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Fossil Free Farming

Can we remove fossil fuels in all of their forms from global agriculture while still feeding a growing population and protecting nature?

Written by:

Stuart Oates NSch

June 2026

A NUFFIELD FARMING SCHOLARSHIPS REPORT

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Dartington Cattle Breeding Trust

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"Leading positive change in agriculture. Inspiring passion and potential in people."

Title	Fossil Free Farming
Scholar	Stuart Oates
Sponsor	Dartington Cattle Breeding Trust
Objectives of Study Tour	To find out if we can remove fossil fuels from agriculture in all of its forms, from synthetic fertilisers and diesel fuel, to single use plastics and chemical inputs.
Countries Visited	New Zealand, Australia, Brazil, France, Belgium, Netherlands, Germany, Austria, UK.
Messages	The headline messages of this report are: 1. The move away from fossil fuels in farming is already happening, and it is being driven by economics rather than ideology. 2. The single greatest opportunity is energy: farms own the land the renewable transition needs, and must retain the value rather than sign it away. 3. The remaining barriers are largely structural - grid capacity, planning, regulation and culture,not technological. 4. Fossil-free farming is a matter of food security and national resilience, not only climate.

EXECUTIVE SUMMARY

My Nuffield study asked a simple but radical question: can we remove all fossil fuels from farming while still feeding a growing population and protecting nature? I wanted to know whether ‘real zero’, rather than offset-dependent net zero, was achievable.

Over almost two years, I travelled through Brazil, New Zealand, Australia and Europe, meeting farmers, scientists, manufacturers, government leaders and entrepreneurs. I began with what I thought was just a pipe dream, with large-scale agriculture standing in the way of any transition. But I returned convinced that the move away from fossil fuels is not only possible but is already underway, driven not by ideology or regulation, but by economics.

In Brazil, soya is fixing all of its own nitrogen, saving farmers billions of pounds a year, biological pest controls operate across millions of hectares, and waste biomass generates significant amounts of electricity and gas. In Australia, remote farms are irrigating with energy from solar and batteries. In New Zealand, seaweed biostimulants are halving nitrogen use. Across Europe, farmers are driving electric tractors, generating biomethane from slurry, growing sustainable fibres for a fossil-free fashion industry, and using AI-guided lasers to replace herbicides. In almost every case, the people leading these changes were doing so because the numbers worked, and 'and any environmental convictions were only secondary.

The single most important finding is that fossil-free farming is full of opportunities, not burdens. The greatest of these is energy: maybe the biggest opportunity in a generation. Farms own the land where the renewable transition must happen, yet too often sell that prospect cheaply to outside developers. We need to own our energy generation and storage landscapes and share the benefits locally.

The principal barriers are not technological; they are structural. Grid capacity, planning policy, weak pollution regulations, tax anomalies, regulatory frameworks designed for a fossil-fuelled past, and the cultural and emotional weight of change. My recommendations therefore focus on removing the structural barriers so that the economically rational choice becomes the easy one, while being honest about the human realities of change.

Beyond this scholarship I am now leading several trials and ventures: upscaling the value of farm-produced and stored power, trialling home-brewed seaweed biostimulant, testing alternatives to single-use plastics on bale coverings, and setting up a rural electric-vehicle charging network.

My conclusion is that we can and will move beyond fossil fuels across most of the world's agricultural systems within the next few decades.

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All photos were taken by the author unless otherwise stated.

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Nuffield Farming Scholars are available to speak to NFU Branches, agricultural discussion groups and similar organisations.

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CHAPTER 1: INTRODUCTION

Figure 1: The author on the family farm on the Lizard Peninsula, Cornwall

Every time we see the news, we're faced with yet another global economic crisis, the rise of an authoritarian regime, biodiversity loss, uncontrolled pollution or climate breakdown. What I realised is that a huge amount of this turmoil is underpinned by fossil fuels. The imbalance of power in many forms lies within them, and if we want to reclaim some of this as an industry, we need to find a way to farm without them in all of their forms.

I am a seventh-generation farmer on the Lizard Peninsula, the southernmost tip of Cornwall. Our family farm has been organic since 1999. We run beef cattle and sheep, grow arable crops, manage habitats and host around two thousand schoolchildren a year. Alongside farming, I work as a broadcast journalist and television producer. That dual career shapes how I think: I am as interested in how we tell the story of farming as in the farming itself.

My study subject is 'Fossil Free Farming'. Can we remove fossil fuels in all their forms, the diesel in our tractors, the natural gas embedded in our synthetic fertilisers, the oil in our single-use plastics and chemical sprays from our food and farming systems, while still feeding, clothing and fuelling a growing global population and protecting nature? Offsetting will never be enough. I wanted to know whether we could move beyond net zero to 'real zero'.

I will be honest about my starting position. As an organic farmer, I was sceptical of large-scale, high-input agriculture, and like many Europeans, my impression of countries such as Brazil was shaped by headlines about deforestation and intensive monocultures. I expected my travels to confirm those views. They did not. What I found repeatedly was that the most advanced moves away from fossil fuels were being made not for ideological reasons but because they made commercial sense. That discovery reframed my entire study.

