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Electric Vehicle Feasibility for Farms in Eastern South Dakota

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ELECTRIC VEHICLE FEASIBILITY
FOR FARMS IN EASTERN SOUTH DAKOTA

BY

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FOR FARMS IN EASTERN SOUTH DAKOTA

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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TABLE OF CONTENTS

	Page
INTRODUCTION	1
REVIEW OF LITERATURE	3
Task Requirements	3
Electric Vehicle Capabilities	6
Assessing Feasibility	11
PROCEDURE	16
Data Collection	16
Task Requirements	21
Electric Vehicle Capabilities	25
Technical and Economic Analyses	27
Technical Feasibility	28
Economic Feasibility	30
RESULTS AND DISCUSSION	34
Task Requirements	34
Literature Values	34
Farm Research Values	40
Electric Vehicle Capabilities	46
Feasibility of Electric Vehicles	55
Technical Feasibility	55
Economic Feasibility	58
CONCLUSIONS	65
REFERENCES	67
APPENDIX	70

LIST OF TABLES

Table		Page
1.	Estimated Percentage Price Increases in Real Terms Over the Period 1980-1990 Under Five Energy Scenarios (Calkins and Black, 1980).	15
2.	Principal vehicle performance requirements for tasks typical of 1-199 acre farms in Eastern South Dakota, as determined from review of literature	36
3.	Principal vehicle performance requirements for performing tasks typical of 200-1000 acre farms in Eastern South Dakota, as determined from review of literature	37
4.	Principal vehicle performance requirements for tasks typical of 1000 acres or more farms in Eastern South Dakota, as determined from review of literature	38
5.	Principal vehicle performance requirements for performing tasks determined from medium (200-1000 acres) farms near Brookings, South Dakota	43
6.	Principal vehicle performance requirements for performing tasks determined from large (over 1000 acres) farms near Brookings, South Dakota	44
7.	Electric Vehicle Hypothetical Designs for 1981	51
8.	Electric Vehicle Hypothetical Designs for 1990	53
9.	Operating Time Required for Proposed Electric Vehicles to Recover the Cost of a Battery Set Through Energy Cost Savings Compared with Conventional Tractors. . .	63

Table | Page

A-1. Power and Energy Requirements for Seventeen Grain and Livestock Farms Near Brookings, South Dakota 71

A-2. Percentages of Daily Energy Requirements That Could Be Met By Proposed Electric Vehicles With No Changes in Task Requirements or Tractor Capabilities. 78

A-3. Percentages of Daily Energy Requirements That Could Be Met By Proposed Electric Vehicles if Tractor Power May be Reduced. 85

A-4. Percentages of Annual Energy Requirements That Could Be Met by Proposed Electric Vehicles for Typical Eastern South Dakota Farms 92

A-5. Farmers Cooperating in This Study. 96

LIST OF FIGURES

Figure		Page
1.	Fuel Use Record Form with Sample Data	18
2.	Field Data Form, with Sample Information	20
3.	Sample Task Requirements Matrix Columns, with Data	26
4.	Comparisons of Energy Operating Costs Between Electric and Conventional Vehicles for Three Energy Cost Inflation Scenarios	61

INTRODUCTION

The oil embargo of 1973 ushered in an era of energy consciousness in the United States. Steadily increasing energy costs and several nation-wide petroleum shortages since then have kept considerations of energy cost and availability in the forefront of economic planning in both the private and public sectors. Among the most severely affected is the agriculture industry, because petroleum consumption is crucial to the efficient production of food and fiber. Conservation measures have been implemented and tractor designers are striving for more fuel-efficient vehicles, but the pressing need to reduce agriculture's dependence on unstable foreign oil supplies will only be met when alternate energy sources can feasibly power farm vehicles.

The development of electric agricultural vehicles could provide the means to reduce agriculture's petroleum dependence. Electric vehicles have been quite successful for some applications where advantages of less maintenance, longer life, lower energy operating costs, better efficiency in start and stop conditions, and easier starting have been noted. Additionally, electric vehicles could utilize off-peak electric supply capabilities. The sale of such electric energy results in savings to the farmer and increased efficiency for the generating facility.

It appears that electric vehicles have potential for agriculture. Therefore research was initiated with the overall goal of assessing electric vehicle feasibility for eastern South Dakota agriculture.

Specific objectives were:

1. Determine vehicle requirements as functions of specific farm tasks for eastern South Dakota farm operations.

2. Define electric vehicle performance characteristics based on current technology and projected 1990 technology.

3. Analyze the technical feasibility of replacing conventional tractors with electric vehicles.

4. Assess the current economic feasibility of electric vehicles and project the 1990 feasibility.

REVIEW OF LITERATURE

Task Requirements

Farm vehicle requirements for performing field tasks have been documented in several references. Kepner et al. (1978) specify normal ranges of draft, energy, power, and forward speed requirements for performing typical field tasks, including plowing, disking, cultivating, planting, and harvesting. Specific energy requirements are expressed in units of energy per weight of crop material processed, specific power requirements in units of power per implement width, and specific draft requirements in terms of force per cross-sectional tilled area or force per implement width. Gill and Vanden Berg (1967) conducted extensive studies of soil dynamics and tillage and have published a text including representative draft and power requirements for certain field tasks. Similar information is included in machinery management texts by Hunt (1977) and Barger et al. (1967). The American Society of Agricultural Engineers Yearbook (ASAE, 1980) also specifies vehicle requirement ranges for performing farm field tasks.

