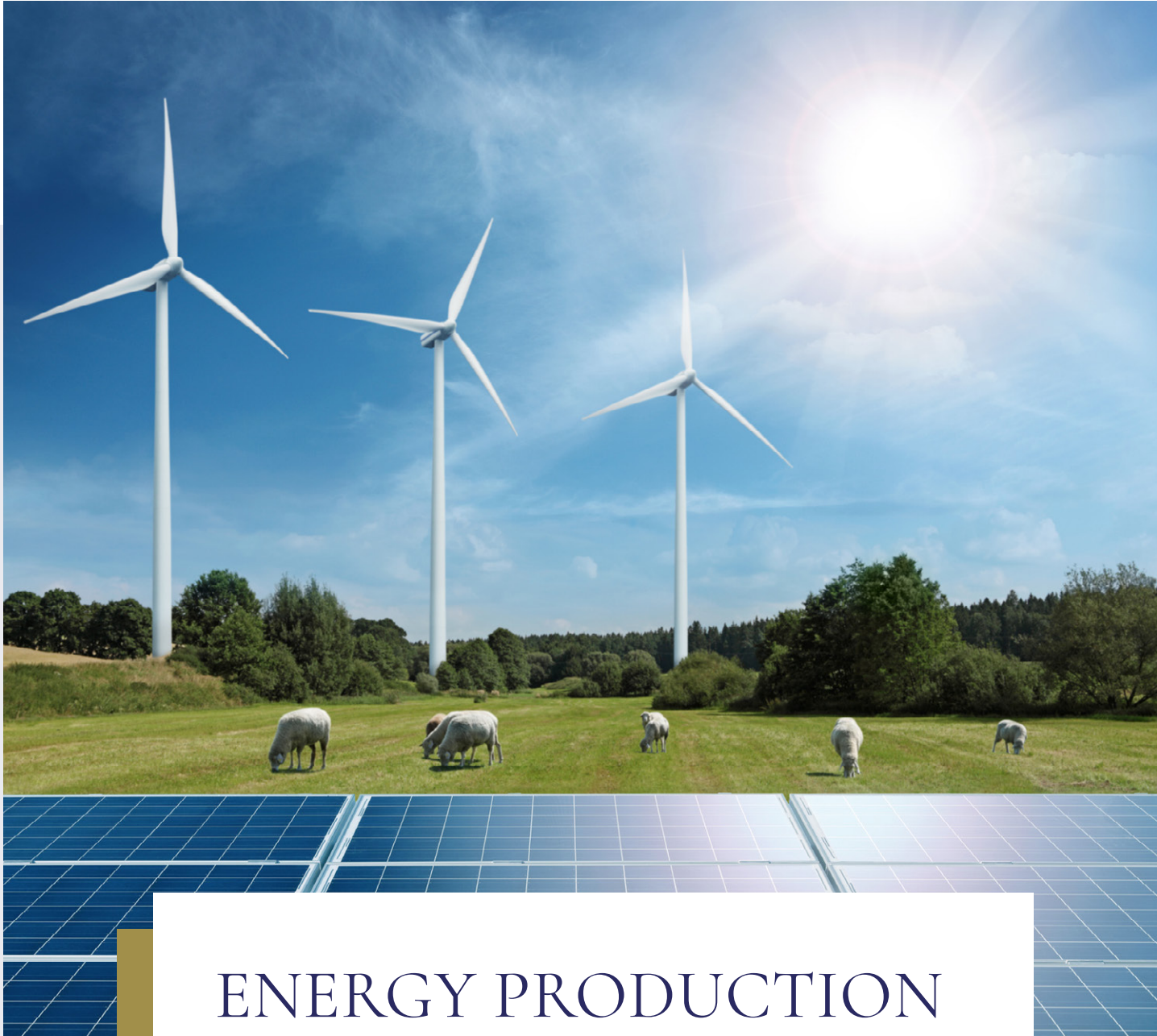




NUFFIELD
Farming Scholarships



ENERGY PRODUCTION

Energy production opportunities
on-farm;

A Bitesize Guide

INTRODUCTION

Each year, up to 25 people aged 25-45 are selected as scholars and sponsored by the Nuffield Farming Scholarships Trust to travel, research and report on subjects they are passionate about and which contribute to advancing farming, food, horticulture, forestry and ancillary industries.

These studies bring new thinking, technology or management approaches from across the globe to the UK. While many know of Nuffield Farming scholarships, few people in the industry are aware of the huge knowledge base of global reports, dating back to 2006, that can be accessed via the online Nuffield Farming library.

This Bitesize Guide, supported by the Elizabeth Creak Charitable Trust, Central Region Farmers Trust, Gloucestershire Agricultural House Foundation and the Royal Agricultural Society of England, gives an insight into the practical experiences and research freely available at:



<https://www.nuffieldscholar.org/reports>



WHAT IS THIS GUIDE, AND HOW SHOULD I USE IT?

This Bitesize Guide on 'Energy production opportunities on-farm' is designed to provide a range of ideas to help anyone who is interested in generating energy on their farm.

The reports featured in this Bitesize Guide are from Nuffield Farming Scholars who have spent no less than eight weeks travelling the globe to further their knowledge and understanding of their chosen study topic, in this case, topics which included on-farm energy generation.

On return from their study tour, they present their findings, the conclusions they have reached and the recommendations to the industry in a variety of formats, including a written report, video and a presentation at the Nuffield Farming Conference.

This Bitesize Guide brings together research, discussions and ideas from relevant Nuffield Farming reports, all highlighted as 'Talking points' and 'In practice' sections, with 'Putting it into action' sections at the end which includes useful links. The Guide features short, thought-provoking extracts - each one includes a URL link and QR code to access the relevant Nuffield Farming report for more information, case studies and discussions.



TALKING POINT 1:

The business of farm energy production

Thomas Clark NSch 2023

We as farmers, managers, and landowners are already in the business of energy production.”

We convert the elements of wind, sunlight and moisture into a calorie harvest such as grains, fruit, pulses, roots, and animal protein. Historically, as farmers we had control of our inputs, with farmyard manure and actual horse power. The oats and hay we grew using the sun's energy were converted by Shire and Clydesdale horses to power machinery and work the lands.

I would argue that we have lost touch with this circular economy of farming, and we need to re-envision this for a sustainable farming future. Farmers are ideally placed to lead innovation in this field of integrated renewable energies; to not only feed the world but meet the power demands as well. I believe with the right industry leaders and governmental support, agriculture has huge potential to capitalise on the route to net zero.

We need not just a five-to-10-year plan but a 100-to-200-year plan, with achievable and ambitious solutions to drive the industry forward to the 2050 targets set in the Paris Climate Agreement (UNCCC 2015). The extension to deadlines within the Government's policies for achieving net zero highlights the challenges arising from a lack of infrastructure and the changes needed in wider industry.

These large changes need to offer the opportunity for farming to be central in future green energy developments.

By finding the correct balance of food, power and biodiversity, I strongly believe we will create the right environment for technologies to be embraced, enabling a leap forward in farming production.

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Putting it into action

MY RECOMMENDATIONS ARE:

1. Sweat your energy assets with productive agriculture, roof top solar PV, fence-lines incorporating solar and wind renewable technologies, fixed renewables on marginal ground and modular rotational systems on productive ground and rotational energy crops.
2. Do not be negligent of the future; capitalise on government funding when available.
3. Government must enable farming to be part of the strategic energy solution for sustainable net zero.



Thomas Clark



We must integrate our energy assets on a per hectare basis allowing the next agricultural revolution to flourish.”



Gate to grid, a responsible model for integrated energy production:
<https://qrco.de/bgrLb9>



TALKING POINT 2:

Farms – natural energy assets

Stuart Oates NSch 2025



The most commercially important finding of my Nuffield Farming study is that farms are natural energy assets, and that farmers routinely undervalue or give away that opportunity.”

The clearest expression of its scale came from the Cornish farmer Andrew Brewer, who put it to me as plainly as it can be put: a 500-kilowatt wind turbine in a decent wind resource generates roughly the same annual profit as a 500-cow dairy herd. One kilowatt per cow. The turbine does not need feed, veterinary attention, housing or staff. It does not get mastitis. It does not require an early morning start in February. It stands in the field and turns, and the money comes in. For a working farmer accustomed to thinking about how to squeeze marginal returns from livestock or crops, the comparison is electrifying.

Throughout my travels I saw this principle in many forms. At a remote cattle station in the Pilbara, Harvest Road Group had cut diesel use dramatically by installing solar and battery storage, simply because delivered diesel in such a location costs far more than power from the sun.

In Germany, Jerome Lintz of Next2Sun showed me vertical, double-sided solar panels arranged in rows across farmland. They produce less total power per hectare than a conventional solar farm, but generate more in the high-value early morning and evening peaks, lose only around a tenth of the land, and leave the ground between the rows in full agricultural production. There are, he told me, no such installations yet in the UK. This could be a key technology in satisfying the often legitimate argument around solar displacing food production.

In the Netherlands, Pieter Winter generates enough biomethane from the manure of his laying hens to supply thousands of homes, and has built a circular network with dozens of neighbouring farms, exchanging feed, manure and fertiliser. Nearby, Djûke Smith van der Maat and Henk Smith described a ‘gateway effect’ on their fruit farm: an electric forklift bought many years ago led to an electric loader, then solar panels, then more electric machinery, each step making the next one obvious.

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Putting it into action

SO WHAT HAPPENED NEXT? THE 2026 UPDATE FROM STUART OATES:

Born out of my Nuffield studies, I have established AgriWatt, which is a farmer-led, ADOPT funded trial looking at upscaling the value of farm produced power.

The project will utilise solar combined with battery storage, with revenue stacking coming from AI driven load-shifting, high-speed electric-vehicle charging and grid services. Its central insight is that British farms exporting renewable power are caught in a commodity gap: they sell at low wholesale rates by day and buy back at high retail rates the rest of the time, capturing only a fraction of the value they generate.

AgriWatt demonstrates that stacking multiple revenue streams onto a single energy infrastructure investment closes this gap. The decision support tool developed through the trial will be open-source and freely available to any UK farmer through the Farm Carbon Toolkit.

Charge.Farm is my second, more commercial venture: a rural electric-vehicle and heavy-goods charging network built around farm-hosted battery storage. The strategic opportunity is considerable. When the same transition reaches the UK freight sector that is being seen in China, rural Britain will need charging infrastructure that currently barely exists. Farms along the major freight routes with space, grid connections and the ability to host battery storage are the natural hosts.