This report sets out what I learned across nine countries, organised by theme rather than strictly by geography: fertiliser and soil; biological crop protection; machinery and fuels; farms as energy assets; natural fibres; livestock; and the cultural dimension of change. It concludes with recommendations and an account of just some of the ventures the scholarship has already set in motion.

CHAPTER 2: BACKGROUND TO MY STUDY SUBJECT

Fossil fuels are woven through every part of the food chain. They appear as the natural gas behind synthetic nitrogen fertiliser, as the diesel that drives our machinery and dries our grain, as the oil-derived feedstocks for pesticides and herbicides, as the polymers in the plastics that wrap our bales and our silage. Each of these dependencies has been treated as a fixed feature of modern agriculture. My scholarship set out to ask whether that is in fact true.

The case for removing these inputs is usually made on environmental grounds. The argument of this report is different and, I believe, more powerful. In a growing number of cases, the fossil input has become the more expensive option, and the biological, electrical or renewable alternative is now cheaper, more efficient, or both. Incentives to innovate remain essential, but often the mainstream transition no longer depends on subsidy or conviction. It follows the money.

In the United Kingdom, the scale of this dependency is substantial. UK agriculture consumes an estimated 1.8 to 2.2 billion litres of red diesel each year in field machinery, vehicles and stationary equipment (Defra, 2024), and applies around 850,000 to 880,000 tonnes of mineral nitrogen fertiliser annually. This figure fell sharply after the 2022 energy crisis but still represents an enormous embedded fossil-fuel input (British Survey of Fertiliser Practice, 2024). Plastic film, oil-derived crop protection products and heating fuels add further significant volumes. British farms are also unusually exposed to global price shocks because so much of this input is imported, as the energy crisis demonstrated.

Agriculture accounts for approximately 11 to 12 per cent of the United Kingdom's total greenhouse gas emissions, but the composition of those emissions is unlike any other sector. Around 55 per cent is reported to come from enteric fermentation in ruminant livestock, approximately a quarter from agricultural soils, principally as nitrous oxide released by synthetic fertilisers and manures, 14 per cent from manure management, and around 7 per cent from the direct combustion of diesel and other fuels in machinery and grain drying (DESNZ, 2024).

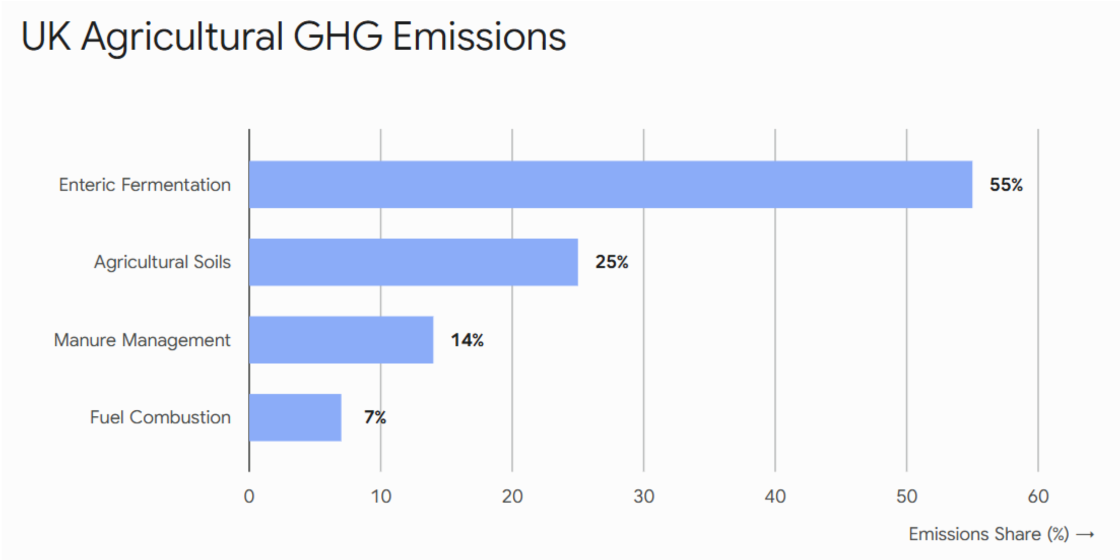

Figure 2: Department for Energy Security and Net Zero (DESNZ), Final UK Greenhouse Gas Emissions National Statistics, 2024

These figures need careful interpretation. The largest share, enteric methane, behaves quite differently from fossil carbon: the carbon in a cow's methane was drawn from the atmosphere only months earlier through the grass it grazed, and returns there within little more than a decade. A stable, pasture-fed herd is running a biological cycle, not continually adding new carbon, a distinction now recognised in metrics such as GWP*. The genuinely additional emissions in livestock are not the cyclical methane but the fossil inputs layered on top: the synthetic nitrogen grown into the grass, the diesel burned harvesting it, and the imported feed. The same logic runs through the whole sector. The diesel in our tractors is a relatively small share, but the inputs purchased to run a farm, above all synthetic nitrogen, account for far more than the visible fossil use suggests. Strip the fossil fuels out, and a very large part of agriculture's footprint goes with them.