Task requirements are expressed as ranges rather than as average values because variations in soil type, farming practices, and implement designs result in a variety of draft, power, and energy requirements. Although the ranges indicated in the sources mentioned are not identical, there is good general agreement among the sources concerning draft and power requirements for the field tasks listed. For instance, Kepner (1978) specifies the draft range for field cultivating five inches deep as 200 to 600 pounds per foot of implement width, while ASAE (1980) lists the draft for field cultivating as 150 to 650 pounds per foot of implement width.

Vehicle requirements data in these texts were determined by numerous researchers using generally similar techniques. Draft forces were measured for various implements by using drawbar dynamometers, usually hydraulic or strain gage type (Clyde, 1937 and Taylor, 1967). Speed was normally determined by timing a measured or automatically recorded distance, or with a tachometer generator driven from a ground wheel (Bowers, 1970).

Livestock production and general utility task requirements generally are not as well defined as are field task requirements. This is partly because there is more variation in farming practices, conditions, and equipment for these types of tasks among farms. For instance, farm loader requirements may vary from less than 20 hp on one farm to nearly 100 hp on another. The Farm and Industrial Equipment Red Book (Implement and Tractor, 1977) notes power requirements for augers, loaders, feeder wagons, feed grinders, fertilizer spreaders, hay grinders, and other farm equipment used for livestock production and general utility tasks. All of these implements are produced in a variety of sizes and the power required to operate the equipment also varies with farming practices. Farm size, number of livestock maintained, and farmer preference affect the choice of implement size for each farm operation.

Annual time available to perform each farm task depends on the agricultural product and climatic conditions. The South Dakota Crop and Livestock Reporting Service (USDA, 1970) publishes information based on thirty year averages which allows computation of time available to perform each of the field tasks without reducing crop yields. Lytle (1980) provided additional climatological data which corroborated the USDA data, and which could be used to determine the time available for each task in any specific year in recent history.

Less information is available for specifying vehicle noise level, weight range, safety, physical size, and maneuverability requirements for performing specific farm tasks. The Nebraska Tractor Test Facilities have recorded the above information for each tractor tested since 1970. Nebraska Tractor Tests are accepted nationally as the most authoritative source of information on tractor performance capabilities.

Acceptable maintenance time is that required to prevent a significant portion of equipment breakdowns that would result in loss of field time. The probability of breakdown is inversely related to machine reliability, which is the statistical probability that a machine will function satisfactorily under specified conditions during a given period of time (Barger et al., 1967). Hunt (1971) determined that the manner in which equipment was maintained was an important factor in determining machine reliability. A general guide for recommended tractor maintenance was suggested by Bowers (1975).

The previously listed literature does not, by itself, provide a comprehensive definition of vehicle requirements for farm tasks in a specific area, such as eastern South Dakota, because of variations in climate, soil types, and farming practices across the nation.

Electric Vehicle Capabilities

There has been little research on designing electric vehicles for agriculture. However, electric vehicle technology is already well established for some applications. Private industry and the Department of Energy are supporting considerable electric vehicle research. Electric fork lifts, garden tractors, and industrial tow tractors are common in the United States, as are electric trains, streetcars, and delivery vans in other parts of the world.

The Department of Energy (DOE, 1979a) is studying electric vehicle components, primarily for passenger vehicle production, but much of the technology could be adapted for electric agricultural vehicles. Developmental activity is not focused just on the improvement of individual components, it also stresses the interactions among components. Projects on motor controllers seek to achieve high efficiency in the controller itself and also to match the controller to the electric motor and battery characteristics. Department of Energy (DOE, 1979a) goals for some of the component research are as follows:

1. Motors: lower cost and weight, smaller size

2. Controllers: lower cost, better power handling capability and greater efficiency

3. Transmissions: lower weight, continuously variable, multi-ratio

4. Vehicle Mass: lower weight, lower material costs and better fabrication concepts

5. Batteries: higher energy densities, lower cost, longer cycle life

6. Auxiliary devices: better heaters, air conditioners, chargers, state-of-charge indicators, and protection devices.

The Department of Energy's assessment of state-of-the-art electric vehicle component efficiencies includes an 81 per cent charger efficiency, a 48 per cent battery turn-around (includes charge and discharge) efficiency, a 90 per cent motor efficiency, and a 90 per cent controller efficiency (DOE, 1980). Present day lead-acid batteries have an energy density of approximately 18 watt-hours per pound based on a one hour discharge time. The effective energy density may be increased from 25 to 50 per cent by increasing the discharge period to 4 to 15 hours (Bishara, 1981).

The Department of Energy (DOE, 1980) predicts the use of nickel-iron and/or nickel-zinc batteries for electric vehicles by 1985. These batteries would have energy densities ranging from 32 to 36 watt-hours per pound. Also predicted are an improvement in charger efficiency from 81 to 90 per cent, an increase in battery turn-around efficiency from 48 to 68 per cent and an increase in both motor and controller efficiencies from 90 to 95 per cent. The effect of these predicted improvements would be an increase from a 32 per cent conversion efficiency to a 55 per cent conversion efficiency between electric power supply and motor output, a 72 per cent increase.

