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AN INVESTIGATION INTO THE FEASIBILITY OF HYBRID AND ALL-ELECTRIC AGRICULTURAL MACHINES

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Abstract

Whilst manufacturers in the passenger car, commercial and public service vehicle industries have introduced hybrid and all-electric vehicles, to commercial success, there is an apparent lack of hybrid and all-electric technology in the agricultural machinery sector.
This project used a three-stage approach to investigate whether current hybrid and all-electric drivetrains could feasibly replace the diesel engine in an agricultural tractor. Firstly, a current systems review, gathered information from a range of industries where alternative powertrains have been successful, to gain an understanding of the properties and capabilities of available systems. The second element; a series of real-world practical tests, collected data about the requirements of agricultural tractors in use, this would be used to determine whether the alternative technology currently available could cope with the demands placed on a machine. Finally, a questionnaire, collected data from those working in the agricultural sector; this would be used to gauge attitudes and opinions towards alternative power systems.
There were two sets of practical tests. The first used a McCormick MC120, in a round bale loading exercise, on a farm in Cheshire, in November of 2015. The second set of tests used a New Holland TS90, operating a feeder wagon, on a medium sized dairy farm, in Derbyshire. These tests ran from November 2015 to early February 2016. Calculations proved the cost of charging an all-electric system capable of producing the required output of the practical tests would be more than the cost of diesel for the same output.

Key words*: all electric technology, agricultural machinery, alternative power systems, power, torque, hybrid.*

INTRODUCTION

The industrial food supply system is the worlds' largest consumer of fossil fuels and one of the greatest producers of greenhouse gases. Cheap and readily available energy is essential, in the construction and maintenance of the infrastructure needed to facilitate the agricultural industry (Church, 2005).
Spackman (2012) warns that fuel security is an ever-increasing issue for everyone.
Increasing costs and environmental awareness has made the use of alternative power methods, such as hybrid and all-electric vehicles, widely accepted in many industries (Phelan, 2015); however, agriculture does not appear to be adopting the technology.
This research project investigated whether hybrid and all-electric technology can feasibly replace the diesel engine, in an agricultural machine, and critically analyse why the technology appears to have been adopted more readily in other industries.
The investigation began with a simple thought. Many cars and buses on UK roads are being powered with hybrid or all-electric drivetrains, so why are there no hybrid or electric tractors?
Alternative drive technologies are becoming increasingly important. Strict emissions regulations and the finite nature of fossil fuels make using alternative drive concepts inevitable (Bosch, 2009).
Mild Hybrid – A combustion engine is supported by a low powered electric motor. The vehicle cannot run purely on electrical power.
Full Hybrid – The vehicle is mainly powered by a combustion engine. It can be driven short distances using electrical power.
Plug-in Hybrid – The vehicle is powered by a combustion engine but can be driven longer distances using electrical power. The battery can also be charged directly from an electrical socket.
Electric Vehicle – The vehicle is powered solely by an electric motor. The battery is recharged from an electrical socket or charging station.

Electric Vehicle with Range Extender – The vehicle is powered solely by an electric motor. A small combustion engine can charge the battery as needed, but the engine cannot power the vehicle alone.

Electric Vehicle Technology

Youngs (2012) explains that AEVs work on similar principles to any rechargeable battery device such as a toothbrush or battery drill. An electric car has a bank of high-voltage rechargeable batteries and at least one electric motor. A controller feeds electricity to the electric motor(s) based on accelerator pedal position. Once drained, the battery pack is recharged. Table 1 lists the specifications of a selection of AEVs.

Table 1. Electric Vehicle Specifications

Make and Model	Electric Motor Kw/Nm)	Battery Pack Output Kw/hr)	Charging Time (hrs)	Battery Pack (Kg)
Volkswagen e-Golf	85/270	24.2 @ 323V	8 @ 240V/13A AC 0.5 @ DC Fast Charge	318
Ford, Focus Electric	107/ 250	23	3-4 @ 32A 6-7 @ 16A 10-11 @ 10A	318
Nissan, Leaf	80/280	24 or 30	4 or 5.5 @ 240V/12A	306
Chevrolet, Bolt	150/ 360	60	2 @ 240V/16A AC 0.5 @ DC Fast Charge	435
Mitsubishi, i-MiEV	49/196	16 @ 330V	6 @ 240V/15A, 14 @ 120V/12A, 22 @ 120V/8A,	150

Table 2. Electric Vehicle Specifications cont

Make and Model	Weight (Kg)	Weight of Battery Pack (Kg)	Price
Volkswagen e-Golf	1585	318	£31650
Ford, Focus Electric	1674	318	£31145
Nissan, Leaf	1945	306	£16,290 –£24,990
Chevrolet, Bolt	1625	435	N/A
Mitsubishi, i-MiEV	1170	150	N/A

Recharging

It is difficult to determine exactly how long it takes to charge an AEV. It depends on the condition of the batteries, the state of charge and the voltage and amperage of the electricity supplied to the vehicle (Plug In America, 2015) 3.3 - Hybrid Vehicle Technology.