Beyond emissions, this is about sovereignty and food security.

British oil supplies are dwindling, and even with increased North Sea drilling we are just decades from running dry. Heavy dependence on imported fertiliser, fuel and feed leaves farm businesses exposed to global shocks. If we are to feed our nation in a time of crisis, we must learn to do so without fossil fuels. The same goes for the ~80 per cent of countries who are net oil importers.

My own farm illustrates both the progress and the distance still to travel. As an organic system we use no synthetic fertilisers or pesticides, which removes two major fossil dependencies at a stroke. Yet we still rely on diesel for our tractors, plastic for our bales and fossil intensive products for construction. We are, like almost every farm in the world, a long way from real zero. The purpose of my travels was to understand what the remaining steps look like in practice, how mature the alternatives really are, and what a realistic path might be.

CHAPTER 3: MY STUDY TOUR

My travels spanned two years of the scholarship period and four continents.

Travel on this scale is not without consequence. I am conscious that this study carried a carbon cost of its own. I travelled roughly 50,000 miles, burning approximately 2,700 litres of oil, generating an estimated 11 tonnes of CO_2 equivalent (about the same as just 3.6 tons of nitrogen fertiliser). Around 90 per cent per cent of it was from long-haul flights. Where I could, I travelled on the lowest-carbon option available. My 5,000-mile European leg was driven in an electric van charged largely on renewable power, and in Brazil the cars were run on sugarcane ethanol, which on a lifecycle basis cut that driving to around a quarter of its petrol equivalent. I make no claim that the journey was free of impact. I make the claim that the knowledge it generated is intended to remove a great deal more carbon than it cost.

In every country, I was generously hosted by Nuffield Scholars, who helped refine my research and connect me with the most incredible people and organisations. Although I spoke to hundreds of people, just a few from each country are summarised below.

Figure 3: A sisal plantation in Bahia, Brazil

Brazil

My month in Brazil was hosted by fellow Nuffield Scholar João Carvalho, whose own scholarship topic is around biofuel feedstocks. Across numerous road trips between São Paulo, Mato Grosso do Sul and Minas Gerais, he shared his deep knowledge of the intricacies of Brazilian agriculture. Just a few of the visits included Embrapa's soybean and beef research centres, Fundação MS, Raízen, GEO Biogas, ABIOVE, Instituto Taquari Vivo, Santa Verginia farm, Inpasa corn ethanol, the Government of Mato Grosso do Sul, and I later went to Rosa sisal community in Bahia.

New Zealand
Following the Nuffield Contemporary Scholars Conference, I visited Lincoln University's agrivoltaics research programme, AgriSea, a seaweed biostimulant company, an all-electric cherry orchard, an inventor developing jute bale netting, and Thriving Southlands, a catchment-scale farmer initiative.

Figure 4: Cattle herding by helicopter in the Northern Territories, Australia

Australia
Visits included Loam Bio, Clear Skies Energy, Harvest Road Group and Harvey Beef, and the Spark Labs agri-food investment group.

Europe
In France, I visited a flax farm and scutching cooperative. In Germany, I saw Next2Sun agrivoltaics. In the Netherlands, I visited the Winter potato and biogas farm, saw the Carbon Robotics' laser weeder and the EOX autonomous electric tractor. In Austria, I drove the Tadus electric tractor and in Belgium, I visited the TRANSfarm research farm.

United Kingdom
Visits at home took me across every corner of the UK, from the New Holland tractor factory in Basildon and EWT turbines in Edinburgh, to Groundswell festival and my own Fossil Free Farming day on my farm in Cornwall.

CHAPTER 4: FINDINGS

4.1 Fertiliser: the largest single opportunity

Synthetic nitrogen fertiliser is the largest single fossil-fuel use in agriculture, and the one that best illustrates how deep the dependency runs. It is manufactured through the Haber-Bosch process, which combines atmospheric nitrogen with hydrogen derived from natural gas under high temperature and pressure. The process consumes around one to two per cent of global energy supply (Smil, 2001; IEA, 2021), or roughly 35 to 40 gigajoules, the equivalent of about a thousand litres of oil per tonne of nitrogen produced (Brentrup and Pallière, 2008). Even this understates the on-farm consequence: the nitrogen use efficiency of synthetic fertiliser is typically only 30 to 50 per cent, so the energy embodied in every kilogram of nitrogen actually taken up by the crop is effectively double again. By contrast, the symbiotic bacteria in a legume root nodule operate close to one hundred per cent transfer efficiency, powered by sunlight rather than gas.