Electric vehicles, other than passenger cars, currently produced in the United States include garden tractors, fork lifts, and industrial tow tractors. Wheelhorse (Greenwalt, 1981) manufactures two models of electric garden tractors, one in the 8 to 10 hp class and one in the 12 to 14 hp class. These tractors operate on standard lead-acid batteries for two to six hours depending on the model and the power-take-off attachments in use. The batteries are expected to last five years and cost about the same as overhauling a conventional engine. Operating costs are estimated to be 50 to 75 per cent lower than those of a gasoline powered garden tractor. Other reported advantages include: quieter operation; no toxic fumes, smoke or odor; less vibration; easier starting; and less maintenance.

Hyster (Kelleher, 1980) produces fork lifts and industrial tow tractors of both conventional and electric design. The electric models are preferred for indoor use because of quiet and pollution-free operation. At present the electric models have purchase prices that exceed those of comparable conventional models by the cost of the battery set, but the electric vehicles are expected to have lower operating and maintenance costs. Hyster also has manufactured an electric, industrial tow tractor capable of starting and moving a 50,000 pound rolling load. With minor modifications this vehicle could perform a variety of agricultural tasks.

S and S Engineering (Bishara, 1981) currently markets low profile electric vehicles used by miners to load coal into conveyor systems. Some of these vehicles operate for an eight-hour shift on one battery charge. S and S Engineering reports lower operating and maintenance costs for electric vehicles than for conventional vehicles, but the electrics have higher purchase prices.

Higher initial costs for electric vehicles arise principally from production scale economics because electric vehicles are not produced in as large a quantity as are conventional vehicles. Increased production scale and anticipated technological advances in electric vehicle components and manufacturing could reduce the initial cost. The cost of lead-acid batteries per unit energy stored is projected to decrease by 60 per cent from 1980 to 1984 (Electric Vehicle Council, 1980).

Battery performance is also predicted to improve greatly in the near future. The Department of Energy (DOE, 1979b) foresees electric vehicle batteries with turn-around energy efficiencies near 72 per cent, up from today's 50 per cent turn-around efficiency. Nickel-zinc batteries may be available soon with energy densities of 36 watt-hours per pound, double that of present-day lead-acid electric vehicle batteries (Bhate et al., 1980). The turn-around energy efficiency for the nickel-zinc battery is expected to be about 70 per cent. General Research Corporation predicts battery energy densities of 27 watt-hours per pound for nickel-iron batteries, 41 watt-hours per pound for nickel-zinc batteries, and up to 55 watt-hours per pound for several exotic battery types (DOE, 1980). Klunder and Katz (1979) project energy densities of 23, 27, and 32 watt-hours per pound for lead-acid, nickel-iron, and nickel-zinc batteries, respectively, in 1986. In addition, battery life is expected to increase from 250 cycles to 1200 cycles for the 1986 nickel-iron batteries. Beyond this decade, sodium-sulfur batteries may have energy densities in excess of 64 watt-hours per pound (Klunder and Katz, 1979). Argonne National Laboratory researchers predict the following energy densities for batteries in 1984: lead-acid 25 watt-hours per pound, nickel-iron 32 watt-hours per pound, and nickel-zinc 39 watt-hours per pound (Yao et al., 1980). Scientists at Argonne National Laboratory project nickel-iron batteries will have useful lives of about 2000 charge-discharge cycles. Eagle-Picher has tested a nickel-iron battery with a turnaround energy efficiency of 67 per cent (Yao et al., 1980). Electric vehicle performance predictions by researchers at the Jet Propulsion Laboratory indicate that, if range is strictly the performance objective, the nickel-iron battery is the prime candidate of the state-of-the-art batteries, and that, if the constraints of technology readiness and cycle life are ignored, the best overall battery of those studied would be the nickel-zinc battery (Schmidt and Graf, 1980).

Assessing Feasibility

Even without the projected improvements, electric vehicles can compete favorably with conventional vehicles in the areas of operating and maintenance costs. A series of comparisons between electric and conventional vehicles in England, where electric vehicles have been used to deliver milk for the past forty years, revealed that energy costs for electric vehicles were from 10 to 75 per cent less than those for conventional vehicles with the average energy cost savings greater than 50 per cent. The maintenance costs for electric vehicles in England were found to average more than one-third less than those for internal combustion engine vehicles (Harrow et al., 1979). Similar operating and maintenance cost savings were documented for electric vehicles under study in other European countries and Japan (Harrow et al., 1979). The United States Postal Service conducted an extensive test of both electric and conventional mail delivery trucks and noted that operating costs per mile were 54 per cent less for the electric vehicles (Lead Industries Association, 1974).

Matching electric vehicles to specific tasks and then comparing the electric vehicles with conventional farm tractors is not simply a matter of selecting equal sized motors. Two factors must be considered when making such comparisons. The first is the difference in motor performance characteristics, which allows an electric vehicle to be temporarily overloaded without stalling. If a conventional vehicle were replaced by an electric vehicle of the same power rating, the electric vehicle would have excess power and an unattractively high purchase price. The second is the difference in on-vehicle energy storage feasibility, which economically penalizes excess battery capacity. This is due to the relatively low energy density and high cost of currently available batteries.