Cobb (2014) explains there are three main types of hybrid electric vehicle (HEV); full, mild and plug-in hybrids; which were explained at the beginning of this section. Lake (2015), explains that most hybrid vehicles work on one of two systems; series or parallel.

Series Hybrid Technology

A series system solely relies on the electric motor to propel the vehicle. The electric motor is powered by a battery pack, or an engine driven generator. A control module determines how much power is required and takes energy either from the battery pack or generator accordingly (Lake, 2015).

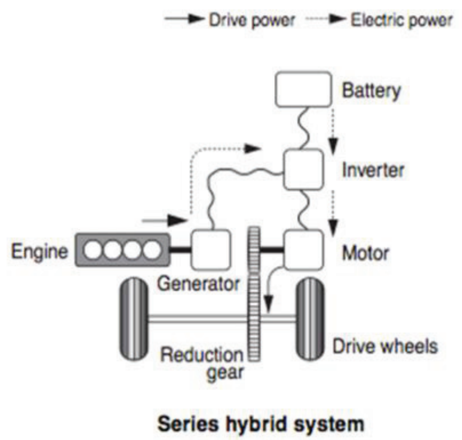

Figure 1. Diagram showing the layout and power flow through a series hybrid system
Source: Katsoupis, 2013

Parallel Hybrid Technology

In a parallel system, both the electric motor and the combustion engine work in tandem to propel the vehicle; the engine and the electric motor are both connected to the transmission. A controller determines when the electric motor is used and when to switch to the engine. In circumstances where short power boosts are required, when accelerating quickly for example, both the combustion engine and the electric motor work together to power the transmission (Lake, 2015).

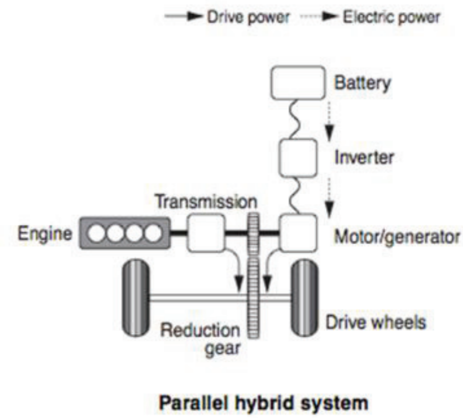

Figure 2. Diagram showing the layout and power flow through a parallel hybrid system (Source: Katsoupis, 2013)

Regenerative Braking

The future feasibility of electrical powertrains is greatly dependant on efficient batteries, intelligent energy management and the recovery of braking energy. Regenerative braking systems are a key element of alternatively powered vehicles (Bosch, 2009).

Solberg (2007) explains that when decelerating, a vehicles kinetic energy is transformed into heat by friction between the brake pads and discs. This heat is dissipated to the atmosphere and the kinetic energy is essentially lost. Recuperation or regenerative braking systems, recover kinetic energy from a vehicle decelerating, by turning the electric motor, which drives the vehicle, into a generator, recharging the batteries.

MATERIALS AND METHODS

The success of hybrid and all electric vehicles in industries has been demonstrated, however, the question was posed as to why this technology has not been implemented in agricultural machines.

The investigation aims are split into three areas:

Current Systems Review – researching the capabilities, benefits and drawbacks of current hybrid and all-electric vehicles.

A Feasibility Study - discovering whether; with current equipment capabilities, it is possible for a hybrid or all electric vehicle to carry out routine tasks, in place of a diesel-powered alternative

A Perception Study – collecting information from, mainly farmers and agricultural workers, to review whether people would buy an electric or hybrid tractor, if it were possible to produce one that could carry out the same tasks as their current machine.

Two farms near Manchester were contacted and participated in the study; they agreed to be of any assistance they could, where and when available. Both farmers agreed they and their staff would complete questionnaires for use in the perception study.

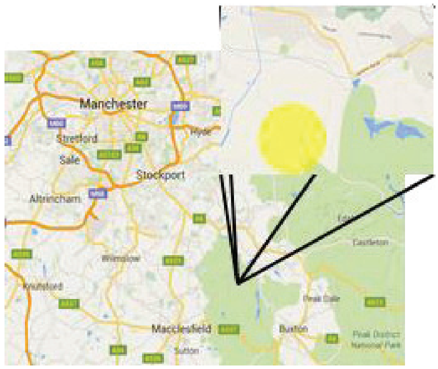

Figure 3. Location of farms used in the research project

Farm 1 has a dairy herd of between 120-130 head, milking twice daily, with just over 142 hectares of grazing and silage land. The owner offered the services of his tractor and feeder wagon, for the feasibility study.