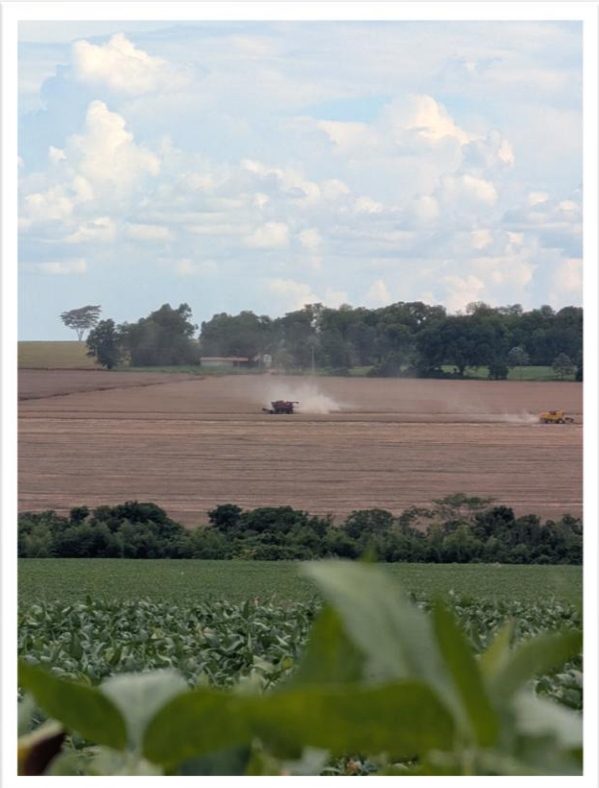
Figure 5: Soya growing and being harvested in Sao Paulo state, Brazil

UK farms apply synthetic nitrogen at intensities that have changed remarkably little despite this energy cost. Winter wheat receives roughly 180 kilograms of nitrogen per hectare on average, and grassland 50 to 56 kilograms overall, with intensively managed silage swards substantially higher (British Survey of Fertiliser Practice, 2024). Reducing these figures while protecting yield is therefore the largest single decarbonisation opportunity in British agriculture.

If synthetic nitrogen is the largest fossil dependency in farming, it is also, encouragingly, one of the most replaceable. The clearest evidence I saw was in Brazil, where soybean has been bred over six decades specifically to maximise biological nitrogen fixation through its symbiosis with rhizobia bacteria, rather than to respond to applied fertiliser. Researchers at Embrapa, Brazil's federal agricultural research corporation, explained that this deliberate breeding strategy is why Brazilian soya now fixes most of the nitrogen it needs from the atmosphere.

The economic consequence is enormous. I was told that nitrogen inoculants save Brazilian soya production an estimated fifteen billion US dollars every year. The bacteria are powered by the plant; the plant is powered by the sun. No fossil fuel is involved at any stage.

Eduardo Riedel, the Governor of Mato Grosso do Sul and himself a sixth-generation farmer, argued when I met him that the pace of change in the next ten years will exceed that of the last fifty, and that the limiting factor is culture rather than technology. He and André Meloni Nassar of ABIOVE made the same essential point: Brazilian farmers operate under stricter mandatory native-vegetation requirements than any of their major competitors, a minimum of twenty per cent on most farms, rising to eighty per cent in the Amazon biome, while being judged by media in those same competitor countries. The data, they argued, does not match the narrative. Renato Roscoe of Instituto Taquari Vivo put the same point more provocatively, challenging me to find anywhere else combining large-scale production with no-till, biological controls, nitrogen fixation and a mandatory legal reserve.

For crops that cannot fix their own nitrogen, two emerging on-farm pathways struck me as significant. In New South Wales, HydGene Renewables in partnership with the UK catalyst developer Nium, and the farm of fellow Nuffield scholar Stuart Tait, is developing a biological process that converts wheat straw into green hydrogen, which is then used to produce ammonia fertiliser. The headline figure is pretty impressive: 6.5 tonnes of straw from one hectare can yield approximately two tonnes of green ammonia, providing synthetic-free nitrogen for around twenty-seven hectares of arable crop. The project has attracted joint UK–Australian government grant funding. The sovereignty argument is compelling regardless of current cost: Australia has almost no domestic fertiliser manufacturing and imports nearly all of it by ship.


Figure 6: Stuart Tait on his farm, NSW, Australia

In New Zealand, AgriSea showed me ten years of self-funded trial data indicating that their seaweed biostimulants allowed farmers to halve synthetic nitrogen fertiliser use while producing approximately sixty per cent more dry matter per kilogram of nitrogen applied compared with the regional average.

4.2 Soil biology: the hidden engine

The more I travelled, the clearer it became that healthy soil biology is what makes low-input farming possible in the first place. The most striking science I encountered was at Loam Bio in Australia, whose central insight is that not all soil carbon is equal. They distinguish between particulate organic carbon, which persists for days to months; aggregate carbon, which lasts decades to centuries; and mineral-associated organic carbon, which can persist for centuries to millennia. Their soil microbial inoculants are designed to turn carbon into that most stable, mineral-associated form, the only type of sequestration with enough longevity to matter on a climatic timescale.

Mycorrhizal fungi also form vast underground networks that reach far beyond plant roots, gathering nutrients and trading them with plants in exchange for sugars from photosynthesis, doing much of the work that we otherwise pay synthetic fertiliser to do. In Australia's sandy soils, where the binding effect of fungi can transform water retention, the potential is especially large. A small percentage increase in soil organic carbon across a vast land area represents an enormous quantity of stored carbon and a meaningful gain in drought resilience. The same principle applies to UK soils, where rebuilding biology reduces the fertiliser bill directly.