There are also differences between the methods of rating power for conventional engines and electric motors.

Internal combustion engines are rated at maximum power; any attempt to produce more power results in a decrease in power output. Electric motors are rated at continuous duty power, and may produce up to twice that much power for short periods of overload (DOE, 1979b). If properly matched to task requirements, electric vehicles can have lower operating and maintenance costs and can compete economically in terms of purchase costs.

For example, the S and S Corporation determined that electric vehicles with power ratings equal to those of existing conventional tow tractors in use at United States' airports were not feasible for replacing the conventional vehicles. Research was conducted to determine the specific task requirements. Much of the peak power demand resulted from breakaway draft required to start heavy loads rolling. The peak loads were found to be of short duration and thus suited to electric vehicles with lower power ratings (Bishara, 1981). The resulting electric vehicle design was economically and technically competitive with the conventional vehicles.

Once the replacement electric vehicles have been properly sized, economic analyses must be conducted to determine electric vehicle feasibility. Operating costs are of primary importance and must be projected for the near future for both electric and petroleum energy.

Calkins and Black (1980) developed a set of energy cost inflation scenarios which predicts energy costs in 1990 (Table 1). The first column is the economists' estimate of the most likely percentage price rise, expressed in real terms, from 1980 to 1990. The next two columns indicate the smallest and largest percentage energy cost increases that could be expected. The last two columns are the electricity optimistic and electricity pessimistic energy cost inflation scenarios. The electricity optimistic scenario has the price of electricity increasing at its lowest expected rate while the prices of petroleum products increase at the most likely rates. The electricity pessimistic scenario has petroleum products increasing in price by the lowest expected rates and the price of electricity increasing at its most likely rate (Table 1).

TABLE 1

Estimated Percentage Price Increases in Real Terms Over the Period 1980-1990
Under Five Energy Scenarios (Calkins and Black, 1980)

	SCENARIO				
FUEL OR INPUT	Most Likely	Optimistic[1]	Pessimistic[2]	Electricity[3] Optimistic	Electricity[4] Pessimistic
Diesel	63	34	159	63	34
Gasoline	63	34	159	63	34
Oil & Lubricants	63	34	159	63	34
L. P. Gas	97	51	270	97	51
Natural Gas	97	51	270	97	51
Electricity	34	0	63	0	34

1. All fuels and inputs expected to increase at lowest likely rate.

2. All fuels and inputs expected to increase at highest likely rate.

3. Electricity increases at lowest expected rate while other fuels and inputs increase at most likely rate.

4. Petroleum based inputs and fuels increase at lowest expected rate while electricity increases at most likely rate.

PROCEDURE

The objective of this research was to determine the feasibility of electric vehicles for agricultural uses in eastern South Dakota. To accomplish this objective, the following procedural steps were established:

1. Determine task requirements for vehicles as functions of task type, farm size, and type of operation for typical eastern South Dakota farms.

2. Establish performance capabilities for electric vehicles ranging in size from 15 to 40 hp based on current technology, and project capabilities by 1990 for electric vehicles ranging from 25 to 60 hp.

3. Determine the technical feasibility of electric vehicles for performing agricultural tasks in eastern South Dakota by comparing task requirements with electric vehicle capabilities.

4. Assess the economic feasibility of electric vehicles for agriculture in eastern South Dakota by comparing initial and operating costs between electric vehicles and conventional farm tractors.

Data Collection

Initially, twenty farm operators in the Brookings, South Dakota, area agreed to participate in the study and to help with data collection. Five of these later withdrew from the program and two more were added to make up the seventeen farm operators who cooperated in the completed study. Since selection was based on willingness to cooperate, it is unlikely that this is an unbiased sample.

Data were obtained by two means from these farm operators. First, daily fuel use records were maintained by the farmers. Second, each farmer was personally interviewed several times to obtain information regarding crop yields, field and utility tasks performed, field sizes, and any atypical circumstances affecting the data.

Each of the farm operators was asked to keep records of farm vehicle fuel usage, usage times, date of use, purpose of use, and acreage covered, daily, for two growing seasons. These data were recorded on forms provided to the farm operators in booklets (Figure 1). These farmer-maintained records were intended to provide a means of quantifying the total energy use, which when co-evaluated with actual performance tests of each farmer's tractors and the farmer interview information would define vehicle performance task requirements.

Each of the seventeen farm operators was personally interviewed several times to assess data collection progress and to collect information pertinent to determining vehicle performance task requirements. A map, developed from standard township maps, was compiled for each of the farmer's fields in the event that soil type would be a

DATE	FIELD LOCATION	FIELD EQUIPMENT USED	HOURS IN FIELD	GALLONS FUEL
6-14	Darrel's alfalfa across road	Chopper	8.5	45
6-21	Greg's corn	8-row cultivator	10	32
6-22	Corn across road	8-row cultivator	12	38
6-23	Shaw's alfalfa	Chopper	5	36
6-25	Peterson's beans	4-row cultivator	16	32
6-26	Corn North 1/4	8-row cultivator	12	46
6-28	George's beans	8-row cultivator	8.5	28

SDSU DEPARTMENT OF AGRICULTURAL ENGINEERING

Figure 1. Fuel use record form, with sample data

factor. For each field the following information was gathered: crop type and yield, fertilizer type and application rate, and chemical type and application rate. Fuel record information was discussed to determine which daily entries pertained to each field. A complete list of all tractor operations performed in each field was compiled (Figure 2). During the interview each farmer was asked to describe each of the different tasks performed in crop or livestock production for that farm operation. The description included: which tractor was used, an estimate of the percentage of that tractor's available power that was utilized in performing the task, ground speed for the tractor and implement, implement size, operating duration (hours per day) for performing the task and tractor maintenance time, min/day, associated with performing that task.