Farm 2 is a 50 hectares' farm situated next door. The farm produces between 1000-1100 round bales of haylage and silage, a year, used for feeding horses and deer at the local farms and Country Park. The owner operates the farm single handed and uses one tractor for everything, his machine was also offered for the feasibility study.

The areas for investigated included:

Passenger Vehicle Technology – Including passenger cars, SUVs and high performance cars.

Commercial Vehicles and Buses – Many bus companies are now using hybrid buses; have they been a success? Investigate their power capabilities.

Articles and Journals – Current and past studies and reports written about the topic.

Manufacturer Future Plans – Research manufacturers' future machinery plans; are there any planning on producing electric tractors?

Testing

Fuel Consumption Test

Record how much fuel a diesel tractor uses completing a measurable, routine task; for these experiments, a tractor operating a feeder wagon and a tractor loading/unloading haylage bales. Fuel consumption recorded 10 times to provide a data set to calculate averages from.

Power Requirement Calculation

Use dynamometer to calculate how much power a machine is using to complete a task, by measuring its fuel usage; known as fuel to power ratio this is given as Horsepower per Litre, this is converted to Kilowatts per Litre, as this is the unit of measurement for electrical power output.

Current System Analysis

Using the output calculation and the previous current vehicle investigation it will be possible to conclude whether, with current technology, it is possible to create an electric or hybrid vehicle to replace the diesel engine.

Perception study

Using mainly questionnaires and interviews; data centred on individuals' perceptions of electric vehicles, questions included:

What does the interviewee do for work, farmer, farmhand, contractor etc?

What main uses do they have for agricultural machines?

What current vehicles do they own?

Does the interviewee own/ever considered owning an electric or hybrid vehicle?

Is there particular reasons they would not purchase an electric or hybrid vehicle

By compiling the data, it is possible to find trends in the answers, for example those who own electric vehicles may be more likely to purchase an electric tractor, whereas those who are contractors may be concerned about the cost implications.

RESULTS AND DISCUSSION

The first practical tests recorded the amount of fuel used and time taken to complete common farmyard tasks, these results were used to calculate average fuel use per minute figures.

Figure 4. Measuring fuel used

Table 3. Displaying the time taken and fuel used to complete the ten bale handling tests

Test No.	Time Taken (min/sec)	Fuel Used (ml)	
1	6:28	560	
2	6:27	600	
3	6:06	580	
4	6:14	650	
5	6:07	600	
6	6:36	480	
7	5:37	475	
8	6:57	470	
9	5:56	560	
10	6:02	500	
Total	72.52	5475	
Average (mean)	7.25	547.5	75.6 ml/min

The second set of tests used a dynamometer to determine the power and torque requirements of the practical tests, based on the amount of fuel used.

Figure 5. Tractor under test using a Fromet dynamometer

Eight tests were run with each machine used in the practical tests

Each test lasted fifteen minutes and demanded an increasing amount of power and torque from the machines.

The results collected from the dynamometer tests were plotted onto scatter charts. Using the average fuel consumption per minute figures previously calculated, the power and the torque demand of the practical tests is determined.

Table 4. Showing the fuel used and the power produced through each of the fifteen-minute dynamometer tests, at set output increments

Time (min)	Power %	Power (hp)/Kw)	Fuel (ml)	Torque (lb/ft)/(Nm)
15:00	10	11/8	1900	62/84
15:00	25	29/22	2900	145/196.6
15:00	50	57/43	4200	292/395.9
15:00	75	86/65	5300	446/604.7

Table 5. Showing the fuel used and the torque produced through each of the fifteen-minute dynamometer tests, at set output increments

Time (min)	Torque %	Torque (lb/ft)/(Nm)	Fuel Used (ml)
15:00	10	83/113	2470
15:00	25	209/284	3720
15:00	50	417/567	4880
15:00	75	626/851	5200

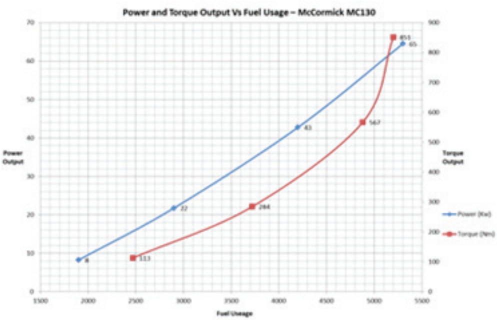

Figure 6. Showing power and torque output v^s fuel use for McCormick MC130 tractor

The McCormick tractor produced a stable power curve with strong correlation between power production and fuel consumption. Using the data in Table 6, it is possible to estimate the power output of the tractor at the desired fuel usage rate of 1314 ml in fifteen minutes.

It is apparent, from the data that the more power produced, the more efficient the engine becomes; meaning using the mean average of all results for calculations would not provide accurate figures. Instead the 10% output value will be used, as it is closest to the expected figure. At a rate of 237.5 ml/Kw, the tractor would expectantly produce 5.5Kw of power, when using 1314 ml per fifteen minutes.