Figure 7: Embrapa soya research centre, displaying generations of plant breeding in a no-til environment, Sao Paulo state, Brazil

Brazil's no-till revolution tells a similar story. Embrapa researchers explained that adopting permanent soil cover and minimal disturbance reduced soil erosion dramatically while protecting the fungal networks that reduce fertiliser need, and eliminated the fuel burned in repeated cultivation passes.

4.3 Biological crop protection: commercial reality

Figure 8: Meeting with startups in PWC Agtech Innovation centre, Sao Paulo State, Brazil

The replacement of synthetic pesticides with biological alternatives is far more advanced than I had appreciated. At IdeeLab Biotechnology in Piracicaba, I was taken through what the company described as six successive generations of biological crop protection. The first two generations, single-strain and multi-strain microbial inoculants, are commercial today. The third, purified metabolites rather than live organisms. The fourth uses effector proteins to target specific plant responses. The fifth uses gene editing to enhance traits of the microorganisms themselves. The sixth, RNA interference, disables a pest by interfering with its metabolism rather than killing it outright. The major agrochemical companies are now investing heavily in biological portfolios. The Brazilian nematicide market is already 90 to 95 per cent biological. The pesticide market is at around fifteen per cent and growing fast.

Renato Roscoe gave me the most striking figures of the whole trip. His organisation, Arkun Biotec, works across around 500,000 hectares on which synthetic pesticide use has been reduced by roughly half, and within that, some 20,000 hectares operating with entirely biological crop protection. These are not organic smallholdings but large, high-output commercial soya and maize operations farming at scales that would be considered industrial in any European context.


Figure 9: Carbon Robotics Laser Weeder in an organic onion field, Netherlands

In the Netherlands I saw a different route to the same goal. Carbon Robotics' laser weeder, demonstrated on Guus Koetsenruijter's 80-hectare organic vegetable farm, uses artificial intelligence to identify weeds in real time and kill them with precisely targeted 250-watt diode lasers, eliminating herbicides entirely on the crops it treats. Mr

Koetsenruijter told me the machine had replaced approximately 150,000 euros of annual hand-weeding labour, with a payback period of around five years. The unexpected benefits were larger. Because he no longer needed mechanical pre-drill weed clearance, he could plant earlier, lengthen the growing season and lift yield. His carrots improved in quality because the soil was no longer repeatedly disturbed by cultivation passes. The AI also identified weeds at sub-millimetre scales the humans can't see, killing them before they could compete with the crop.

4.4 Machinery, autonomy and alternative fuels

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 Tadus 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 Figeureu-Bidaud has already successfully replaced a 350hp tractor with a 150hp, diesel, AgXeed robot, so the automation concept is already proven.

Figure 11: Tadus prototype electric tractor testing, Austria

Figure 10: EOX autonomous electric tractor, Netherlands

At the New Holland factory in Basildon, I saw a contrasting story: how the methane-powered T7 is integrated into a mainstream diesel production line, and how far the consequences reach beyond the machine itself, into the entire supply chain. The factory tour clarified something the field demonstrations had not. Asking an incumbent manufacturer to switch fuel is not a design problem. It is an organisational problem of vast complexity: rewriting the supplier network, retraining the workforce, restructuring the dealer system, redesigning the aftermarket parts catalogue. This is the principal reason that the major manufacturers are pursuing multiple fuels in parallel, JCB on hydrogen, New Holland on methane, most also on electric, rather than betting on one. The risk this creates is the one that confronted the major car manufacturers when Tesla appeared: that more focused new entrants will move faster than incumbents distracted by hedging. EOX and Tadus may be those entrants for agriculture, but the greater risk, in my view, is that Chinese tractor companies will take the market in the way they have taken so many others. The race is currently open, but I do not see the focus that the moment requires.

Figure 12: Beside a T7 methane-fuelled tractor at the New Holland tractor factory, Basildon, UK

Clinching evidence came when looking at parallel industries. While at an electric heavy goods vehicle event in London, I saw some of the largest UK freight companies investing heavily in electrification. And then I learned how fast the Chinese market for electric heavy trucks was shifting. Electric heavy goods trucks reached 29 per cent of the Chinese market across 2025 as a whole, but in December 2025 they crossed 50 per cent of new sales in a single month for the first time, with 45,300 electrified heavy trucks registered (Werwitzke, 2026). The economics have crossed over.


Figure 13: Electric Daf XD HGV at the Solar and Storage event, NEC, UK

Mining equipment is also electrifying across the world; their vehicles make even the largest agricultural machines look like toys. If parallel industries are already investing in motors, batteries, electro-hydraulics and charging, the step into agriculture is short. There will be some specific situations where there may be a longer transition, but even there, electrifying attachments and on-board processes, currently driven by hydraulics or belts, will deliver substantial efficiency gains. 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.

Figure 14: Monarch electric tractor next to solar panels at Electric Cherries, South Island, New Zealand

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.

Some simple calculations show that even now we could electrify many of our machines within acceptable weight and range parameters. Electric ATVs and telehandlers already exist and are quite simply a no-brainer, being a much more controllable, powerful drivetrain for both scenarios, with much lower battery requirements and well within acceptable physical and economic dimensions. I would go further and suggest that a 200hp, 300kwh machine could already be made to weigh the same as an equivalent diesel model. Combine this with swappable 150kwh front linkage batteries and you could run non-stop.