In order to quantify the vehicle performance requirements for each farm, it was necessary to determine the performance capabilities of the tractors already in use on that farm. For instance if a farmer reported that disking required 90 to 100 per cent of the available power of brand X, model Y tractor, and that particular tractor was in need of performance-improving maintenance, the accuracy of the results would suffer unless the capability of that particular tractor was adjusted accordingly. To accomplish this

FIELD NUMBER	ACRES	CROP	FERTILIZER	CHEMICALS	FIELD NAME IN DATA BOOK	FIELD OPERATIONS DONE	YIELD
1	125	Corn	100 lbs 7-21-7 80 lbs NH_3	Eradicane Dyfonate	Greg's East side	Chop stalks Disk Vibra-shank Disk-plant Anhydrous cultivate	90 bu/ac
2	70	Oats	100 lbs 30-20-10	2-4-D	Greg's oats	Disk Disk Drill Spray Chisel-plow	95 bu/ac
3	30	Flax	None	2-4-D	Across road	Disk Vibra-shank Drill Spray	22 bu/ac
4	70	Corn	100 lbs 7-21-7 80 lbs NH_3	Lasso Dyfonate	George's corn	Vibra-shank Disk Disk-plant Anhydrous cultivate	93 bu/ac

Figure 2. Field data form, with sample information

dynamometer and fuel consumption tests were performed on two, and in some cases three, of each farmer's tractors.

Additionally the following information about each of the farmer's tractors was requested: fuel type, tractor noise level at the operator's position as rated by the farmer, number and sizes of tractor tires, and the location and weight of any added ballast.

Task Requirements

Vehicle requirements to perform agricultural tasks were quantified for each individual task identified on the seventeen eastern South Dakota farms which formed the basis for this study. To facilitate data collection and analysis, farm tasks were grouped into the general categories of row crop, small grain, hay, and livestock production plus utility, which included the general farmstead tasks not attributable to any specific production category. Within each general category, specific tasks were identified (e.g. plowing, cultivating, windrowing) according to the practices on each individual farm operation. Fourteen vehicle performance parameters were selected which, when quantified for an individual task and compared with a vehicle's capabilities, indicated whether the vehicle was suitable for performing that farm task. The fourteen vehicle performance parameters are as follows:

1. Productive capacity: For field tasks this is specified in acres per hour based on the implement size and the ground speed. This figure implies 100 per cent field efficiency which is unrealistic, but which is valid for making comparisons when all such entries are computed in the same manner.

2. Power range: This is the farmer's estimate of the percentage of available power used, by the particular tractor to perform the task. In several instances it seemed apparent that the farmer's estimate of power used was in error, or the farmer declined to make an estimate. For these cases, an estimate based on information obtained from the literature, Kepner (1978) and ASAE (1980), was added and documented as such.

3. Speed range: Speed for each task was indicated by the farmers, and since most tractors were equipped with speedometers, these estimates were deemed reliable.

4. Draft, torque, or lift: These values were calculated from the power and speed parameters.

5. Operating duration: This is the number of hours per day that the farmer spends performing the given task, and was obtained from farmer interviews and from examination of fuel use records.

6. Annual operating time: This quantity, in hours, was calculated from the field charts (Figure 2) and the productive capacity. For instance, if from the field charts it was determined that a total of 600 acres were disked, and if the productive capacity for disking on that farm was six acres per hour; then the annual operating time would be 100 hours.

7. Noise level: Farmers rated each tractor used for noise level at the operator's position, using a scale of one to ten, where one was like a sewing machine and ten hurt the ears.

8. Weight range: This value, expressed in pounds per square inch, is the pressure the tractor exerts on the soil at the rear wheels and was calculated by dividing the tractor's total weight including ballast by the rear tire bearing area and multiplying by 0.8 since approximately 80 per cent of the tractor's weight is carried by the rear wheels when the tractor is under load. (Barger et al., 1967).

9. Maintenance time: This is the average time, in minutes per day, attributable to each specific task that the farmer spends for preventive maintenance and checks on the tractor used to perform that task. Maintenance time values were obtained from the farmer interviews.

10. Physical size: Physical size parameters are the wheelbase and treadwidth range, in inches, of the tractor

the farmer uses to perform the task.

11. Maneuverability: Maneuverability is the turning radius, in inches, required for a turn without brake application for the particular tractor model involved. These values were obtained from Nebraska Tractor Test data for the tractor model used by each farmer for each task and may not necessarily represent the maximum acceptable turning radii.