Table 6. Calculating power output per unit of fuel for the McCormick tractor, used for the bale handling tests

Power %	Power (Kw)	Fuel Used (ml)	Power Produced per Unit of Fuel (ml/Kw)
10	8	1900	237.5
25	22	2900	131.8
50	43	4200	97.7
75	65	5300	81.5
AVERAGE			137.1

The same calculations are used to estimate the torque requirements of the practical tests. These figures are more difficult to calculate accurately as the tractors torque curve did not have as close a correlation as the power curve.

Table 7, lists torque output per unit of fuel; similarly, to power, torque production becomes more efficient as it increases. Therefore, the calculations will use the 10% values. At the rate of 21 ml/Nm, the tractor produces 63 Nm of torque, using 1314 ml of fuel in fifteen minutes.

Table 7. Calculating torque output per unit of fuel for the McCormick tractor, used for the bale handling tests

Torque %	Torque (Nm)	Fuel Used (ml)	Torque Produced per Unit of Fuel (ml/Nm)
10	113	2470	21.9
25	284	3720	13.1
50	567	4880	8.6
75	851	5200	6.1
AVERAGE			12.4

Feeder Wagon Test

Table 8. Displaying the time taken and fuel used to complete the ten feeder wagon tests

Test No.	Time Taken (mins)	Fuel Used (ml)	
1	94.52	8550	
2	91.00	7890	
3	65.47	6000	
4	93.46	8750	
5	83.49	8300	
6	73.40	6840	
7	70.10	6830	
8	67.00	6450	
9	61.40	6160	
10	60.00	5810	
Total	759.84	71580	
Average	75.84	7158.0	94.74 ml/min

Table 9. Showing the fuel used and the power produced through each of the fifteen-minute dynamometer tests, at set output increments

Time (min)	Power %	Power (hp)/(Kw)	Torque (Nm)	Fuel Used (ml)
15:00	10	9/7	87	1225
15:00	25	22/17	220	1870
15:00	50	44/33	465	2450
15:00	75	66/50	683	3680

Table 10. Showing the fuel used and the torque produced through each of the fifteen-minute dynamometer tests, at set output increments

Time (min)	Torque %	Torque (lb/ft)(/Nm)	Power (hp)	Fuel Used (ml)
15:00	10	53/72	6	1275
15:00	25	132/180	15	1500
15:00	50	265/360	26	1875
15:00	75	397/540	41	2550

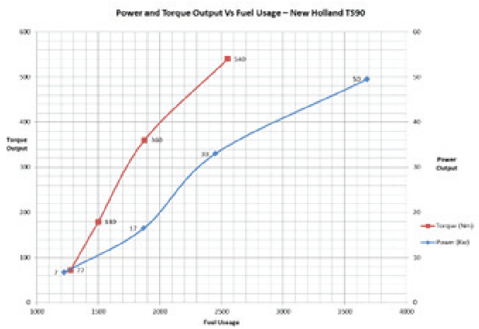

Figure 7. Showing the torque and power production figures (Y axis) against fuel usage (X axis)

The feeder wagon tests provided more useful data, than the bale handling exercise.
On average the test used 94.1ml/min of fuel.
To replicate the power and torque requirements of the practical tests the tractor must use 1412ml of fuel during the fifteen-minute dynamometer test.
Figure 7 displays the power and torque output where this figure is reached.

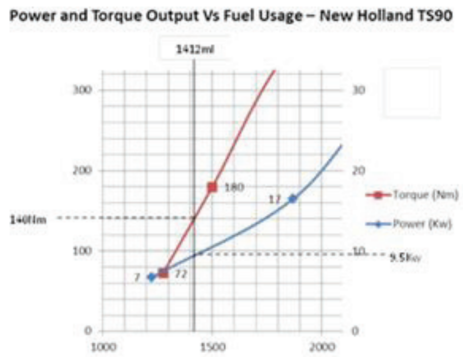

Figure 8. An extract from Figure 7, showing the fuel consumption at 10% and 25% power and torque outputs, 1412ml is marked with the black line, on the X axis, the power and torque figures are marked with the dashed lines on the Y axis.

Questionnaires

The original proposal called for 100 questionnaires to be completed, the sample size reduced to 30 throughout the study, as the questionnaires retrieved more information than originally expected.
The largest issues participants identified, were charging time (21, 27%), cost of purchase (18, 23%), capabilities (16, 20%).

Analysis of Questionnaires

The lead in questions collected information about the participants' job role and machinery usage. These questions were designed to discover whether there were correlations between participants' machinery usage and purpose, and their openness towards new technologies. When the responses were compiled, there appeared to be no correlation.