Stuart Oates



Farms are natural energy assets, and farmers routinely undervalue or give away that opportunity.”



Fossil free farming: <https://qrco.de/bgzogn>



TALKING POINT 3:

The pros and cons of renewable energy

Jim Shanks NSch 2009

Pros:

- **Low greenhouse emissions:** Even the 500m³ of concrete at the bottom of a large wind turbine will have a carbon footprint that can be repaid in three to four months of the turbine running.
- **Security:** Wind, water and sun are all sources we have in the UK so we need not depend on other nations to guarantee supply.
- **Sustainability:** The resources we harness are free and will be around for millions of years to come.
- **Localised production:** Not only will this cut down on losses but the benefits to local communities and local economies should be significant.
- **Jobs:** Germany, with 18% of electricity produced at present from renewable sources, has over 400,000 people employed in the sector. By 2020 Germany aims to produce 47% of its electricity from renewable sources.
- **Flexibility and sustainability of supply:** Wind and solar cannot meet the demands due to their erratic peaks and troughs however when you take renewables as a package, the likes of biomass and biogas production along with pumped hydro storage provide an elite supply profile, capable of level supply and with the flexibility to deal with peak wintertime demand.
- It is estimated by the German Biogas Association that should each household in Germany pay 56 euros/year more on their energy bills, that would cover the cost of 100% renewable energy generation.

Cons:

- High cost of capital outlay.
- To deliver a truly renewable economy, attitudes must change and preconceptions must be binned.



Jim Shanks

“Wind, water and sun are all sources we have in the UK so we need not depend on other nations to guarantee supply.”



Energy from agriculture: <https://qrco.de/bgrLhj>



TALKING POINT 4:

Wind turbines - the myths

Jim Shanks NSch 2009

- They're inefficient - they only work 30% of the time. Wind turbines are frighteningly efficient - it's the wind that isn't! I learned in Germany that the maximum theoretical energy capture is 59% should the wind be allowed to pass through the other side of the turbine. To achieve 100% then there would need to be a complete blocking of the wind put in place so effectively there would be no wind on the other side. At present, wind turbines are harnessing up to 90% of the total theoretical potential. Be aware also that a diesel internal combustion engine will only work at 40% efficiency.
- We can't base our electrical generation on an intermittent source. There are three flaws to this argument:
 1. The wind will blow in different places at different times. Admittedly, this is not the most robust of arguments for wind power.
 2. As part of a larger renewables package, level and flexible supply can be achieved. Large scale trials in Germany set the level of electrical generation above what could be supplied from the solar and wind troughs and backed it up with biomass, biogas and pumped hydro storage. The result was production could be set at a required level or increased and decreased when demand dictated. It is my belief that in the future, pumped hydro storage will act as an accumulator tank for wind energy. During surplus/ peak production the energy will be used to pump water up a hill and during deficit/ trough production, the energy will be reclaimed from the water on high by running it through a hydro turbine and generator.
 3. We are at present in the transition between the fossil fuel economy and the hydrogen economy. Right now, there is no need for wind generation to stand alone as we have the other fuels to back it up. In the future, as we come to rely more on wind energy, peaks will be stored as hydrogen and utilised in the troughs.
- They kill birds: Some of the earlier, smaller turbines killed the odd sparrow. Dogs, cats and cars kill.
- Noise: Noise is an overplayed argument by the opponents of wind energy as anyone will know if they have been to a large wind project. While it cannot be denied that during certain windflows, noise is emitted, it is dwarfed by existing noise in the area, for example traffic, wind and rain.

“ Wind turbines are frighteningly efficient - it's the wind that isn't!”



Energy from agriculture: <https://qrco.de/bgrLhj>



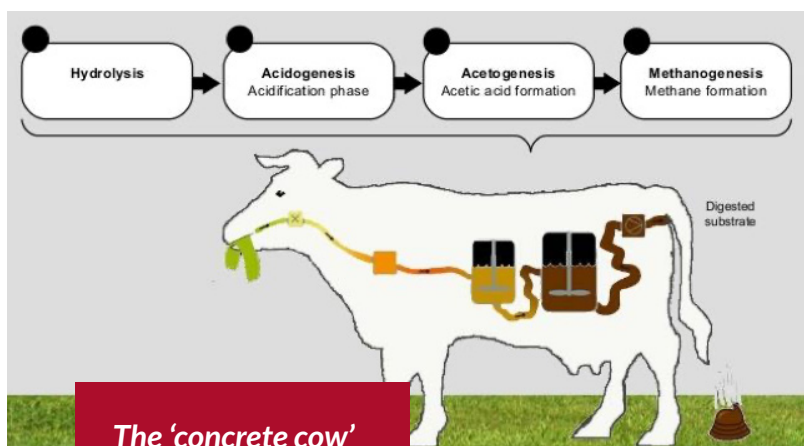
TALKING POINT 5:

What is AD?

Chris Rose NSch 2018

Anaerobic digestion (AD) is the process of bacteria breaking down organic material (such as crops, manures or food wastes) in the absence of oxygen. The biogas created can be used for heating, electricity generation or the gas can be cleaned and injected into the national grid network. The biogas created is a mixture of methane (CH_4) and carbon dioxide (CO_2). AD at its simplest is often referred to by many in Germany and the rest of Europe as a 'concrete cow'.

The fundamentals of anaerobic digestion are not new, in fact it was first discovered over 200 years ago in 1776 when scientist Alessandro Volta performed an experiment in which he disturbed the sediment of a shallow lake, captured the gas it released, and, illustrated that it was indeed flammable. Commercial applications followed 100 years later when streetlights in the city of Exeter were powered by biogas produced from the anaerobic digestion of sewage. Since then, the scientific understanding of the different mechanisms that lead to the production of methane has been undertaken and put into large scale operation successfully. There are numerous resources available online that detail the complex biological process that creates methane gas. However, put simply, AD can broadly be summarised as a 'concrete cow' as illustrated below.



Anaerobic Digestion does not just produce biogas, there are also multiple other outputs that can be valorised. In addition to methane, other valuable products are produced such as heat, CO_2 as well as nutrient rich fertiliser (digestate).



Chris Rose

Put simply, AD can broadly be summarised as a 'concrete cow'."



Anaerobic digestion: maximising the outputs and reducing reliance on subsidies: <https://qrco.de/bgrLqU>



TALKING POINT 6:

Key points for considering investing in AD

Chris Rose NSch 2018

In order for a biogas project to be a likely profitable venture there has to multiple elements involved. The following recommendations give a good starting point for a profitable AD process and one for which, if such a model could be achieved , minimal subsidies would be required.

- Feedstock Supply: the days of 100% energy crops are likely behind us. The future will likely lie in the by-products, residues and wastes.
- Co-location with a secondary business which will profit from the heat, electricity, gas or CO₂ production, such as large corporations looking to offset CO₂ emissions, or wanting to secure a carbon free or even carbon negative supply. Large corporations' green credentials will act like the once-government subsidies were. They will help monetise the public good aspect.
- Solve a waste problem. Identify existing waste streams that are not cost efficiently dealt with. This market will be more competitive, however, as long as there is organic matter there will likely be a pre-treatment method in order to access its full biogas potential.
- Identifying the market that will give a long term source of cost reliant and secure feed will be the key. Any subsidies that are available will likely only be around waste or residue material.
- Digestate: Quality is key. A poor quality digestate may save money in the short term through reduced investment. However, any investment in digestate treatment and nutrient recovery will be a worthwhile investment that will reduce the risk of pollution incidents and competition with others in a saturated market place.
- Work to the strengths of biogas and fill the gap that other renewables cannot. This includes peak load demand feeding schemes and gas storage and renewable gas for HGV transport.
- Engineering design, right first time. Rather than look to what has been done already in the commercial biogas sector, look to lessons learnt by AD plants in other sectors, in particular the water treatment sector. Decades of experience here provide multiple design lessons.
- Biology robustness: AD is a biological process, if the bacteria are not happy the biogas will not be created. Biological management protocols and KPIs have a key part to play.
- Modify, adapt, evolve with engineering challenges. The best AD plants visited have in house operations and maintenance teams that take responsibility, can react quick and do not rely on third parties. Not the cheapest but will likely pay dividends.
- AD plants must be designed in order to maximise the full energy flows. All heat flows need to be valorised to the maximum. Third party heat supply arrangements in an ideal world but in feedstock pre-treatment at the very least.
- Co-digestion with sewage sludge. Sewage sludge is a feedstock that will only increase with increasing population. It is one of the few readily accessible 'wastes' that can be secured at competitive price due to the diverse geographical distribution of treatment works.

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Putting it into action



A French biogas plant



For a biogas project to be a likely profitable venture there has to multiple elements involved.”



Anaerobic digestion: maximising the outputs and reducing reliance on subsidies: <https://qrco.de/bgrLqU>



In practice: AD - Dyson Farming, Carrington, UK

Will Brown NSch 2023

Dyson Farming at Carrington is part of a wider arable farming operation but of particular interest was the relationship between the anaerobic digestion plant and the glasshouse production facility. Interestingly the company opted for glasshouse production despite considering a vertical farm while planning the enterprise. Using artificial lighting was viewed unfavourably compared to natural sunlight.

The anaerobic digestion plant supplies energy to the grid, whilst the additional heat energy is transferred to heating the glasshouse facility. The feedstock requirement of 150t per day is incorporated into the arable cropping rotation (28% of cropping area), growing crops including oats, vetch, and rye, in addition to maize. These crops also contribute towards Countryside Stewardship options, adding to the overall financial performance. The digestate was then fed back into the arable enterprise.



AD plant feedstock

“The AD plant supplies energy to the grid, with additional heat energy transferred to the glasshouse facility.”



Finding synergies between vertical farms of the future and traditional farming systems : <https://qrco.de/bgrM9H>



TALKING POINT 7:

What can biogas from AD do?

Chris Rose NSch 2018

Biogas production is different from many other forms of renewable energy, it can:

- Provide a natural gas alternative (not just electricity that renewable energy forms such as hydropower, wind and solar create).
- Provide electric output on demand – gas can be stored relatively easily – large scale electricity storage is proving problematic.
- It can de-carbonise our current home heating system with little disruption (conversion from gas to electric would be disruptive to consumers and would not use our current gas network infrastructure).
- De-carbonise road transport – providing renewable methane gas for HGV road transport will help solve the problem of how to power HGVs on our roads, where batteries have struggled with to date.
- Reduce damaging methane gas emissions to the atmosphere through the avoidance of food waste going to landfill or composting.
- Provide flexible gas production – there is no reliance on natural conditions such as wind or sun – if the demand for production is not there, feeding can be reduced or ramped up according to meet gas demands.
- Provide valuable by-products such as heat, CO₂ and nutrients and organic matter that can be returned to soils.