12. Annual time available to perform task: This indicates the time, in hours, that is available to perform a given task based on climatic conditions and crop development, as reported by Durland (1980).

13. Pollution problems: This performance parameter, while important, would be difficult to quantify; and since electric vehicles produce virtually no emissions, there was no attempt to establish a requirement in this area.

14. Safety requirements: Safety features of currently produced late model tractors were assumed acceptable for meeting the safety requirements of agricultural tasks.

Placing the vehicle performance parameters on the vertical axis and the tasks, grouped under the general task categories on the horizontal axis, a matrix was formed which served as the principal data storage and analysis tool (Figure 3). The completed matrix for a given farm often involved four tractors and all five task categories, with nearly a thousand entries.

Electric Vehicle Capabilities

A decision was made to assess electric vehicle capabilities in 1980 and to project capabilities by 1990 for use in analyzing the feasibility of electric vehicles for agricultural purposes. This decision was to accomodate the directives of the Department of Energy (Christianson, 1980), which was partially funding this study.

Preliminary analysis of electric vehicle advantages and disadvantages indicated that electric vehicles would be most likely feasible in the lower size range. Through cooperation with the Department of Energy (Christianson, 1980), hypothetical vehicle sizes of 15, 25, and 40 hp were selected for 1980 and 25, 40, and 60 hp for 1990. Larger sizes were not chosen because preliminary analysis of weights of high-powered electric vehicles indicated that such vehicles would be excessively heavy, causing unacceptable soil compaction if used for many field operations. Additionally many farmers buy large tractors to have a power reserve in the event that timeliness is an important factor due to climatic conditions; and analysis of the optimal large tractor size would involve a timeliness study beyond the scope of this research.

Electric vehicle capabilities were determined

TYPE, SIZE OF VEHICLE	VEHICLE PERFORMANCE CRITERIA DATA	VEHICLE PERFORMANCE AND TASK REQUIREMENT DESCRIPTION OF PARAMETERS / TASKS	ROW CROP PRODUCTION		
			FIELD CULTIVATE 15'	STALK CHOP 4-38"	HAUL SILAGE 12 TON
JOHN DEERE 4020		PRODUCTIVE CAPACITY	7.7 A/Hr	6.1 A/hr	—
	94.9 hp @ 1161 pto rpm	POWER RANGE	61.2 hp	32.6 hp	49-57 hp
	1.3 to 17.6 mph	SPEED RANGE	4-4.5 mph	4 mph	5-15 mph
	11,250 lbs @ 2.6 mph 795ft-lbs	DRAFT, TORQUE OR LIFT RANGE	5390 lbs	132-465 lbs 292 ft-lb pto	1224-1426 lbs
	2.7 to 6.0 gph	OPERATING DURATION REQUIRED	10 hrs	6 hrs	3-4 hrs
		ANNUAL OPERATING TIME REQUIRED	26 hr/yr	8 hr/yr	4 hr/yr
		ACCEPTABLE NOISE LEVEL	7	7	7
	9125 lbs	WEIGHT RANGE REQUIRED	3.7 psi	7.5 psi	7.5 psi
		ACCEPTABLE MAINTENANCE TIME REQUIRED	1/2 hr/day	1/2 hr/day	1/2 hr/day
		TIME AVAILABLE	176-219 hr/yr	≫8 hr/yr	96-160 hr/yr
	Wheelbase 100" tread width 60"-91"	PHYSICAL SIZE	✓	✓	✓
	150"	TURNING RADIUS	✓	✓	✓

Figure 3. Sample task requirements matrix columns, with data

through study of electric vehicles currently produced in the United States and in foreign countries, and through analyses of electric vehicle component capabilities. Specific electric vehicles, which are currently produced and operated on a commercial scale in several European countries and Japan, were studied. These included automobiles, vans, and delivery trucks of various sizes. Commercially produced and marketed United States electric vehicles analyzed included electric fork lifts, garden tractors, and industrial tow tractors.

Batteries, motors, controllers, transmissions, and other components, which could be adapted for agricultural use, have been researched by the Department of Energy and private industry. Current component capabilities have been assessed and future capabilities projected by the Department of Energy (Electric Vehicle Council, 1980).

Technical and Economic Analyses

The overall feasibility of electric vehicles for agriculture in eastern South Dakota depends on two major criteria. First, technical feasibility, which implies a comparison between the task requirements and the electric vehicle capabilities to determine which tasks specific sized vehicles could perform. Second, economic feasibility, which involves comparing the initial, operating, and maintenance costs between conventional and electric vehicles.

Technical Feasibility

Prior to detailed quantitative comparisons between task requirement parameters and electric vehicle capabilities, the task requirements parameter list was reduced by removing those parameters which electric vehicles could satisfy in a manner comparable or superior to conventional vehicles with no major design difficulties. These included noise level, pollution problems, physical size, maneuverability, safety, and maintenance time requirements. Further study of the vehicle performance parameters list indicated that electric vehicles could satisfy the requirements of the whole list, if the following three basic conditions were met: (1) sufficient power to perform the specific task, (2) sufficient operating duration capability to perform the task for a reasonable length of time between battery charges or changes, and (3) weight low enough to avoid excessive soil compaction and energy consumption.