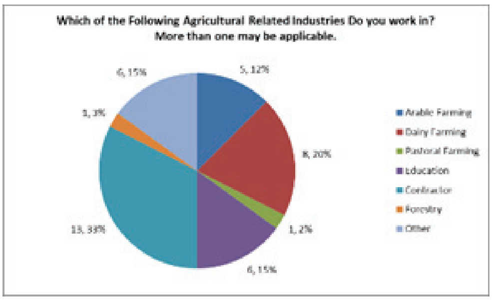

Figure 9. Showing spread of participants' industrial background

Questions gathered information from a wide range of agricultural workers, of the thirty questioned; only 6.7% owned a hybrid or electric vehicle. The report began by investigating how alternatively powered vehicles are becoming popular in the passenger vehicle market; the responses from this question demonstrate an apparent lack of these vehicles being used by the agricultural workforce.

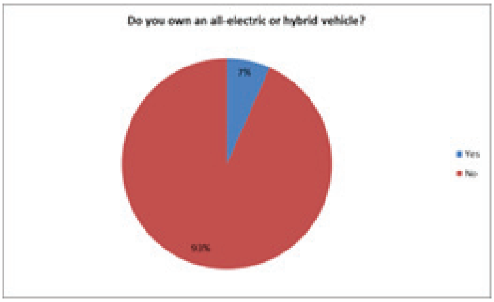

Figure 10. Showing percentage ownership of electric powered vehicles

20% of participants answered that they had considered purchasing an alternatively powered vehicle, two of which already owned vehicles, leaving the others, who considered purchasing a HEV or AEV but never did.

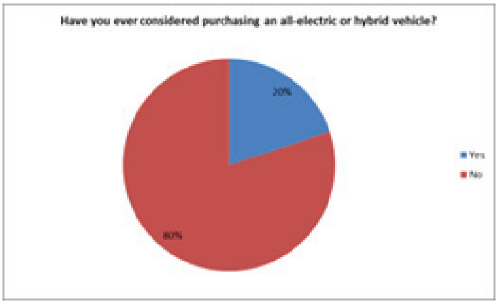

Figure 11. Indication of considering the purchase of an electric powered vehicle

Those participants who had considered purchasing an alternatively powered machine, but hadn't bought one, had researched the topic, including the views and opinions of current and previous owners.

Participants were asked which technology they believed would be more suitable in an agricultural environment. Hybrid systems were considered as more suitable for agricultural uses. The lack of a need to charge a hybrid vehicle and the benefits of having a diesel engine, for backup in case of electrical failure and the lighter weight of a hybrid system over a heavy bank of batteries and a large electric motor.

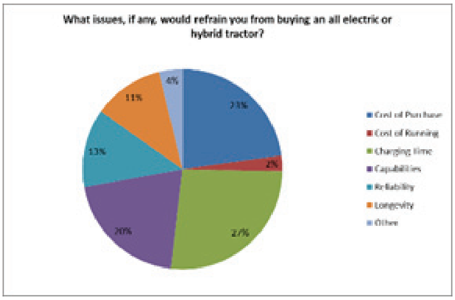

Figure 12. Showing reasons for not purchasing an electric powered vehicle

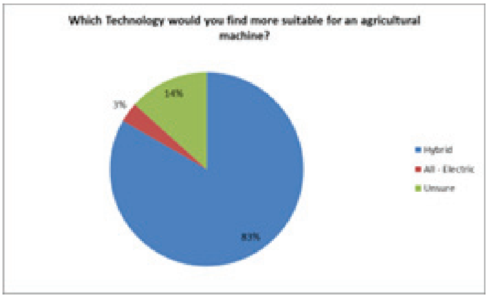

Figure 13. Indicates which of the electric vehicle technologies would be considered more suitable for agriculture

The responses from 67% participants showed that they would consider replacing a current vehicle with an alternatively powered tractor.

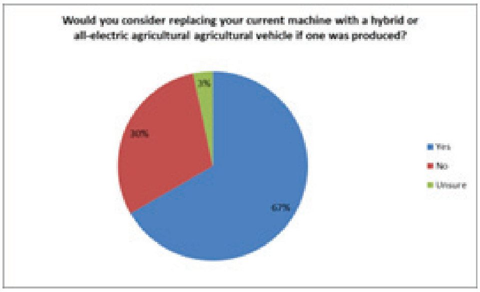

Figure 14. Indicates the concept of replacing a current agricultural machine with an electric powered alternative

66% of participants answered that they would consider purchasing a hybrid or all-electric tractor, if one were produced.

Capability and feasibility are two separate concepts.

Whilst the results from the investigation demonstrate, there are a range of all-electric systems capable of the outputs required from a tractor.
The feasibility of an all-electric or hybrid system replacing a diesel engine goes beyond their capable outputs. Cost of purchase, cost of running, predicted lifespan and weight were areas analysed by the investigation.
Using the data collected from the practical tests and the specifications compiled throughout the current systems review the investigation analysed how alternative drivetrains would cope with the demands placed on a tractor through regular use.
The concerns raised in the questionnaire responses, became focus points for the discussion.
Cost of purchase, running costs, capabilities and lifespan were the main areas for discussion.