“Biogas from AD can provide flexible gas production – there is no reliance on natural conditions such as wind or sun.”



Anaerobic digestion: maximising the outputs and reducing reliance on subsidies: <https://qrco.de/bgrLqU>



TALKING POINT 8:

The other benefits of AD on-farm

Gary Thompson NSch 2021



In addition to generating energy, the challenge of reducing ammonia loss and exporting excess phosphate and potassium economically could be partially answered by using Anaerobic Digestion (AD)."

In exploring a centralised system, I visited Sustainable Bio Solutions AD plant near Kiplev, Denmark producing bio-methane for direct injection to the gas grid, by processing approximately 850,000 tonnes of raw waste streams, of which 60% was animal manures. To supply this an average of 90 trucks in and 90 trucks out were required every day of the year.

The continuous truck movements highlighted the challenge of a centralised system, in particular the movement of low dry matter, low energy density slurry. The plant had no surplus heat available for vacuum evaporation, (due to direct to grid gas injection) therefore the spent digested product had the same problem of high-volume low-density nutrients that due to the wet autumn and spring of 2023-20-24, crop growers, with poor trafficability soil conditions, didn't want to apply.



AD plant, Kiplev, Denmark

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Putting it into action

TRANSPORT TO AD, THE SOLUTION:

A 2023 DAERA-funded small business research initiative at BH Estates in Northern Ireland demonstrated that separating bovine slurries and transporting the solids (25-30% dry matter) to a local anaerobic digester contained 75-80% of the energy value of grass silage.

Therefore, if grass silage was valued at £40/t, delivered slurry solids have a theoretical value of approximately £32/t, (before taking into account local practical and regulatory challenges) making separation and bulk transport of slurry solids by truck a viable possibility.



Gary Thompson



Fertiliser reduction: A road map for UK dairy: <https://qrco.de/bgrLzH>



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TALKING POINT 9:

AD plants – the conclusion

Chris Rose NSch 2018

1. AD plants should aim to be based primarily on wastes/residues instead of purpose grown energy crops.
2. New biogas plants would benefit from a partner or sister business to utilise either the gas/ electricity or heat that is produced. In an ideal world this business should be co-located on site or at least close.
3. The future biogas plant could benefit large corporations needs and desires to become carbon neutral – this is a great opportunity to work with large corporations and help them meet both their zero waste and energy neutral corporate goals.
4. A demand orientated approach for flexible biogas production would fit into the current renewable energy production framework.
5. Co-digestion of food waste and sewage makes perfect sense and will benefit both the water sector and waste treatment sector – overall more energy will be produced more locally.
6. Government policy has to catch up to reflect this factor in the UK.



Anaerobic digestion: maximising the outputs and reducing reliance on subsidies: <https://qrco.de/bgrLqU>



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Putting it into action

In practice: Poultry litter burner – Whittern Farms, Herefordshire, UK

David Throup NSch 2022

During a visit to Whittern Farms in Herefordshire, I had the opportunity to meet with James Write, the farm manager, to gain insights into the newly installed litter burners. The farm has implemented three litter burners as replacements for the older woodchip boilers used to heat their broiler farms. The decision was made to utilise the poultry manure produced on the farm as a fuel source.

This approach is well-suited for broiler production due to the typically dry and stable nature of the manure throughout the birds' rearing period. This strategy significantly reduces the need to export manure from the farm and eliminates the necessity to import approximately 4,000 tonnes of woodchip previously required by the older boilers.



Fluid bed burner

The manure from the birds is placed in a shed where an autoloader can feed the boiler. The boiler is a fluid bed type where the manure is burnt on a bed of sand and produces heat upwards of 800°C to incinerate any dangerous exhaust fumes. The ash produced at the end can be bagged and sold into fertiliser production.

Once the litter burner is up to operating temperature it cannot be stopped so any excess heat it just vented outside into the atmosphere. James recognises this is a waste and is now looking into uses for ways to utilise the heat waste, e.g. use the excess waste for drying or heating alternative products.

SO WHAT HAPPENED NEXT? THE 2026 UPDATE FROM DAVID THROUP:

“The burners only really stack up if you have a use for the heat and with RHI (the Renewable Heat Incentive grant). I've got laying hens and have decided to build a drying floor which was developed by a farmer in the Netherlands, so I'll compost the manure to reduce its moisture content and dry it. This will increase its value as fertiliser and make it easier to transport from a haulage point of view. It's the first one in the UK and we hope to have the produce available next year – we have a lot of interest in the process.”



David Throup



Poultry manure: a study into the storage, bi-product capabilities & the impact on the environment: <https://qrco.de/bgrMDi>



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Putting it into action

In practice: The innovators – John Vrieze, Baldwin Dairies, USA

Jim Shanks NSch 2009

One of the highlights of my travels was getting the opportunity to quiz some of agriculture's finest innovators. Many of those whom I met had ventured out from conventional agriculture and found their feet in a new, energy producing world. There were two people however, that really pushed the boundaries further than most and they were John Vrieze of Baldwin Dairies, Wisconsin, and Dennis Haubenchild of Princeton, Minnesota (see p31). Both men were awarded the USA innovation in Agriculture award (John in 2000 and Dennis in 2009) and their passion is energy from agriculture.

John operates what he calls a closed loop system which allows energy to be generated from waste then utilised on other enterprises on farm. At present the enterprises at Baldwin Dairies include:



The Dairy Herd

- Produces milk and slurry
- The slurry is put through an AD plant to produce heat and power



Fish production

- The power from the AD unit is used to heat and areate the fish tanks.
- The resulting effluent has no e-coli.
- Fish are sold between 6-8 months at 1.5lbs and command a 30% "green" premium



Hydroponic Lettuce production

- The electricity produced from AD is used to light, heat and power the pumps within the greenhouse
- 500,000 plants per year produced
- The effluent from the fish is used to fertilise the lettuce production

FUTURE CONSIDERATIONS INCLUDE:

1. **Processing dead calves:** Protein used for fish food
2. **Algae production:** Once the technology is there to extract oil from algae John would grow algae in his greenhouse. Algae is very responsive to CO₂ so the CO₂ would be piped in from the biogas to stimulate rapid growth
3. **Fat boiler:** At the time of my visit, John was in the process of installing a fat boiler to utilise waste fat to increase greenhouse capacity



Energy from agriculture: <https://qrco.de/bgrlhj>



TALKING POINT 10:

Short rotation coppice

Stephen Briggs NSch 2011

Choosing coppice species (willow, poplar, ash, alder, hazel, silver birch, sycamore, sweet chestnut and lime) as the agroforestry tree species can provide a shorter term regular income from coppicing. Short Rotation Coppice (SRC) energy crop is becoming increasingly lucrative as a renewable crop with regular income, especially with the increasing costs of fossil fuel energy. SRC energy crop is well suited to agroforestry systems and a wide range of tree species can be used for harvesting.

The Forestry Commission argues that over a five year period, sustainably produced wood fuel has the potential to save the equivalent of approximately 7million tonnes of CO₂ emissions per year by replacing fossil fuels.

Energy crops grown in the alleys between trees is also a real option for farms. Miscanthus, willow, hemp etc. can all be grown as an alley crop between timber species in agroforestry systems. Research at the University of Guelph in Canada is evaluating SRT willow as an alley crop in agroforestry systems.



Short rotation willow, Canada

In Germany most agroforestry systems are employing alnus (alder) or poplar (populus) spp. for the production of timber for woodchip used for heating or energy generation, planted as shelterbelts or at 24-32m spaced rows, with 6-9m in-row spacing, with arable crops or pasture in the alleys.

Much of the recent agro forestry research has focused on optimisation of tree densities, the impact of trees on wind loading and evaporation and the shade tolerance of understorey species such as clover, medic, rye grass etc. As in other countries, there is a common trend towards moving away from 12-18m alleys to 24m and 36m wide alleys, to accommodate large modern machinery.



Stephen Briggs



Short Rotation Coppice is becoming increasingly lucrative as a renewable crop with regular income."



Agroforestry: a new approach to increasing farm production:
<https://qrco.de/bgrMLn>



TALKING POINT 11:

Hydro power

Jim Shanks NSch 2009

My perception of hydro generation changed throughout my scholarship. My original thoughts and experiences with hydro were all very positive for the following reasons:

1. Consistency of generation. Although generation levels will vary, hydro delivers a far greater consistency than wind and PV.
2. Lifespan. Hydro, above all other forms of renewable or conventional generation, will command the longest lifespan. Hydro turbines can expect to last over and above 70 years with many predictions of 100 years.
3. Zero input and low maintenance once running.
4. Low construction cost. While economies of scale naturally come into play, hydro will generally come with a lower capital expenditure than wind at under £1,000 per kW installed.

Throughout my scholarship it became apparent that the benefits of hydro generation were not as apparent as I first thought for the following reasons:

1. Lack of viable sites. The need for a water source, high flow and a large drop (head) makes hydro generation the most poorly distributed renewable generation source.
2. Environmental impacts. Many of the larger turbines were built in an era when electricity generation took precedence over the environment. At present, the disturbance of river flow is a major concern to environmental agencies and further limits the viable sites available.

Term	Level of generation
Pico Hydro	0-5kW
Micro Hydro	5-100kW
Mini Hydro	100-1000kW
Small Scale Hydro	1-10MW
Large scale Hydro	10MW+

The scale of hydro generation depends on two factors:

1. the flow of water
2. and the head.

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Putting it into action

The 'head' is the term used to refer to the drop in water. The standard calculation for power output would be:

WATTS = FLOW(l/s) x HEAD(metres) x 9.81(weight of water) x TURBINE EFFICIENCY

The other more simple way of calculating the output that was often used when I was in Sweden would be:

1 l/s over 75 metres drop results in 1 horse power (735 Watts) *

*but this does not take into account turbine efficiency.

Turbine efficiency will normally range from between 45-70% and depends on several factors:

- Scale
- Consistency of flow
- Head
- Flow
- Type of turbine. Different turbines are developed to work at optimum conditions.

The photo shows a large conventional hydro plant in Northern Sweden. Many of the large plants in Sweden act as a bridge for public access as well as a point of generation. This particular plant generates 36MW/hour.



“ It became apparent that the benefits of hydro generation were not as apparent as I first thought.”



Energy from agriculture: <https://qrco.de/bgrLhj>



TALKING POINT 12:

Agrivoltaics

David Oates NSch 2025



The most contentious land use debate in British farming today is solar.