Once the matrices, discussed previously, had been completed for each farm operation, entries were studied and it was found that the tasks could be grouped according to a second scheme of heavy, medium, and light field work, livestock production, and general utility tasks. Analysis of the data revealed that minimal information would be lost by such a grouping, and that a grouping was needed to reduce the volume of raw data to a more manageable level. Tasks were grouped in this manner to delineate important differences among the tasks which reflected the capability of a specific sized vehicle to perform the tasks.

Vehicle requirements for heavy, medium, and light field tasks, livestock production, and utility functions were further grouped according to farm size. According to the latest agricultural census 26 per cent of the eastern South Dakota farms are from one to 219 acres, 55 per cent are from 220 to 1000 acres, and 19 per cent are larger than 1000 acres (U. S. Census, 1974). For purposes of this research, farms under 200 acres were termed small, those from 200 to 1000 acres medium, and those over 1000 acres large.

Of the seventeen farms represented in this study, there were no small farms, twelve medium farms, and five large farms. The ratio of medium to large farms in this study was similar to that noted by the agricultural census data for eastern South Dakota. Fifteen of the seventeen farms included livestock operations; of the two that didn't, one was medium and one was large. The average size of the medium farms was 615 acres; the large farms averaged 1,650 acres. Fifteen of the seventeen farm operations were thus categorized as (1) medium sized with livestock, or (2) large sized with livestock. Since there was only one farm in each size range without livestock, no conclusions were drawn concerning non-livestock farms, but the corresponding data were included in the overall averages.

To determine the technical feasibility of electric vehicles, daily energy requirements for a given task group and the energy capabilities of the four proposed electric vehicles sizes were compared. Vehicle energy requirements in horsepower-hours were expressed in terms of required power and operating duration.

These comparisons were made under two different assumptions, which were designed to produce a range of electric vehicle feasibilities that bracketed the true feasibility. The first assumption was that the farmer would not use an electric vehicle unless the tasks could be performed in the same manner and at the same times as currently performed by conventional tractors. In the second case it was assumed that the farmer could readjust work schedules to make maximum use of the electric vehicle on an annual basis. In each case the percentage of the energy requirement for a task group that could be met by each of the four proposed electric vehicle sizes was calculated.

Economic Feasibility

Once the technical feasibility of electric vehicles had been studied, efforts were directed toward assessing the economic feasibility. The initial cost of an electric vehicle is expected to exceed that of a conventional vehicle of similar capacity by the price of the battery set (Buck, 1980) and (Kelleher, 1980).

Present-day lead-acid batteries cost $100 per kilowatt-hour (kwh). Nickel-iron batteries are expected to cost $70 per kwh by 1984 (Electric Vehicle Council, 1980). Since battery capacity must increase with electric vehicle power rating, the larger electric vehicles would have a greater initial cost disadvantage, compared to conventional farm tractors, than would the smaller vehicles. However the larger electric vehicles would generate greater operating and maintenance cost savings. Cost of the battery set was amortized over the expected life of the battery to distribute the initial cost of the battery set on an hourly basis.

To make operating cost comparisons for vehicles performing agricultural tasks, a specific fuel consumption of 14.6 horsepower-hours per gallon of diesel fuel was used for conventional vehicles. This figure represents an average for the twelve most fuel efficient tractors of 40 hp or less tested at the Nebraska Tractor Test facility (Ewing, 1980). Current diesel fuel prices were obtained on May 20, 1981, from six Brookings, South Dakota, area farm delivery fuel dealers: Buskrud Oil Co., Cenex Fuel Co., Farmers Union Co-op Oil Co., Hillestad Oil Co., Jackrabbit Oil & Tire Co., and Standard Oil Co. Electric vehicle operating efficiencies included conversion losses for the motor, controller, battery, and charger. For 1980, motor and controller efficiencies were 90 per cent, battery turn-around efficiency was 50 per cent, and charger efficiency was 81 per cent (DOE, 1979a). Efficiencies for 1990 were based on Department of Energy projections as follows: motor and controller efficiencies of 95 per cent, a battery turn-around efficiency of 67 per cent, and a charger efficiency of 90 per cent (DOE, 1979a). Electric energy costs on farms in eastern South Dakota were obtained on May 20, 1981, from six eastern South Dakota rural electric cooperatives: Codington-Clark Electric at Watertown, H-D Electric at Clear Lake, Inter-County Electric at Mitchell, Sioux Valley Electric at Colman, Tri-County Electric at Plankington, and Whetstone Valley Electric at Milbank.

To project the operating cost comparisons to 1990, energy cost inflation scenarios developed for the study by economists at Michigan State University in cooperation with the Department of Energy were used (Table 1). The electric pessimistic scenario has diesel fuel increasing in real cost (adjusted for inflation) by 34 per cent over the decade, and has electricity increasing in cost by 34 per cent. The electric optimistic scenario predicts that in ten years diesel fuel will cost 63 per cent more and electricity will cost the same in real terms as it does today. These two scenarios establish a range within which the most likely energy cost inflation scenario lies, which is a real cost increase of 63 per cent for diesel and 34 per cent for electricity. The wide range results from the international uncertainty concerning energy supplies.