Machinery Requirements

The test result and analysis section calculated how much power and torque a machine must produce in order to complete the routine tasks, used for the investigation. To complete the bale handling exercise, the tractor used 5.5 Kw of power and 63 Nm of torque over an average time of 6:15 (min:sec). The tractor completing the feeder wagon exercise needed to produce 9.5Kw of power and 140 Nm of torque for an average time of 1:12:06 (hr:min:sec).

Electrical Vehicle Capabilities

The Electric vehicle section at the beginning of the report analysed popular all-electric vehicles; their capabilities listed in Table 1. All five of the electrical systems fitted to the example vehicles were capable of producing the power and torque requirements of both practical tests. To be deemed feasible, the electrical system would need to be able to complete the tasks repeatedly. The largest battery, by power output, in Table 1, is used in the Chevrolet Bolt, with a maximum power output of 60 Kw/hr. This battery coupled with its motor, could continually produce the power required by the bale handling exercise for 10:56 (hr:min), and the feeder wagon exercise for 6:20 (hr:min). The smallest battery, by output, fitted to the Mitsubishi i-MiEV, could sustain the required output of the bale handling test for 2:54 (hr:min) and the feeder wagon test for 1:42 (hr:min). Both times are longer than the maximum time taken to complete either exercise.

Weight and Fuel

All-electric vehicles have no engine or fuel tank. The McCormick MC120 carries 196 litres (L) of diesel, weighing approximately 170Kg (Argo Tractors, 2009). The tractors engine, weighs 306Kg, plus approximately 20 L of coolant and oil (Perkins Engines Company Limited, 2014).
The combined weight of the tractors fuel and engine equals approximately 496 Kg; 62 Kg heavier than the most powerful and heaviest electrical system of the range in Table 1, (pp.12); Taking into account that the bale handling exercise consumed 87.6 ml/min of fuel, the fuel on board, could complete the task continually for 37:20 (hr:min), using the calculations from the previous section this is over three and a half times longer than the predicted length of time an electric system could manage.
The 4-cylinder turbo charged engine in the New Holland TS90 weighs 408 Kg (New Holland Agriculture, 2016). The fuel tank has a capacity of 159 L; approximately 140 Kg of diesel (Tractor-Database, 2012); giving a combined weight of 548 Kg. This is 113 Kg heavier than the Chevrolet Bolts' electrical system, previously used for comparison. As discussed the electric motor and batteries are capable of producing the tasks requirements for 6:20 (hr:min). At an average fuel usage rate of 94.1ml/min the tractor carries enough fuel to continually run for approximately 28:10 (hr:min); over four times the length of the electrical system.

Cost

Tables 1 and 3 provide comparative prices for the Volkswagen Golf and Ford Focus. The e-Golf is over £ 11000 more expensive than the petrol example; the difference between the Focus electric and diesel model is over £12000; approximately 30% more costly.

Cost of Recharging

The charging time of an AEV depends heavily on the type of charger used. The Chevrolet Bolt

has been used for comparison in the previous sections, however, the exact specification of its on-board charging system was unobtainable. Therefore, the Volkswagen system will be used for this comparison.
The Volkswagen system charges at a rate of 7.2 Kw/hr and a full charge takes 8 hrs. The Energy Saving Trust, (2016); states the average UK electricity price for March 2016, is 13.86 pence per Kw/hr (ppKw/hr). With a 7.2 kw/hr draw for 8 hrs at 13.86 ppKw/hr; a full charge would cost approximately £7.98.
Using previous calculations, it can be determined that the e-Golf's 24.2 Kw/hr battery pack could produce the feeder wagon exercises required power for 2:30 (hr:min); on a full charge. To complete that task for the same amount of time at the fuel usage rate of 94.1 ml/min; the diesel-powered tractor would use 16.94 L of fuel.
The Agriculture and Horticulture Development Board, (2016); states the average UK red diesel price for March 2016 is 38.62 pence per litre (ppl), equalling a total cost of £6.54, for 2:30 (hr:min) of required output.

Lifetime
Cobb, (2014); discusses lifetime expectations of electric vehicle batteries. The author explains that the majority of AEV and HEV manufacturers provide battery pack warranties with their vehicles. The warranty periods are described as a good estimate for what users can expect from a battery pack over a given time.
The Nissan Leaf, listed in Table 1, is sold in the UK with a battery warranty, guaranteeing a minimum of 75% battery output for 8 years for 30 Kw/hr packs and 5 years for 24 Kw/hr packs (Nissan Great Britain, 2015).
The battery from the Chevrolet Bolt, the most powerful of the range, is covered by an 8-year warranty. The manufacturer states that, depending on use, the batteries capacity would reduce by 10-30% over the warranty period (Chevrolet, 2015).
The New Holland TS90 tractor, used for the feeder wagon tests, is 13 years old and has completed over 6000 hrs of service. When new, the manufacturer claimed the engine could produce 90 hp, the dynamometer results, show the tractor is now capable of 87.4 hp, a loss of 2.6 hp or less than 3%, over its lifetime.
The larger, McCormick MC120 tractor left the factory with a rated output of 115 hp; during the dynamometer tests, (see appendix 8); the tractor produced 114.3 hp, a loss of 0.7 hp or 0.6%, over four years and over 1500 hrs of service.