Thousands of acres of productive agricultural land are being committed to ground mounted solar arrays, and the farming community is understandably alarmed. Fields that were growing crops are now covered in panels for 35 years, often with minimal agricultural activity underneath.

This debate of solar farms, however, is framed incorrectly. The choice is not between solar and farming, it is between poorly designed solar which takes land out of agricultural production and well-designed solar which can increase the range of crops and sustain yield of the existing ones. Agrivoltaics, the co-location of solar energy generation and agricultural production on the same land, is one of the most powerful examples of stacking land uses in practice, and it is already working at scale across the world.

Solar farms can offer a range of opportunities to farmers and the wider industry. In Germany, research plots show that shade tolerant crops including potatoes, clover, and certain cereals perform comparably to unshaded equivalents while the panels above generate income, significantly exceeding typical solar developer rental rates. The critical variables are not just panel height, spacing, and orientation, but the physical design of the mounting systems and appropriate crop selection for each site's conditions. PV panels offer a big opportunity for high-value fruit and vegetable markets protecting crops from hail, frost, and direct sun.

In the UK, the clearest stacking opportunity for agrivoltaics is land already marginal on soil, exposure, or market access, where energy and grazing can sit alongside farming rather than replace it. The higher the land's agricultural potential, the greater the investment needed in the structural design of the panels themselves. That principle should be the starting point for any planning framework.

Appropriate scale and context are also critical factors in locating agrivoltaic development. A farm-scale or community-scale installation designed around the needs of the farming enterprise it sits within is a fundamentally different proposition from a utility scale solar park that happens to have a few sheep grazing between the panels.

Scale determines whether the agricultural system can genuinely dominate the land use or is merely tolerated within it. Context, the soil type, the farming enterprise, the local grid connection, the processing infrastructure available, and the farm's long term business plan, must

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Putting it into action

shape the design and location of any agrivoltaic system. The best agrivoltaic projects are those where the farmer initiated the design; the worst are those where a developer brought a template and asked the farmer to fit around it.

A more challenging view is also warranted: with the right design, agrivoltaics has a role to play even on higher grade land. Vertical, transparent, and tilting panel systems that allow full machinery access, combined with shade tolerant crops or protected horticulture beneath, could expand the range of fruit and vegetables grown in the UK by moderating temperature and moisture stress.



David Oates in a vertical agrivoltaic system, Germany.

“With the right design, agrivoltaics has a role to play even on higher grade land.”



Stacking land uses for business and environmental sustainability:
<https://qrco.de/bgznPI>



In practice: Solar – Waverleigh Farm, Australia

Thomas Clark NSch 2024

Karin Stark and Jon Elder run Waverleigh Farm, outside Narromine, New South Wales (NSW), a 2,500 hectare cropping farm consisting mainly of irrigated cotton and dry land wheat. The pressures of the changing weather patterns have been felt by the family with floods, droughts and hotter summers. With cropping becoming more difficult and not having a viable wheat crop for a couple of years, an increased production pressure was put onto the irrigated land. It was across the irrigated cotton area of approximately 550 hectares where rising diesel costs, over \$300,000, were being noticed in running the bore and pump infrastructure.

Opportunity was highlighted in new technologies and in 2018 the decision was taken to install 500kW of solar panels on 1ha of land, seizing the potential to produce their own green electricity on farm. The power generated is used to power the country's largest solar-diesel hybrid pump. In doing this, fuel costs were reduced by 40% and carbon dioxide emissions reduced by 500 tonnes per annum.

However, this large-scale hybrid system does have its challenges, as there can be an inconsistency in generation on a cloudy day, or in mornings and evenings. This results in fluctuations in supply where the diesel generator can fail to match power demand smoothly, with drops causing shutdown of the bore pumps. The current solution to this is battery storage. However, this is another costly investment that is not currently justified in their opinion. Despite these challenges, the system is still on track for a five-year payback. Importantly this highlights some of the challenges faced for a cleaner future; as well as many benefits that can be drawn from an integrated system. Until the high costs in technology are reduced or grants are made available to fund such projects, they will be slow to gather pace throughout the industry.



Karin Stark and Thomas Clark

“Despite challenges, the system is still on track for a five-year payback.”



Gate to grid, a responsible model for integrated energy production:

<https://qrco.de/bgrLb9>



TALKING POINT 13:

Agrivoltaics, agricultural value and the Italian approach

David Oates NSch 2025

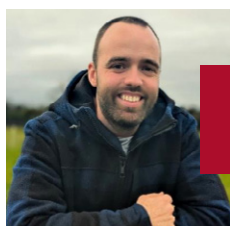
The absence of design standards that protect agricultural value is the central problem in the current UK debate on agrivoltaics. The planning system needs to establish minimum requirements for genuine co production: minimum panel height, minimum active agricultural footprint, and mandatory monitoring of soil health and food output, favouring applications that improve rather than merely preserve agricultural productivity.

Government data and independent satellite analysis confirm that between 17,000 and 21,000 hectares of UK land is now covered by ground mounted solar panels, the vast majority of it formerly agricultural. Sheep grazing beneath panels is legitimate land use stacking, animals benefit from shade, grass is managed, food is still produced. But it is not agrivoltaics. Agrivoltaics requires a more symbiotic relationship where farming remains the primary activity and the solar system is designed around it. The Italy model (below) shows what genuine minimum standards look like. Agrivoltaics are not inherently good or bad. It depends entirely on how it is designed, who benefits, and what the agricultural system beneath the panels looks like. Done badly, it is an agricultural land grab in green clothing.

Agrivoltaics – the Italian model

Italy has enacted the clearest legislative distinction currently in force between genuine agrivoltaics and solar displacement of farmland, banning conventional ground mounted solar PV on agriculturally classified land outright. The only exemption is for ‘advanced agrivoltaics’, a precisely specified dual use category.

To qualify: panels must be elevated a minimum of 2.1 metres; at least 70 per cent of land must remain in active agricultural production; electricity output must be no less than 60 per cent of a standard array of equivalent size; and continuous monitoring of crop yields, water savings, soil fertility, and farm continuity must operate for the lifetime of the installation. The Italian government backed this with €1.1 billion of public funding. The country’s first agrivoltaic auction was oversubscribed, attracting bids totalling 1.7 GW. The principle is clear: the panel is a guest on agricultural land, not its replacement.



David Oates

“Agrivoltaics are not inherently good or bad.”



Stacking land uses for business and environmental sustainability:
<https://qrco.de/bgznPI>



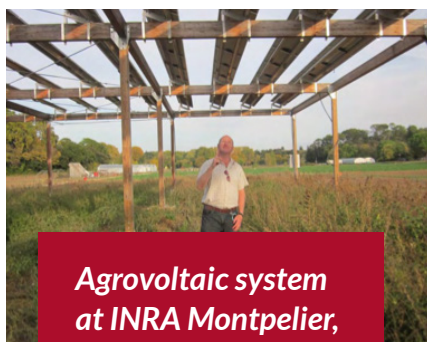
TALKING POINT 14:

Agrovoltaics

Stephen Briggs NSch 2011

At Montpellier in southern France INRA is developing, with financial and other support from a solar power company, Sun'R (www.sunr.fr) an 'agrovoltaic' system. The 'agrovoltaic' combines elements of agroforestry (agro) and photovoltaic (PV) technologies together. This gives crop production with the added bonus of simultaneous electricity generation. This is achieved with an array of solar panels erected at about 4.5m above the ground, in which the amount of light reaching the ground is variable, depending on the density and arrangement of the panels (i.e. 25%, 50% & 75% cover by PV panels).

Under the panels, research plots of selected arable and vegetable crops are grown with research monitoring of microclimatic conditions at crop level, crop response, yield, quality and other response variables. The study is based on the presumption that crops could be grown under reduced light, as long as the light was sufficient for daily photosynthetic requirements, while the quality of some crops, like lettuce, would be enhanced. At the same time, electricity could be generated from the excess light.



**Agrovoltaic system
at INRA Montpellier,
France**

The array was open on the sides, so that absolute humidity was unlikely to be affected in a major way but it reduced temperature and thus, increased relative humidity, which would likely result in greater water use efficiency. Early results suggest that there is no crop yield decline with a PV cover of 25% and little impact with a 50% PV coverage. This type of system has potential for complementary land use activities and improving 'output', especially on smaller farms with high value cropping.

SO WHAT HAPPENED NEXT? THE 2026 UPDATE FROM STEPHEN BRIGGS:

"On-farm, we have installed some solar PV and I have worked with a number of projects on agrovoltaic system development, using the principles of agroforestry and stacking to combine energy and agricultural crop production on the same land parcels."



This type of system has potential for ... improving 'output', especially on smaller farms with high value cropping."



Agroforestry: a new approach to increasing farm production:
<https://qrco.de/bgrMLn>



In practice: Ivanpah solar thermal, California, USA

Alex Fowlie NSch 2014

At the time of this study, the Ivanpah solar development is the world's largest concentrating solar thermal power plant and consists of a 392MW solar thermal project built approximately 50 miles south of Las Vegas, just on the Californian side of the California/Nevada border. Construction commenced in 2010 and was completed in 2013 with 2,600 construction workers employed at its peak and costing approximately \$650m in employee wages along the way.

It consists of three 1,000-acre 'fields' of mirrors which reflect the light onto a centre tower which has a water boiler at the top. The water is heated by the mirrors to create high temperature steam which is piped to turn a conventional turbine with the electricity generated going into the grid system. The system is totally automated with all 300,000 mirrors being software controlled to track the sun and optimise output. This system generates enough power for 140,000 homes and involves significantly less land use than traditional photovoltaic panels, and 95% less water than wet cooled panels. The Ivanpah project cost \$2.2 billion with the main investors being Google NRG, Bechtel Corporation and the Department of Energy. It has had its controversies with a reported 150 bird mortalities in its first month due to birds flying through the concentrated rays and catching fire or flying into the mirrors. Details of how much the scheme is receiving per kWh are strictly confidential but one internet source⁴ put the figure at 12 cents per kWh which was significantly less than standard PV could create electricity for when the contract was signed in 2008.



Ivanpah solar thermal plant

However the system would now be approximately double the cost to install due to the vast reduction in PV panel costs against only a small reduction in the solar mirror system cost: so today a new PV system could produce power at approximately half the price (6 cents per kWh). Without knowing the full details of costs and pros and cons I am unable to evaluate its effectiveness vs. standard systems but it was an extremely impressive piece of engineering to see first-hand.