What about the other fuels?

Hydrogen is often touted as a long-term option, and for many years I believed it would dominate. But the energy losses involved in producing it, storing it, transporting it and converting it back to motion are too great, and the technology in all of those processes is also prohibitively complex and expensive. Unless very large quantities of cheap surplus electricity become available, hydrogen will not have a major place in agricultural machinery.


Figure 15: Methane capture over pig slurry pits,

Methane is currently a wasted resource on a vast scale. It rises off slurry stores and dung heaps and into the atmosphere, where its warming effect is roughly 28 times that of CO_2 over 100 years, and 80 times over 20 years (IPCC, 2021). Even flaring would be an improvement on direct release. My view is that slurry stores should be covered as standard and capture should be mandated. The captured gas can then be used to fuel tractors like the New Holland T6 and T7 models. While valuable, there are now emerging technologies that can convert it into synthetic crude oil or sustainable aviation fuel, potentially at lower cost than upgrading it to fuel-quality biomethane. The highest-value use is to displace the petrochemical inputs we currently struggle to replace. If this is to take a foothold, we could lose the production resource before the methane tractor market has even taken hold.

Methanol and ethanol have advocates, but as I was told in Brazil, where ethanol is widely available, that energy density is too low to make either a serious diesel replacement in tractors. For reference, ethanol has around 58 per cent and methanol has just 48 per cent of the energy compared to diesel, so tanks would have to be proportionally larger for the same working hours.

Figure 16: Promoting fossil free farming with my plot combine running on HVO fuel at Royal Cornwall Show

Transition fuels also have a role. Hydrotreated vegetable oil offers up to a 90 per cent reduction in carbon dioxide equivalent emissions, with no engine modification and no warranty impact; our own tractors now run on it and I have noticed only improvements in performance. It's claimed to burn cleaner than diesel, reducing wear and the need for maintenance. I call it a transition fuel as hydrotreated vegetable oil (HVO) sold in the UK is made of waste oils, which could only ever supply a small portion of the national fleet. We could grow crops to make HVO, but it's an incredibly inefficient use of land, which can't be scaled on our already limited farmland and would have its own environmental and social impacts.

4.5 Farms as energy assets

The most commercially important finding of my 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.

Figure 17: Next2Sun vertical agri-solar demonstration site, Germany

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 United Kingdom. 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.

Beyond the farm gate is where I see even more opportunity, particularly in community engagement and benefit. But in the UK, we have an energy system that needs massive reform: a centralised grid needing huge upgrades, and renewable planning and ownership models that favour large corporates. We are on the brink of repeating the North Sea oil mistake. Norway placed that wealth in a sovereign fund for its citizens; the United Kingdom dispersed it to private shareholders. New funding and rules to support community ownership offer a glimmer of hope, but farmers must be part of this conversation.

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 United Kingdom 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.

4.6 Natural fibres and the fashion industry

An unexpected strand of my study was the role farming can play in decarbonising and cleaning up other industries, of which fashion is among the most significant. The global fashion and apparel industry generates an estimated two to four per cent of global greenhouse gas emissions, a climate impact comparable to the entire global aviation sector (Ellen MacArthur Foundation, 2017; Global Fashion Agenda and McKinsey & Company, 2020). But maybe even more significant is the amount of microplastics from plastic fibres being washing into our rivers and seas. Polyester, a direct petrochemical product, accounts for around half of global textile production by volume. Linen, made from flax, currently accounts for less than half of one per cent. In Normandy, I visited the flax farmer Laure Figeureu-Bidaud and the scutching cooperative manager Bertrand Coulier. Flax is one of the lowest-input arable crops available, can be grown with minimal or no synthetic fungicide, most disease control is sulphur-based, approved for organic production, and has a spring growing cycle of around 100 days, too short for most disease pressures to establish. I was told that western Europe - France, Belgium and the Netherlands - produces approximately eighty per cent of the world's flax, in a maritime climate very similar to south-west England.