Hybrid Vehicle Suitability
The report has discussed, in detail the feasibility of electric drivetrains in agricultural tractors. The following sub-section will analyse the various hybrid drivetrains explained in the current systems review.
Reputable sources of information concerning hybrid vehicle systems and their capabilities were difficult to find throughout the investigation. Many books and articles had been written about the working principles of the systems, however, there appeared to be a distinct lack of comparable data between hybrid vehicles and their fossil fuelled alternatives. When discussing comparative pricing and weight in the following text, only one vehicle manufacturer provided enough data to form an argument. Many of the theories and technologies discussed by manufacturers were deemed unsuitable for an agricultural product, as this section explains.
Agricultural tractors are designed to meet a unique set of requirements; including pulling heavy loads at low speeds for long periods, in low traction conditions. So far, development of hybrid and all-electric systems has been directed at the needs of passenger cars, which have their own requirements, not always similar to those of agricultural machines, (Hewson, 2009).

Regenerative Braking
Regenerative braking and kinetic energy recovery systems are fundamental elements of any hybrid system. These systems recover energy through vehicle deceleration. This technology is utilised frequently in a car or truck, constantly speeding up and slowing down throughout a journey. In situations, such as fieldwork, where tractors are travelling at constant speeds, with a stable load, for long periods; a system that relies on deceleration is less suitable.

Commercial Vehicle Systems
Commercial vehicles use parallel hybrid systems. The Renault HYBRIS truck relies on

electrical power to propel the vehicle from stationary to 20 Km/hr, at which point the diesel engine in the vehicle takes over and accelerates the vehicle to top speed.

The McCormick MC120 measured the distance travelled throughout the bale handling tests, accurately, and calculated an average distance of 389 metres; the tests took an average time of 6:15 (min:sec), giving an average speed of 3.7 Km/hr

The New Holland tractor, used for the feeder wagon tests, did not have the capacity to measure distance travelled accurately; therefore, a Trimble wheel was used to measure the total distance covered by the exercise; approximately 700 metres; travelling took an average time of 8:33 (min:sec), giving an average speed of 4.9 km/hr.

If a speed sensing system, such as the one in a Renault truck were to be utilised, for the tractors, completing the practical tests, the combustion engine would not engage, as the speed would remain too low. This point links back to a statement made by Hewson (2009), who commented that tractors are required to pull heavy loads at low speeds; a system which uses only electrical power at low speeds would limit the scope of use of a machine.

Cost and Weight

The Volkswagen Golf is a passenger car, available in both a hybrid and combustion engine version. Similar to the comparison between the all-electric and petrol Golf, made in the previous section, the Golf GTE hybrid is over £13500 more expensive and 350 Kg heavier than the petrol model.

Eriksson (2013); commented, in an article reporting on hybrid commercial vehicles; that the current cost of hybrid technology is forcing the overall cost of a vehicle so high that it is difficult for operators to achieve any economic gains from them. AEVs were also proven less economically viable where purchase costs and a calculated approximate charging costs, were both higher than diesel alternatives.

The information publicly available for the three commercial vehicle examples did not include comparative weight or cost data. The gross vehicle weights were quoted, however, the tare weights; those which measure a vehicle's weight with no load, were not specified; therefore, the study could not compare the payload differences between a hybrid and diesel example.

The topic of weight relates back to an argument made by Randall (2012); who commented how it is unlikely that pure-electric trucks will become available in the near future due to significant sacrifices to vehicle payload, with the use of a battery pack and motor.

Series Systems

Series hybrid systems use a combustion engine as an electricity generator. All motive power and propulsion is by electric motors, the power supply is either by a small battery pack, or directly from the generator.

An article published in Profi (2015); reported that transmission manufacturer, ZF had produced a prototype electronic wheel drive. The system is designed for retrofitting to trailed equipment and not as a replacement for the mechanical drive and diesel power used in tractors.

The possibility that tractors will become more like mobile diesel electricity generators, used to power electrical machinery and implements, links to an article written by Patrico (2013); where the author discussed the idea of replacing mechanical hydraulic pumps, hoses and shafts with more efficient electric motors. The main drawback of the system is described as a chicken and egg scenario, where tractor manufacturers will not develop a hybrid machine until there are electric implements to power; however, implement manufacturers will not produce electric machinery until there are diesel-electric tractors to pull them.

CONCLUSIONS

Using the information compiled throughout the study, the following points were concluded:

All of the all-electric systems reviewed were capable of producing the power required by the exercises.

The tractor diesel systems and engines were both heavier than any of the all-electric systems.