Alex Fowlie



Opportunities for farmers in the 'new energy' sector:
<https://qrco.de/bgrRj6>



TALKING POINT 15:

Rotational wind and solar power

Thomas Clark NSch 2023



Where good productive arable ground is required for electricity generation then modular wind and solar could be used in rotation.

Modular systems already exist in the construction industries with remote sites and equipment being powered by solar technologies. The photo shows a modular system providing power to construction works in metropolitan Perth, Western Australia. Farms should be looked at in a similar way, with many areas of potential from set aside areas, land with marginal productivity and biodiversity sites that can all be integrated with renewables.



Modular solar PV, Australia

The energy production from 1 hectare of cropped land can produce an approximate 32MWh of energy based on 8t/ha of wheat, compared with 480MWh from solar generated from a 500kW array. Equating this to approximate revenues; for solar power, electricity at 5p/kWh would be £22,500/ha and wheat at £195/tonne would be £1,560/ha. This high profit generation reflects the current industry, where mono-block solar farms are constructed in the most cost-effective densely packed sites which often take land out of production for a contract period in the

region of 30-40 years. To run a fixed site for this long will inevitably see compaction issues along service routes, a need for chemical weed control as burdens build on the longer-term leys and reinstatement works to revive dormant soils. A much more ethical method of production would be to rotate such infrastructure on a modular basis and create a rotation.

The rotation could be carried out alongside or on top of fallow lands, or incorporated within Economical Focus Area (EFA) or Sustainable Farming Incentive (SFI) areas, which will maximise the output of farmed assets. Speaking with Marcel Vroom, industrial designer from the Netherlands, there are good solutions in modular and robotic solar that can be used on productive agricultural ground. Interestingly, the Netherlands cap the solar canopy of agricultural land at 10% and Germany caps at 15%, closely aligned with areas SFI or EFA in the UK.



Rotation could be carried out alongside or on fallow lands, or incorporated within EFA or SFI areas.



Gate to grid, a responsible model for integrated energy production:
<https://qrco.de/bgrLb9>



TALKING POINT 16:

Solar fences

Thomas Clark NSch 2023



Solar fencing is a low disturbance method of securing electrical generation from productive landscapes with added positive benefits to the biodiversity.”

Witnessing the agvoltaics system at La Greenhouse in Italy there were clear opportunities for UK applications. Solar can be run on gantry systems along fence lines, allowing energy to be generated from marginal land already marked out with fences. In doing so these structures would pull cabling infrastructure to field boundaries, facilitating access to power.

This may carry a higher cost as the panels are not so densely grouped and additional cable would be required. However, with increased infrastructure and connectivity, the ability to bring sensors and robotics into the field becomes more attractive, allowing key production decisions to be supported and profitability increased. As service tracks will be required, this additional lane would be incorporated into additional biodiversity belts with establishing wild grasses or native flora to increase the credentials and integrated pest management (IPM) benefits of these areas.



Solar gantry, Italy



Solar fencing is a low disturbance method of securing electrical generation from productive landscapes.”



Gate to grid, a responsible model for integrated energy production:
<https://qrco.de/bgrLb9>



In practice: Battery electric storage systems, California, USA

Alex Fowlie NSch 2014



My main aim of travelling to the USA was to get a better understanding of energy storage and what advances were likely within the industry (at the time of my Scholarship in 2014). The first company I visited was Tesla."

The battery is such a crucial part of the vehicle development that Tesla are building their own 'Gigafactory' to build these themselves and, with an expected cost of \$5 billion, it shows just how much potential they see in the battery industry. All their batteries are lithium-ion as found in a mobile phone or laptop and they plan on developing a 'powerwall' which will be available to homes and businesses to provide independent energy storage.

Tesla has said that with their Gigafactory they will be able to halve the cost of these batteries. Today they would cost approx. \$8,000 for a 10kWh capacity battery. Tesla are offering delivery in 2016 with work well under way on the Gigafactory which will produce 50GWh in annual storage by 2020 – enough for 500,000 Tesla cars. Currently Tesla are getting their batteries from Japan.

Southern California Edison Company (SCE) provided me with a space on the internal company tour of one of their advanced technology labs which is at the forefront of their future technology and operational offerings. Here I saw everything from the above mentioned 'powerwall' system being used on a pilot scheme where a group of houses was being run totally from renewable energy, to smart grids which could isolate and repair circuit problems without human intervention.

What they were doing was fascinating and again energy storage was one area where they were expecting the biggest advance in the coming years. They have already built a 32MW battery



Battery storage at Tehachapi

storage warehouse next to the Tehachapi Windfarm. This is simply banks of lithium-ion batteries. When I requested a tour of the plant I was told that no one worked there and it was very boring with nothing to see other than banks of batteries - they sent me this photo in lieu of a visit.

Within the advanced technology lab I saw powerwall storage first hand (but on a smaller scale) and this is the reason I am most excited about this form of energy storage. I have been

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Putting it into action

to a hydrogen storage centre in the UK and seen pumped hydro storage solutions but, being a simpleton, these have always been too technical and required too much operational input for me to be excited about the opportunity of owning such storage; whereas a simple bank of batteries within a shed and requiring zero input is something I feel I could just about manage.

SO WHAT HAPPENED NEXT? THE 2026 UPDATE FROM ALEX FOWLIE:

“On farm at home we have put up three 500kW wind turbines, 50kW solar, and 2MW of biomass for grain drying and district heating farm cottages - when I did my Nuffield I think I had just done one 500kW turbine at home. The turbines are all direct export to the grid but the solar and biomass is used on farm which helps reduce our energy costs.

With Muirden Energy it's more of the same, but on a bigger scale. We've built out about 70MW of wind ranging from 225kW to 27.6MW and that's been a combination of joint ventures with landowners or straight rental projects. We also put up ten 50kW roof top solar and various biomass boilers for the hen rearing sheds [Muirden is part of egg producer Duncan Farms].

We built out our first totally subsidy-free site with Muirden a couple of years ago and are continuing to develop new projects, with 200MW of wind and 20MW of solar approved but grid delays are a massive hold up! These new sites need to be large scale to have any chance of stacking up so the majority are now 40MW+ in size. We are keeping an eye on batteries, and the egg business is looking to install its first battery on one of the solar sites to utilise more of the power generated on site.”

“A simple bank of batteries within a shed and requiring zero input is something I feel I could just about manage...”



Opportunities for farmers in the 'new energy' sector:
<https://qrco.de/bgrRj6>



TALKING POINT 17:

Alternative fuels for machinery

Stuart Oates NSch 2025

Every major tractor manufacturer is now pursuing some sort of alternative fuel programme. But which fuel will win in the mainstream? While I expected to stay on the fence while innovations are still happening, I now think we're long past the trials phase. Battery electric tractors will win this race.

I reached that view by way of several routes. In Austria, I drove a Tadis prototype electric tractor, which dispenses with a gearbox in favour of a single reduction gear per motor, and which I found among the most controllable farm machines I have ever operated. The retail model will feature 160hp with a 196kwh battery.

In the Netherlands, I tried the EOX electric autonomous tractor. With 175 horsepower and a 150kwh battery, an 800-volt electrical architecture supporting 232-kilowatt fast charging, and approximately 16,000 newton metres of torque at each wheel. Its commercial logic depends on high utilisation: an autonomous machine can work continuously through the day and into the night, spreading its capital cost across far more hours than a conventional tractor with a driver achieves.

For very large arable operations - the Australian wheat belt, the Brazilian Cerrado, the American plains - the same machine paired with a mobile solar charging trailer becomes a credible alternative to a fleet of diesel tractors.

In France, flax grower, Laure Figueureu-Bidaud has already successfully replaced a 350hp tractor with a 150hp, diesel, AgXeed robot, so the automation concept is already proven.

At Electric Cherries in New Zealand, switching from a PTO- driven sprayer to one powered by the tractor's batteries through a cord tripled working time from four hours to twelve. The Zoomlion hybrid combine I saw at Agritechnica is the same principle at scale. The single credible argument standing in the way of full electrification is battery weight and density, and the rate of progress, particularly in solid-state chemistry, suggests that this is a problem of years rather than decades.



The Monarch electric tractor at Electric Cherries, New Zealand

Battery electric tractors will win this race."



Fossil free farming: <https://qrco.de/bgzonn>



TALKING POINT 18:

Renewables and vertical farms

Will Brown NSch 2023

Vertical farms are characterised by their high energy requirement, particularly when compared to outdoor or glasshouse production. Reducing energy consumption was a top priority for all vertical farms visited. It is also the reason why all commercial vertical farms were focussing on leaf crops which are much faster to yield, hence requiring less light energy.

Obtaining energy use data from vertical farms is challenging, as was evident throughout this project. Many hosts were not able to share data, or where possible, information was dependant on factors such as: farm size, farm layout, crops grown, outside temperature, farm capacity. The range of energy usage varied greatly across the farms visited.

Example energy requirement of vertical farms*

Energy Requirement per M ² / Day	2.63	kWh
Energy Requirement of 10,000 M ² Farm / Day	26.3	MWh
Energy Requirement per Year	9599.5	MWh
Typical Lettuce Yield / M ² / Year	50	kg
Lettuce Yield from 10,000 M ² / Year	500	tonne
kWh / kg Lettuce	19.20	kWh

* Data taken from three businesses and standardised to calculate an approximate energy requirement per kilogram of lettuce

Assuming 1kg lettuce requires 19.2kWh to grow inside a vertical farm, that equates to 0.21kg CO₂, and £5.76 (30p/kWh). Of this

cost, light energy makes up >50%. Many vertical farms are countering energy costs by utilising renewable energy. For instance, GrowUp Farms in Kent, UK, are using local forestry as a biofuel. Several other farms were using solar energy, either on site or outsourced.

If renewable energy is internally sourced, it is important to calculate the opportunity cost of this energy – the revenue lost from not selling it to the grid. There is no such thing as free energy. For example, if photovoltaic solar panels are installed to power a vertical farm, the alternative potential income must factor to show the true cost to the vertical farm. It could be the case that selling energy to the grid is more profitable and lower risk than using the solar to power the vertical farm.



Will with his wife and son on a farm visit in Japan.

“There is no such thing as free energy.”