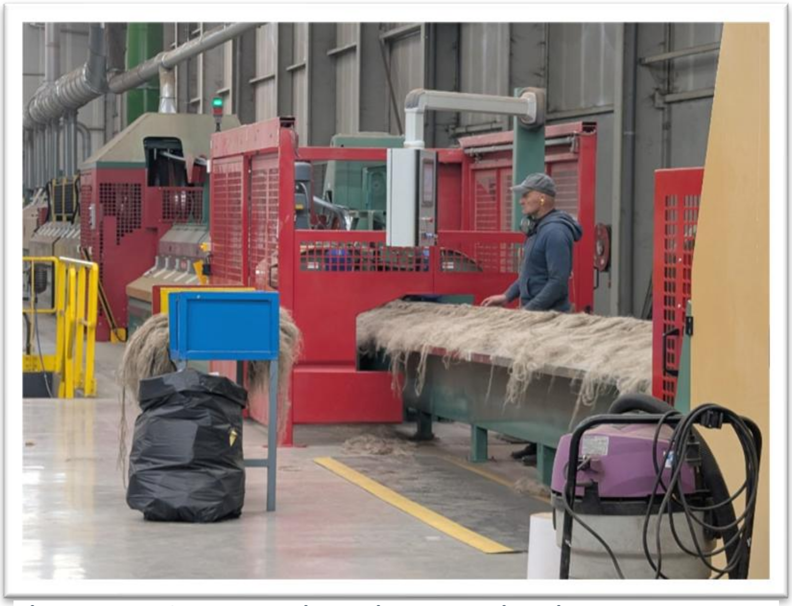

Figure 18: A flax scutching mill processing line, Normandy, France

Every fraction of the crop is used: long fibres for linen, short fibres for blended yarns and even for composite panels in cars in place of plastic, woody shives for board and animal bedding, and seed for oil. My father once grew a trial of flax in Cornwall; it grew well, but there was nowhere to process it. The lesson is that the bottleneck is not the crop but the processing infrastructure; a gap, and therefore an opportunity, for British agriculture.

4.7 The cultural dimension of change

Not everything in this transition is rational, and I think we underestimate the emotional dimension at our peril. At a tractor-pulling event in the Netherlands, surely one of the least fossil-free activities imaginable, I found myself staying for hours, talking to enthusiasts about machines they clearly loved. Koen Koppen, a local farmer, enthused at every old model on the track. “You’re not even a farmer if you don’t have a tractor”, Yne Janssen told me as she watched her father and brother competing in a Fendt 1930. When I asked them whether a tractor-pulling event could work with electric tractors, the answers were not a simple no. They were complicated. The noise mattered. The smell mattered. The community gathering around the spectacle mattered. “The event is about farmers coming together,” Koen told me. “The tractor is the excuse, not the point.”

Figure 19: Tractor pulling competition, Netherlands

Figure 20: Classic tractors lined up for a road run for my uncle’s 80th birthday celebration, Cornwall, UK

It made me think of my own first tractor, a Ferguson TE20 that I restored with my father and used to drive around our farm with my siblings in the link box behind me. It ran on petrol or TVO. I remember the precise sound of its engine, the cracks in the rim of the steering wheel, the smell of the warm oil. That machine is part of who I am in a way that is difficult to quantify on a spreadsheet. The transition away from fossil fuel machinery is asking people, in some sense, to part with something woven into their identity. We have already seen, in the slow public acceptance of electric cars, how powerfully this emotional dimension shapes the pace of change. Farming is no different. A transition that pretends this dimension does not exist will move more slowly, not faster.

CHAPTER 5: DISCUSSION

The evidence from nine countries points to one conclusion I did not expect at the outset: the move away from fossil fuels in farming is already happening at commercial scale, and where it happens it is driven primarily by economics rather than by regulation or environmental conviction. The biological alternatives to synthetic inputs are becoming cheaper than the inputs they replace; electric drive is more efficient than mechanical transmission for many tasks, and energy generated on farmland is more valuable to the farmer who owns it than to the developer who leases the land.

This reframing changes the nature of the policy discussion. If the transition were purely ideological, the solution would be subsidies and regulation. Because it is substantially economic, the more important task is to remove the structural barriers that stop rational decisions being made. This includes constrained grid capacity, slow and costly planning, tax anomalies, and regulatory frameworks built around a fossil-fuelled model of farming. Remove these, and the economically sensible choice becomes the easy one.

I believe we can feed the world with lower artificial inputs alongside a more symbiotic relationship with nature, but only with structural changes to our food system and global diets. Without those changes, Pieter Winter's pessimism may be vindicated, in that we cannot yet feed the world without synthetic inputs, as efficiency gains are repeatedly swallowed by rising consumption. He was not alone in raising this concern. Balmford and colleagues, in a major review of the environmental costs and benefits of high-yield farming, reach the same conclusion from the opposite direction: that high-yield systems can deliver net environmental benefit only if they are explicitly coupled with measures to constrain agricultural expansion and to prevent the rebound effect from cancelling the gain (Balmford et al., 2018).

A second tension is between input reduction and land use: the argument that lower-input farming requires more land, causing greater habitat loss elsewhere, deserves engagement. The Brazilian model I observed with high output, biological inputs, no-till, mandatory legal reserves, shows high yields and lower inputs can be achieved together in many places. That combination, however, depends on a legal framework built over decades. Realising both at once requires bold system redesign at all levels from farm to government.

The community ownership of energy is, to me, the most urgent issue raised by my travels. The United Kingdom is deploying renewable energy on farmland at speed, but in a way that too often exports the value to distant capital. The window for farmers and rural communities to own these assets is open now and will not stay open indefinitely. This is where I believe the greatest prize, and the greatest risk of a missed opportunity lies.

CHAPTER 6: 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)

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 Engalnd, 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.

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.

- The largest change to global diets in a generation is likely to come in the form of nutrient density. If people begin paying for nutrient volume rather than simply crop weight, biologically based systems could be the biggest ‘commodity’ producers. Develop nutrient density labelling and measurement frameworks to support this transition.