The example all-electric and hybrid vehicles were both over £13,000 more expensive than a comparable combustion engine car.

The cost of charging an all-electric system capable of the required output, of the feeder wagon tests - £7.98. The cost of diesel for the same output, from the test tractor- £6.5.

In addition, the data collected demonstrated how two farmers were regularly using a fraction of their machines potential. Posing the question; Do farmers need to purchase the large, powerful machines seen in modern farmyards, or are they purchasing machines, which are wasting more energy than they are utilising?

Areas for further study

This investigation drew together a small amount of information from many different sources. The practical testing element, although successful in terms of data collection, only collected data from a small number of machines and activities. In future, it would be beneficial for another study to gather more information from a larger amount of farming practices, to better understand what is required from modern agricultural machines. Whilst the two tasks selected were common and routine, they were not representative of the range of tasks tractors are designed for. Future studies may look at the power and torque requirements of heavier tasks, such as cultivation, harvesting or application processes.

Controllability of the tasks made gathering accurate data difficult with this study. This became apparent when collecting data from the feeder wagon exercise; as explained in the discussion section; it was impossible to accurately determine the power requirements of the task at specific points, such as loading and travelling. A future study may benefit from taking more time collecting results in stages throughout the exercises.

Although the original proposal never attempted to investigate the topic of machinery use and size, the data collected showed how two farmers were regularly using machines, which were only utilising a fraction of their potential. It is questionable as to whether large powerful machines are really necessary for tasks which, in these cases could be easily completed with less powerful tractors.

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REFERENCES

Agriculture and Horticulture Development Board, 2016. Monthly Fuel Price Tracker.

Church N., 2005. Why Our Food is So Dependent on Oil. Resilience, 1 April.

Cobb J., 2014. How Long Will An Electric Car's Battery Last? Hybrid Cars - Auto Alternatives, 30 April.

Eriksson C., 2013. Volvos' Electric Hybrid as Reliable as a Diesel Truck. Automo.

Hewson J., 2009. There are Major Barriers to the Mass Production of Electric Tractors. The Guardian, 25 November.

Katsoupis J., 2013. How Your Toyota Hybrid Works. [Online] Available at: www.wellesleytoyota.com/bid/328878/How-Your-Toyota-Hybrid-Engine-Works

Lake R., 2015. The Difference Between Parallel Hybrid Cars & Series Hybrid Cars. [Online] Available at: http://www.livestrong.com/article/174905-the-difference-between-parallel-hybrid-cars-series-hybrid-cars/

Patrico J., 2013. Hybrids Are Here ... Almost. Progressive Farmer, November.

Perkins Engines Company Limited, 2014. 1100 Series - 1104D-44TA. London: Perkins Engines Company Limited.

Phelan M., 2015. Survey says: Acceptance of Alt-fuel Cars on the Rise. [Online] available at: http://www.freep.com/story/money/cars/mark-phelan/2015/06/20/electric-vehicle-buyers-survey-hybrid/71082232/

Profi, 2015. ZF Electric Drive. Profi, November, p. 50.

Randall P., 2012. Don't Expect to See Any Pure Electric Trucks Any Time Soon. [Online] Available at: http://thechargingpoint.azurewebsites.net/news/UK-haulage-goes-hybrid-with-Renault.html

Spackman P., 2012. Crops for fuel are big business at Cereals 2012. Farmers Weekly, 18 June.

Spackman P., 2012. Crops for fuel are big business at Cereals 2012. Farmers Weekly, 18 June.

Robert Bosch, 2009. Chassis Systems Control. Heilbron: Robert Bosch Gmbh.

Tractor-Database, 2012. New Hollnad TS90. [Online] Available at: http://www.tractor-db.com/en/tractor/1333/new-holland-ts90

Youngs J., 2012. How Do Electric Cars Work? [Online] Available at: http://www.jdpower.com/cars/articles/safety-and-mpg/how-do-electric-cars-work

ABBREVIATIONS AND TERMINOLOGY

All-electric Vehicle – AEV; a vehicle propelled by an electric motor and batteries.
Hybrid Electric Vehicle – HEV; a vehicle propelled by an electric motor, working in tandem with a petrol or diesel engine.
Horsepower – hp; a unit of power, equal to 0.74 Kilowatts.
Kilowatts – Kw; a unit of power, equal to 1.34 Horsepower.
Kilowatts per hour – Kw/hr
Decibel – db; a unit of sound level.
Second- sec; a measure of time
Minute – min; a measure of time
Hour – hr; a measure of time.
Volts – V; a measure of electrical voltage.
Amps – A; a measure of electrical amperage.
Alternating Current – AC
Direct Current – DC
Millilitres per Minute – ml/min; a measure of consumption per minute.
Gross Vehicle Weight – GVW; the maximum permissible weight a vehicle can weigh.
Data Protection Act 1998 – DPA
Market Research Society – MRS
Information Commissioners Office – ICO