Finding synergies between vertical farms of the future and traditional farming systems : <https://qrco.de/bgrM9H>



TALKING POINT 19:

Renewables and hydrogen

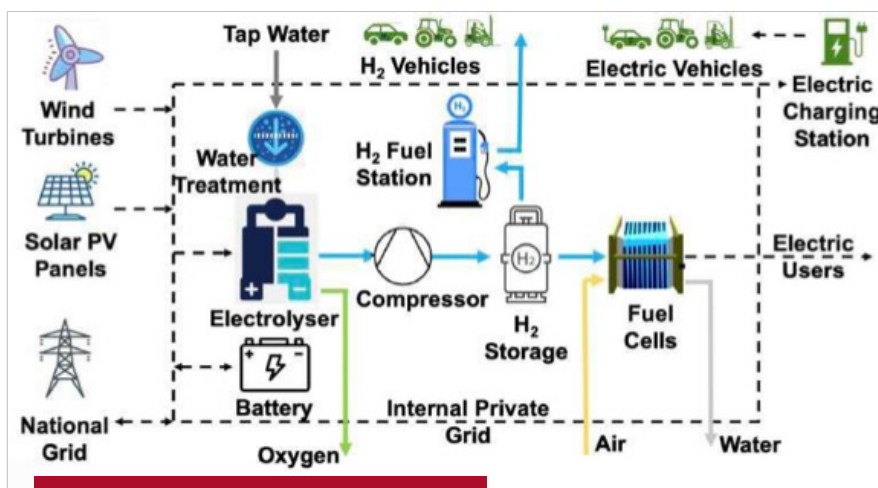
Thomas Clark, NSch 2023

As part of my Nuffield, I had the chance to talk with senior scientist at The James Hutton institute, Professor Alison Hester, who explained the HydroGlen at Glensaugh in North east Scotland. Run on the James Hutton Institute upland farm, it is a green (renewable) hydrogen farming community project.

The project will study the feasibility of modular green hydrogen production on farm and how this can work for farming communities as part of the energy transition.

Glensaugh currently has a 50kW wind turbine and 70kW of solar that will be used in the production of hydrogen, that will be stored on site. The hydrogen will go on to fuel vehicles and power machinery or be further processed by a fuel cell, producing electricity on demand.

Stored hydrogen is another form of battery power that has multiple uses, making it a flexible alternative to standard battery storage. Enabling farms to create their own fuel would build resilience to fluctuating market prices and help make farms more economically viable and sustainable. In finding a solution that works for rural communities, farmers can once again move towards becoming energy self sufficient.



A non-technical summary of the HydroGlen project



Enabling farms to create their own fuel would build resilience to fluctuating market prices.”



Gate to grid, a responsible model for integrated energy production:
<https://qrco.de/bgrLb9>



In practice: After my Nuffield Scholarship...

Jim Shanks NSch 2009

Since returning home to the farm in Roxburghshire from my Nuffield Farming Scholarship travels (in 2009/10) I have started work on three renewable projects:

1. A 330 kW turbine on farm. Due to the highly attractive feed in tariff rate of 18.4p/kW under 500kW, this level of project in my opinion represents the best return on investment.
2. A 250 kW biogas plant. Having learned from my experience in Europe about collaboration and the utilisation of break crops I have started work on this small scale biogas project. The structure involves me inputting slurry into the plant. Also I have convinced my two arable neighbours to grow red clover as a break crop instead of OSR which I will use as a feedstock.

The benefits to my neighbours include:

- Growing a low input crop for a fixed price
- Increasing the soil structure through the clover's advanced root system
- Capitalising on the 'free' nitrogen the clover will fix
- Greater utilisation of existing silage equipment

The benefits to myself include:

- Receiving a feedstock locally that will secure the gas output I need for a viable project.
 - Minimal adaption to existing silage pits will allow for the greater volume of silage.
3. Securing the rights to develop 20.7MW of wind production on a farm ideally suited for wind energy generation within the Borders. After having my ambitions for a larger development at home crushed by grid, radar and transport problems, I decided that the best route forward was to secure the legal rights to a farm that didn't have such issues and had a much higher wind speed to boot. At present, I'm negotiating with local communities about the best way forward with the hope they will realise the potential and secure part of the project for community investment and take ownership of a stake.

Over the next 12-18 months my fate will be in the hands of planning officers and local councillors. However, should I succeed, then hopefully it will allow others to realise for themselves the potential in renewable energy. Time will tell...

SO WHAT HAPPENED NEXT? THE 2026 UPDATE FROM JIM SHANKS:

"We never did get the wind turbine on farm, or at the other site. They were an uphill, expensive battle through planning and we decided to let that lie.

But today, along with the dairy cows, Standhill where we farm now hosts a range of enterprises including anaerobic digestion, biomass systems and a new four-acre

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Putting it into action

glasshouse. Now our 500 acres produces 2 million litres of milk a year, 1,600MW of clean green electricity, 8,500MW of renewable heat as well as 300 tonnes of tomatoes under the 'Sweet Red Balls' brand.

For the AD plant, we use slurry from the dairy herd and wholecrop rye. The electricity generated powers the farm and glasshouse, with the remainder going to the national grid, while the heat produced is captured and used to dry wood chip.

The waste CO₂ produced in the AD fermentation is fed to the growing tomato plants inside the glasshouse (tomato plants love CO₂), while the digestate goes back on the land.

Most of the heat used in the glasshouse comes from our two wood chip boilers. The wood is sourced locally, with much of it coming from woodland at Standhill and adjacent plantations.

My next plan is to look at working with Nvidia computers. They are looking for sites as use of AI grows - I could supply power to them instead of the grid and would get heat back which I can use in the glasshouse.”

“ We never did get the wind turbine on farm, or at the other site. They were an uphill, expensive battle through planning...”



Energy from agriculture: <https://qrco.de/bgrLhj>



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In practice: The innovators – Dennis Haubenchild, Wisconsin, USA

Jim Shanks NSch 2009

Dennis Haubenchild is a man at the very forefront of what can be achieved with agriculture, energy and hydrogen. Simply typing his name into Google results in 40,000 hits. Previous to my visit Dennis had just received the Innovator in Agriculture award. He was the first person to refine hydrogen from biogas and store it and utilise it on farm.

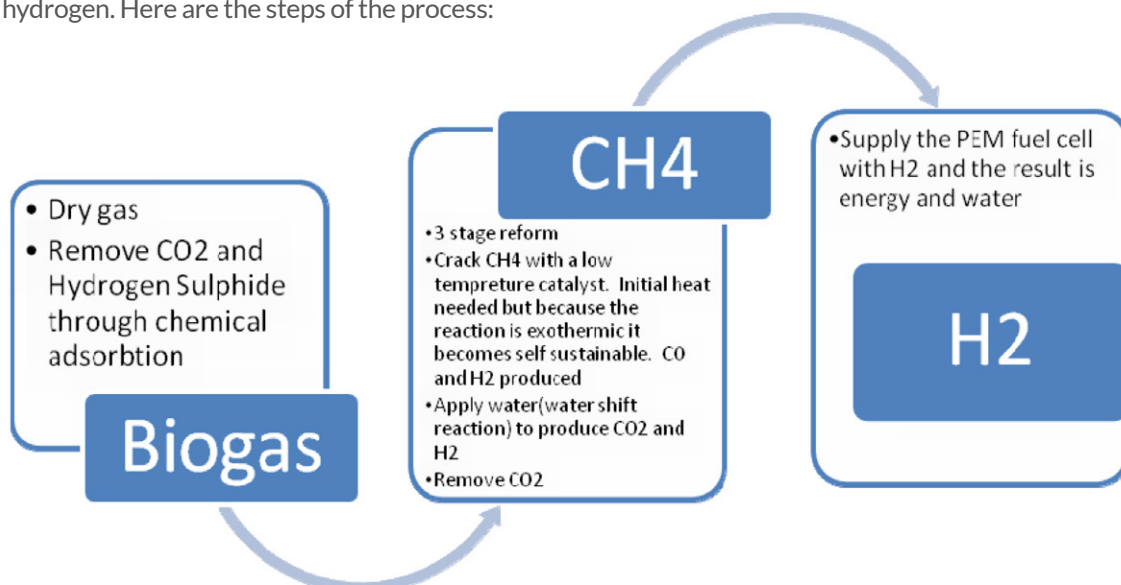
Dennis' name first came to me when I met with Christophe Le Maitre from New Holland in Germany. I was interested in the concept NH were developing with fuel cells to create energy independent farms. Christophe was very honest when he said that they learned a great deal from Dennis' project. I knew at once that my Scholarship would not be complete without a trip to Haubenschild's dairy in Princeton, Minnesota.



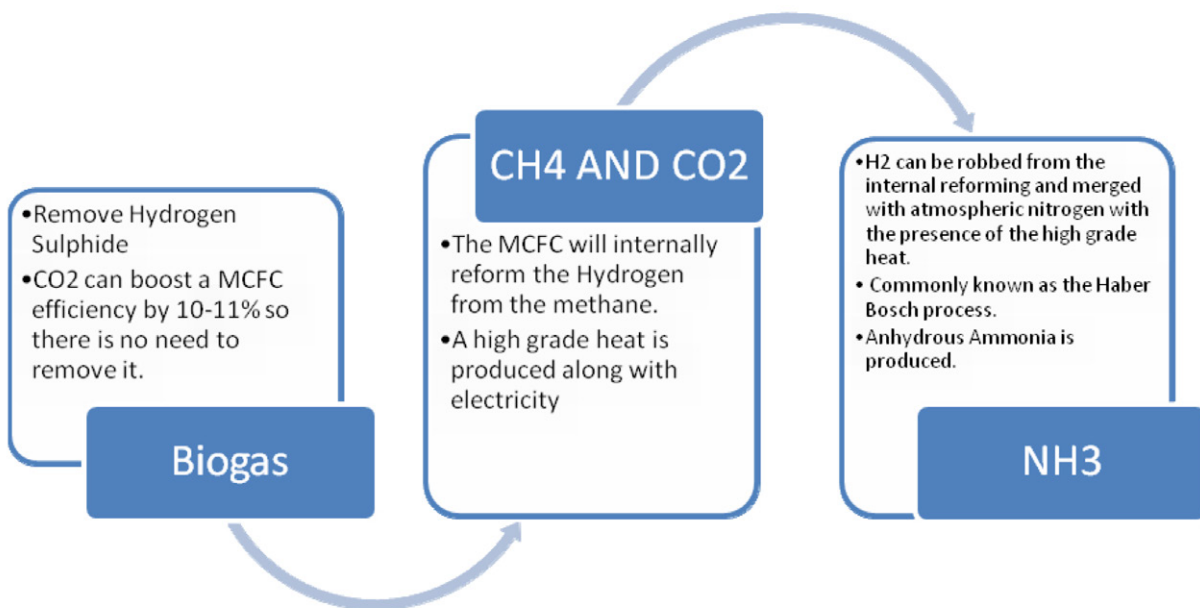
Dennis Haubenchild (left) and Jim Shanks

Dennis was primarily driven by securing energy independence, both for the United States and on farm. "All the easy energy is gone and we need to start generating energy we can

use in 21 days, not 21 million years. Agriculture can produce 60% of the world's food and 100% of the world's energy". Like in many countries, the main stumbling block to a prosperous renewable economy is the national grid. Dennis was not sympathetic to the grid operators and part of his drive to produce hydrogen was to be able to store energy and bypass the national grid. Dennis' desire was to implement a high temperature fuel cell. However the funding available limited him to a Proton Exchange Membrane Fuel Cell that worked at low temperature and on externally reformed pure hydrogen. Here are the steps of the process:



Dennis had greater dreams than simply the production of hydrogen. He wanted to take hydrogen to the next level which is ammonia through a high temperature fuel cell (Solid Oxide or Molten Carbonate). This would be the process he would have chosen had the funds been available.