CHAPTER 7: AFTER MY STUDY TOUR

My intention is to inspire a fossil free movement, developing policy, technological and social solutions to make the transition equitable and beneficial to all. I also intend to open our farm for research as a working demonstration 'fossil free farm', to share openly what succeeds and what fails. We have many existing projects.

- **Hosting farm visits** – We will continue to host thousands of schoolchildren, as I believe this is the best way to affect cultural change, but we will also increase links with other farmers and policy makers, while developing our offering as a trials farm for research and innovation projects.
- **AgriWatt** – ADOPT trial looking at upscaling the value of farm produced energy while supporting a distributed grid through battery storage
- **Charge.Farm** - A rural electric-vehicle and heavy-goods charging network built around farm-hosted battery storage.
- **Sisal twine** – I led an Innovative Farmers trial using sisal twine and other sustainable coverings on round bales. I will be taking this forward with manufacturers and policy makers.
- **Home-brew seaweed biostimulant** – We lead an Innovative Farmers trial looking at the potential for farmers to make their own crop and soil biology stimulant using locally grown seaweed.
- **Community wind** – We are working on a project to install a 1MW, 50 per cent community owned wind turbine.
- **HVO** – We have switched our existing tractors to HVO fuel while we consider electric and other alternative fuel options.
- **Electrification** – We have switched all of our personal vehicles to electric, except my old Land Rover Defender, which I accept is out of sentiment. Our farm buggy is also now electric. All of these vehicles are quite simply better than their petrol or diesel alternatives.
- **Resilient crops** – We are working on a number of projects breeding up heritage varieties of grains and legumes. Using populations and companion cropping, we hope to create more pest, disease and climate resilient crops which rely less on chemical inputs.

A final thought

I set out unsure whether real zero was possible. I have returned convinced that it is, not as a sacrifice, but as the greatest opportunity of my farming lifetime. The question is no longer whether the transition will happen, but whether British farmers will lead it or follow.

CHAPTER 8: ACKNOWLEDGEMENT AND THANKS

I am indebted to the Nuffield Farming Scholarships Trust, and to my sponsor, the Dartington Cattle Breeding Trust, for the extraordinary privilege of the opportunity to undertake this study.

I would also like to thank all those who gave me time and experiences which have been genuinely life changing. While many deserve a special mention here, I couldn't possibly fit them all, but I hope I can do them justice in carrying their messages and ideas forward.

However, I must thank my family, in particular my parents for giving me so much freedom to go away for months at a time. My brother Dave and I were fortunate to become the first siblings to be awarded Nuffield scholarships in the same year, with a plan to support each other and take it in turns to go away. But despite this, there was a 6-week period when we were both travelling at the same time through the dark days of winter. Dad stepped into the breach, keeping the farm going without complaint, but I promise we won't do that again!

REFERENCES

Balmford, A., Amano, T., Bartlett, H. et al. (2018) 'The environmental costs and benefits of high-yield farming', Nature Sustainability, 1(9), pp. 477–485.

Brentrup, F. and Pallière, C. (2008) 'GHG emissions and energy efficiency in European fertiliser production', Proceedings of the International Fertiliser Society, 639, pp. 1–24.

Defra (2024) The British Survey of Fertiliser Practice: Fertiliser Use on Farm Crops for Crop Year 2023. York: Department for Environment, Food and Rural Affairs.

Defra (2024) Total Income from Farming in the United Kingdom. London: Department for Environment, Food and Rural Affairs.

Department for Energy Security and Net Zero (2024) Final UK Greenhouse Gas Emissions National Statistics: 1990 to 2022. London: DESNZ.

Ellen MacArthur Foundation (2017) A New Textiles Economy: Redesigning fashion's future. Cowes: Ellen MacArthur Foundation.

Global Fashion Agenda and McKinsey & Company (2020) Fashion on Climate: How the Fashion Industry Can Deliver the Urgent Action Needed to Hit the 1.5-Degree Pathway. Copenhagen: Global Fashion Agenda.

HM Revenue and Customs (2024) Fuel and power (VAT Notice 701/19). London: HMRC.

International Energy Agency (2021) Ammonia Technology Roadmap: Towards more sustainable nitrogen fertiliser production. Paris: IEA.

Canadell, J.G., Monteiro, P.M.S., Costa, M.H. et al. (2021) 'Global carbon and other biogeochemical cycles and feedbacks', in Masson-Delmotte, V. et al. (eds.) Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

Jevons, W.S. (1865) The Coal Question: An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of Our Coal-Mines. London: Macmillan and Co.

Salvagiotti, F., Cassman, K.G., Specht, J.E., Walters, D.T., Weiss, A. and Dobermann, A. (2008) 'Nitrogen uptake, fixation and response to fertilizer N in soybeans: A review', Field Crops Research, 108(1), pp. 1–13.

Smil, V. (2001) Enriching the Earth: Fritz Haber, Carl Bosch, and the Transformation of World Food Production. Cambridge, MA: MIT Press.

Werwitzke, C. (2026) 'Year-end surge: electric trucks outsell diesel for the first time in China', electrive.com, 23 January. Available at: https://www.electrive.com/2026/01/23/year-end-surge-electric-trucks-outsell-diesel-for-the-first-time-in-china/ (Accessed: 6 June 2026).

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