In my opinion, the Molten Carbonate fuel cell is far more suited to agricultural practices than the PEM fuel cell. Due to the ability of the MCFC to utilise biogas in a highly effective manner and the advancement of hydrogen to ammonia by harnessing the high grade heat produced, the PEM fuel cell remains destined for vehicular prototypes for now.

“Dennis was the first person to refine hydrogen from biogas and store it and utilise it on farm.”



Energy from agriculture: <https://qrco.de/bgrLhj>





Action that can be taken immediately (Do now)

Putting it into action: Energy efficiency on farm

Jim Shanks NSch 2009

For me, this was where my study had begun. As a dairy farmer, I realised that I was spending a disproportionate amount of time focussing on vet bills whereas my energy bills were roughly of a similar amount and commanded a lot less of my time and efforts. Added to this, the impact I could have on my energy bills were far greater than what could be achieved by spending all my time trying to source cheap drugs. While my study expanded from simply looking at energy reduction and generation to offset consumption, I nonetheless gained a great deal from my time looking into the possibilities of energy reduction in the dairy business.

Average dairy energy consumption:

The average consumption per cow in the UK is 296kW/cow/year; however, the range is from 100-550kW/cow/year. Economies of scale are not always relevant in energy consumption. Larger herds tend to be more automated which reflects on the electrical consumption.

On dairy farms there are four major parts to energy consumption:

1. Vacuum pump and milking equipment
2. Milk cooling
3. Water heating
4. Miscellaneous such as lighting, feeding, manure handling and ventilation

If it can be measured it can be managed.



There was one thing all energy efficient farms had in common - an energy consumption monitor."

Having toured many of the most energy efficient dairies in Europe and America, there were many different theories to energy efficiency. However there was one thing all energy efficient farms had in common - an energy consumption monitor. Never has the term, "if it can be measured it can be managed" been more appropriate. Knowing your electrical consumption will motivate you to drill into electrical bills like never before and will be far more beneficial and cheaper than an energy audit done by a consultant. Other changes on farm as a result of this scholarship include; disposing of my aquasilent vacuum pump and replacing it with a variable speed drive pump, with energy savings of around 60% although they would range from 30-80%; looking at the efficiency of our plate cooler; and considering how we reduce our water heating costs.



Energy from agriculture: <https://qrco.de/bgrLhj>





Actions that require some planning (start planning)

Putting it into action: Recommendations for on-farm energy generation

Jim Shanks NSch 2009

Own it: Whatever renewable path you choose to go down, make sure you realise the true returns. For the last 10-15 years, we as farmers have a shocking record of selling off our most valuable resources to the Square Mile and beyond for a tiny proportion of the income. The risk you will take in planning is real. However, should you be successful, the reward is huge.

Collaborate: Collaboration is even more important when implementing a renewable device than it is in conventional agriculture. In all the countries I visited, collaboration was evident not just between farmers but between local businesses, local communities, local councils and large investors. The benefits include:

- Access to the best sites for development
- Easier access to finance
- Greater acceptance at local level
- Capitalisation on economies of scale

Be ambitious: If you have the resources then harness them. You wouldn't graze Highland cattle on prime arable land so don't underutilise your natural resources either. Putting a 15kW turbine on a site that could accommodate 10MW helps no-one other than ill-informed NIMBYs. Should you have a site capable of producing 10MW of production and, for whatever reason, don't want to develop it yourself, my number is at the end of this report!

Don't feel morally obliged to utilise your land for food production: The increase in prices paid for energy production will inevitably see a reduction in food production. Let the market decide your route. If food processors and retailers want food, then they must be prepared to pay over and above what can be achieved through energy.

Whatever your opinion on global warming, we in agriculture have the opportunity to use the concept to our advantage when selling ourselves: When it comes to saving the planet, we are the solution. We must use this argument to our advantage.

“ Whatever renewable path you choose to go down, make sure you realise the true returns.”



Energy from agriculture: <https://qrco.de/bgrLhj>



TALKING POINT:

The future for energy on farm

Stuart Oates NSch 2025

Recommendations for farmers

- Treat your land as an energy asset. Before signing a land lease with a developer, work out what it would mean to own the generation yourself; the difference in value is substantial.
- Investigate community-ownership structures for wind and solar, using available community energy funding to cover early survey and planning costs.
- Stack revenue from a single energy investment: self-supply, grid services, local sales and vehicle charging can all flow from the same battery and connection.
- Begin reducing nitrogen now through legume integration, undersowing and biostimulants, which can cut purchased fertiliser without waiting for new technology.
- Run biological crop-protection and natural-fibre trials, and switch to HVO as an immediate, drop-in reduction in fossil diesel.
- Consider removing single use plastics, such as plastic bale netting; our own sisal twine trial showed no loss of quality (see the report - <https://innovativefarmers.org/farmer-led-research/sisal-for-baling>)

Recommendations for government

- Support electrification and energy efficiency in farming at all levels, from tractor drivetrains research and development to fossil derived nitrogen fertiliser alternatives.
- Reform DNO grid connection rules and planning for farm-scale renewables, and improve the mechanisms for genuine community benefit and ownership.
- Simplify local and peer-to-peer electricity trading so that power generated on a farm can be sold affordably to its neighbours.
- View farms as an opportunity space for a distributed grid, opening up opportunity for rural business expansion, electrification of haulage fleets, lower infrastructure upgrade costs, and increased local and national energy sovereignty.
- Recognise low-fossil practices within the Sustainable Farming Incentive in England, the Sustainable Farming Scheme in Wales and the Rural Support Plan framework in Scotland. For example, a sustainable bale coverings supplement per ha would be incredibly good value and simple to administer.
- Support feasibility work on domestic processing for natural fibres such as flax, where the crop suits the UK but the infrastructure is absent.

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Putting it into action

Recommendations for industry and researchers

- Develop UK standards and pilots for agrivoltaics, including the vertical systems already proven on the Continent.
- Accelerate farm-scale anaerobic digestion, including simple slurry-cap systems for smaller herds, to use the large quantity of farm waste energy currently going unused and disproportionately increasing our sector emissions.
- Embrace structural change as an inevitability. Electrification is coming, so let go of preconceptions and embrace the opportunity across all areas of farming innovation.

“*Treat your land as an energy asset.*”



Fossil free farming: <https://qrco.de/bgzonn>





Long-term options to consider (Think ahead)

Think ahead: Resources for further information

There are a range of organisations and establishments who can help with energy on farm and renewables.

This list (which is not exhaustive or in any particular order) may be able to provide help and support in terms of researching renewables and energy on-farm.

Defra/gov.uk website

Reports and data, including 'Bioenergy Crops in England and the UK: 2008-2023' (link below) which has comprehensive statistics and information on the agricultural area of bioenergy crops, biofuels, plant biomass (including miscanthus, short rotation coppice and straw) and anaerobic digestion.

<https://www.gov.uk/government/statistics/bioenergy-crops-in-england-and-the-uk-2008-2023/bioenergy-crops-in-england-and-the-uk-2008-2023>

Defra/gov.uk website

Defra has a useful annual report about on-farm energy use in England. It provides details on the types of fuel used by farm businesses, as well as the generation and sale of renewable energy by farm businesses, including future plans.

<https://www.gov.uk/government/statistics/energy-use-on-farms-in-england/energy-use-on-farms-in-england-202324>

Desnz/gov.uk website

The Department for Energy Security and Net Zero (Desnz) publishes an on-going tracker of public attitudes to renewable energy. This includes data on support for renewable energy, different types of renewable energy, attitudes towards local wind farms, local solar farms and renewable energy.

<https://www.gov.uk/government/statistics/desnz-public-attitudes-tracker-spring-2025/desnz-public-attitudes-tracker-renewable-energy-spring-2025-uk>

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Putting it into action

RASE

The Royal Agricultural Society of England (RASE) offers a range of reports, including Future Fuels in Agriculture and several sector-specific publications on decarbonising agriculture and net zero. It also runs a series of events and visits which include renewables and farm energy use, and has a specific focus on 'The Farm of the Future'.

<https://www.rase.org.uk/reports/>

Innovation for Agriculture (i4agri)

Connecting farmers with farming research, i4A helps farmers put innovation into practice. It works with agricultural researchers, businesses, landowners, and farmers to develop the knowledge and technologies that will make modern farming more sustainable, resilient, and productive. It runs practical and interactive workshops, farm walks, and on-farm demonstrations.

<https://www.i4agri.org/>

Energy Now

Styling itself as 'The Renewable and Low Carbon Energy website for farmers and landowners', the Energy Now website is a source of news, interviews and useful resources for almost all on-farm energy sources. It features case studies, advice and information and related webinars.

<https://energy-now.co.uk/>

AHDB

This AHDB page 'Powering the farm with low carbon energy' covers topics including benefits for the environment and your farm, low carbon energy options and planning and implementation. It also includes sources for further information, including information on green fuels for agriculture.

<https://ahdb.org.uk/knowledge-library/powering-the-farm-with-low-carbon-energy>

Farm Advisory Service (FAS) – Scotland

Scotland's Farm Advisory Service offers information on farm renewables as a diversification enterprise to reduce electricity and heating bills, with excess sold to generate an additional income. It offers videos, downloadable information and a programme of meetings covering everything from slurry to woodlands, and wind to rivers.

<https://www.fas.scot/environment/climate-change/renewable-energy/>

Farming for a Better Climate (Scotland)

A Scottish Government initiative delivered by SAC Consulting, this programme provided practical support to farmers across Scotland. Working with farmers, farm consultants and the latest scientific advice, the project identified and shared realistic ways to improve farm efficiency, with case studies, information guides and videos all still available to view.

<https://www.fas.scot/farming-for-a-better-climate/>

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Putting it into action

Farm Carbon Toolkit

Created by farmers for farmers, it works to further the understanding of greenhouse gas emissions in agriculture. It provides tools and services to measure environmental impacts, training and events, and has information on renewables and energy use in addition to advice around measuring and improving soil health, regenerative agriculture, greenhouse gas emissions and other ecosystem services.

<https://farmcarbontoolkit.org.uk/>

Solar Energy UK

The organisation represents 440+ member companies across the UK energy sector and besides solar, it has strong links to storage, EVs and smart grids. Its website includes some useful resources, including best practice for solar on farmland plus a list of relevant solar-related events. It says that together with industry partners, it is working to deliver 60GW of UK solar by 2030.

<https://solarenergyuk.org/>

British Hydro

A membership organisation representing the hydro power sector, its membership is diverse, covering all sizes and types of hydropower from pico (micro) hydro to pumped storage hydropower. Its website contains comprehensive information for all sizes of hydropower developments, plus event listings and other useful information.

<https://british-hydro.org/>

The Official Information Portal on Anaerobic Digestion

A useful source of information on all things AD, this website was created in 2009 as an independent authoritative resource, supported by Government and industry. The site was developed and is maintained by NNFCC, and includes information on many AD-related topics, as well as a supplier list and on-farm case studies.

<https://www.biogas-info.co.uk/>

UK Anaerobic Digestion and Bioresources Association (ADBA)

ADBA is a membership organisation representing the AD sector. It gives support to AD operators, plant managers, plant owners and developers, providing expertise and facilitating collaboration among experts, officials and peers. It organises free information sessions which are group meetings in-person locally where possible and online for local and national audiences. Its website includes a list of members, as well as event dates and other resources.

<https://adbioresources.org/>

Integrating Trees Network (Scotland)

The Network, supported by Scottish Forestry and the Scottish Government, helps raise awareness of the multiple benefits that planting trees can have on land and businesses. Its member farmers and crofters host events across Scotland, providing an informative and supportive network for other farmers and crofters who are considering planting trees.

<https://www.forestry.gov.scot/integrating-trees-network>

European Agroforestry Federation

The European Agroforestry Federation (EURAF) is the primary organisation promoting the use of trees on farms across Europe. Representing more than 500 members from 24 countries, EURAF works with policymakers, researchers, and farmers to advance sustainable, high-productivity agriculture through integrating trees on-farm.

<https://euraf.net/>

Biomass Resources Service

Hosted by Forest Research, the site for biomass energy resources includes information about types of woodfuel, where it comes from and how it can be produced, forestry as a source of woodfuel and energy crops. It also includes a list of equipment suppliers to produce the various forms of woodfuel, some of their characteristics, advantages and disadvantages.

<https://www.forestresearch.gov.uk/tools-and-resources/fthr/biomass-energy-resources/>

Climate Farm Demo

A European-wide network of 1,500 pilot demo farmers and their advisors who are implementing and demonstrating climate smart solutions for a carbon neutral Europe. This EU-funded project aims to increase knowledge exchange with a view to adapting agricultural production systems to climate change and to achieving a carbon neutral agricultural sector by 2050. Its website includes lists of relevant events across Europe, and reports from previous visits/events.

<https://climatefarmdemo.eu/>

Farming Connect (Wales)

Farming Connect has a range of resources on renewables, including e-learning through Business Wales' Business Online Support Service (BOSS) and podcasts. Its Try-out fund offers up to £5,000 to put towards an on-farm trial to try-out ideas with the aim of improving efficiencies and profitability within agricultural businesses while protecting the environment.

<https://businesswales.gov.wales/farmingconnect/>

NFU Energy

NFU Energy offers consultancy and advice on technologies including solar, wind, heat pumps, anaerobic digestion and electric vehicles. It has an in-depth knowledge hub on the various technologies, and offers help in staying compliant with all necessary schemes and a gateway to unlocking various incentives.

<https://nfuenergy.co.uk/>

FarmPEP (Performance Enhancement Platform)

FarmPEP is a knowledge exchange site, co-designed by an industry wide partnership supported by Innovate UK to connect people, organisations, initiatives and resources with topics. Each topic's summary page has links to useful content and organisations. It links to the ADOPT hub, where farmers can obtain funding for on-farm technical projects.

<https://farmpep.net/>

UK Agri-Tech Centre

An independent organisation, it aims to deliver solutions to agriculture's most complex challenges by accelerating innovation through expert insight, advanced facilities and strategic support. In collaboration with farmers, the agri-food industry and some of the best research institutions and most innovative companies in the world, provides leadership and guidance to progress change.

<https://ukagritechcentre.com/>

Nuffield Farming Scholarships Trust - Scholarships

NFST aims to inspire passion in people and develop their potential to lead positive change in farming and food. It awards about 25 life-changing scholarships each year that unlock individual potential and broaden horizons through study and travel overseas, with a view to developing the farming and agricultural industries. More than 1,000 Nuffield Farming Scholars have completed their studies and travel.

<https://www.nuffieldscholar.org/>

Nuffield Farming Scholarship Trust - Next-Gen Scholars

The Next-Gen Scholarships are focussed on young people aged 18-24 as part of Nuffield Farming Scholarships Trust's initiative to develop young talent. They aim to help young people establish themselves in agriculture, using the Nuffield Farming network to link successful applicants directly to farmers.

<https://www.nuffieldscholar.org/scholarships/nuffield-farming-next-gen-scholarship>

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Putting it into action

Think ahead: Academic resources

Universities, research centres and other academic institutions can be a useful point of contact if you are considering energy production on farm. They may be able offer a research project with an undergraduate or postgraduate student or help with other queries. Again, this list is not in any order and is not comprehensive:

University of Leeds

Energy Leeds and the Global Food and Environment Institute (GFEI) are working together to establish the University of Leeds as a leader in agri-energy systems. This builds on the university's existing energy research strengths including processing of waste and slurry, the development of alternative fuels such as biohydrogen, renewable energy systems, transport decarbonisation, energy storage and smart energy systems. It has an on-farm demonstration <https://www.leeds.ac.uk/agricultural-energy-systems/doc/agri-energy-systems-work>

Lancaster University

Focusing on agrivoltaics (solar), Lancaster is researching and demonstrating its capabilities by co-locating crops or grazing with ground-, building- or glasshouse-integrated photovoltaic (PV) arrays. It says stimulating agrivoltaic development through demonstration stands to benefit the UK economy through regional agriculture and energy production, and through the concentration of skills, innovations, know-how and markets that can equip the UK for global leadership. <https://www.lancaster.ac.uk/energy-lancaster/research/agrivoltaics/>

Aston University

This Birmingham-based university's Supergen Bioenergy Hub has an overall aim of developing sustainable bioenergy systems that support the UK's transition to a sustainable, affordable and resilient low-carbon energy future. <https://www.supergen-bioenergy.net/>

Sheffield University

Specialising in photovoltaics, it says its research delivers real-world results that monitor and improve solar electricity generation and performance in the UK. It also researches the development of next generation solar-cell technologies. <https://sheffield.ac.uk/energy/our-research/solar>

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Putting it into action

Harper Adams

Harper Adams University has departments, curricula and research specialisms in a wide variety of subjects, including technology, science, environment, engineering, entomology, plant science, animal wellbeing, veterinary science, sustainability, digital, data science and policy. It is home to The School of Sustainable Food and Farming.

<https://www.harper-adams.ac.uk/>

SRUC

SRUC has a focus on education, research, and consultancy (through SAC Consulting). Working in partnership, it focuses on solving the ‘wicked challenges’ facing the planet, including climate change, biodiversity and access to nutritious food and clean water. Its Challenge Centres focus on critical areas to generate solutions and share research that delivers impact that brings about change.

<https://www.sruc.ac.uk/research/challenge-centres/>

Royal Agricultural University

The RAU’s approach to research is formulated around collaborations between scientists, farmers and innovators. Running its own farm, it leverages collaborations and develops innovative research projects, embracing farmer-science and farmer-led innovation networks. Its six research clusters include sustainability, regeneration and biodiversity in agriculture, livestock health and welfare and food policy, quality and security.

<https://www.rau.ac.uk/research/research-at-rau>

The James Hutton Institute

The James Hutton Institute’s research projects drive agricultural innovation, environmental sustainability, and biodiversity conservation, with research spanning crop resilience, soil health, land use studies, and climate change adaptation. It also runs projects on its own farms, including the HydroGlen at Glensaugh in North east Scotland (see p28).

<https://www.hutton.ac.uk/>

<https://www.hutton.ac.uk/research-projects/>

Cranfield University

Cranfield has a soil science specialism and is also part of the AGROMIX project. This aims to drive a transition to more resilient and efficient land use in Europe, looking at synergies found in mixed farming (crop + livestock) and agroforestry (trees + crops and/or livestock) systems and the associated value chains. The initial research is on 12 contrasting pilot sites across Europe and involves 10 universities, 7 research institutes and 11 other partners.

<https://www.cranfield.ac.uk/research-projects/agromix>

SPONSORS



Central Region Farmers Trust

Central Region Farmers Trust's mission is to provide funding for education that benefits agriculture and horticulture in the central region. It strives to support farmers in adopting sustainable farming practices and enhancing their skills for a thriving agricultural sector.

www.centralregionfarmerstrust.org



Gloucestershire Agricultural House Foundation

Helping agriculture in Gloucestershire by supporting the education, development and needs of people in the industry.



Elizabeth Creak Charitable Trust

The Elizabeth Creak Charitable Trust is a grant giving body that invests in people who will advance healthy, fair and sustainable UK food production. Grants finance projects that help farmers innovate to survive and thrive while scholarships support and encourage individuals to innovate sustainable practices in farming.

www.elizabethcreak.co.uk



Royal Agricultural Society of England (RASE)

The Royal Agricultural Society of England (RASE) is an independent charity and membership organisation dedicated to supporting the progression of knowledge and innovation within the agricultural community.

www.rase.org.uk

IN SUMMARY

This Bitesize Guide, from the Nuffield Farming Scholarships Trust and RASE, provides a snapshot of the breadth and depth of reports available at



<https://www.nuffieldscholar.org/reports>



The website also features reports from global Nuffield Farming Scholars, including Australia, New Zealand, USA and Brazil. The reports are a rich source of inspiration, case studies and thought-provoking recommendations for farming, food, horticulture, forestry and ancillary industries.

Please get in touch at info@rase.org.uk if you have questions, comments or feedback.



NUFFIELD
Farming Scholarships