Although lower maintenance costs and useful vehicle service life appear to favor electric vehicles (Harrow et al., 1979), those factors were not included in this economic analysis. Operating costs of conventional and electric vehicles were compared for 1980 and 1990 using each of the three energy cost inflation scenarios. The economic feasibility of electric vehicles was determined by ascertaining whether or not the operating cost savings would equal or exceed the extra initial cost, within the normal wear-out life of a conventional tractor, or the life of the battery set, whichever is shorter.

RESULTS AND DISCUSSION

Three basic steps were performed to accomplish the objective of determining the feasibility of electric vehicles for agricultural uses in eastern South Dakota. First, the vehicle performance task requirements were determined. Second, capabilities of electric vehicles were researched and projected for the present and for 1990. Third, task requirements and electric vehicle capabilities were compared to determine technical feasibility, and costs were compared to determine economic feasibility.

Task Requirements

The vehicle performance task requirements in agriculture were determined by quantifying the fourteen vehicle performance parameters, identified in the Procedure, for each specific farm task. This was accomplished by (1) reviewing existing literature and by (2) analyzing vehicle performance requirements on seventeen Brookings, South Dakota, area farms.

Particularly valuable references were Kepner's (1978) Principles of Farm Machinery and the Agricultural Engineers' Yearbook published by ASAE (1980).

Literature Values

1. Power range: The power required to perform heavy, medium, and light field work, livestock production, and general utility tasks on small, medium and large farms

ranges from 10 to 175 hp, Kepner (1978) and ASAE (1980), (Tables 2, 3, and 4).

2. Speed range: Values for speed requirements range from zero to fifteen miles per hour, Kepner (1978), Barger (1967), and ASAE (1980), (Tables 2, 3, and 4).

3. Draft, torque, or lift: These requirements, along with the speed values, determine the power requirements. The values were obtained from Kepner (1978) and ASAE (1980) for each task (Tables 2, 3, and 4).

4. Operating duration: The literature did not specifically give operating durations required because these vary with the amount of work to be done. The range of one to twelve hours would be acceptable in most cases (Tables 2, 3, and 4).

5. Annual operating time: This was based on the assumed farm size, recommended implement sizes for the given farm size, the speeds determined earlier, and tasks generally required to produce the average crop and livestock mix reported in the literature, Hunt (1977). The values for annual operating time, as well as the values for the first four parameters listed, were subdivided to provide a range of requirements for each task group and farm size mentioned (Tables 2, 3, and 4).

TABLE 2

Principal vehicle performance requirements for tasks typical of 1-199 acre farms in Eastern South Dakota, as determined from review of literature.

	Heavy Tillage[1]	Medium Field Work[2]	Light Field Work[3]	Livestock Production[4]	General Utility[5]
Power Range (Drawbar Horsepower)	60-70	40-50	20-30	25-35	10-20
Speed Range (mph)	4-6	3-15	2-15	1-15	1-6
Draft (lbs)	3750-6550	980-4325	70-2970	700-5000	100-1500
Torque(ft-lbs at PTO)		170-455	136-292	136-435	146
Lift (lbs)			1500	1000-2500	1000
Operating Duration Time (hrs)	8-10	5-10	2-10	1-6	3-7
Energy (hp-hrs)	585	337.5	150	105	75
Annual Operating Time (hrs)	98	174	195	300-350	45
Energy (hp-hrs)	6370	7830	4875	9750	675

1. Tasks include moldboard plowing, chisel plowing and field cultivating.
2. Tasks include disking, fertilizing, silage chopping, combining, baling and hauling heavy loads.
3. Tasks include seeding, windrowing, light hauling, mowing, raking, dragging, spraying, stalk chopping, planting, row cultivating and corn picking.
4. Tasks include grinding, loader work, sewage handling, livestock moving and snow moving.
5. Tasks include operating augers and elevators, digging post holes, moving machinery and hauling rock.

TABLE 3

Principal vehicle performance requirements for performing tasks typical of 200-1000 acre farms in Eastern South Dakota, as determined from review of literature.

	Heavy Tillage[1]	Medium Field Work[2]	Light Field Work[3]	Livestock Production[4]	General Utility[5]
Power Range (Drawbar Horsepower)	100-110	55-65	20-30	30-40	10-20
Speed Range (mph)	3-6	3-15	3-15	1-15	1-6
Draft (lbs)	4140-10,525	820-7565	70-3495	1000-7500	100-1500
Torque(ft-lbs at PTO)		170-525	136-292	230-450	225
Lift (lbs)			1500	1000-2500	1500
Operating Duration Time (hrs)	8-12	5-10	4-11	2-8	3-8
Energy (hp-hrs)	1050	450	187	175	82.5
Annual Operating Time (hrs)	290	410	420	700-1000	50
Energy (hp-hrs)	30,450	24,600	10,500	29,750	750

1. Tasks include moldboard plowing, chisel plowing and field cultivating.
2. Tasks include disking, fertilizing, silage chopping, combining, baling and hauling heavy loads.
3. Tasks include seeding, windrowing, light hauling, mowing, raking, dragging, spraying, stalk chopping, planting, row cultivating and corn picking.
4. Tasks include grinding, loader work, sewage handling, livestock moving and snow moving.
5. Tasks include operating augers and elevators, digging post holes, moving machinery and hauling rock.

TABLE 4

Principal vehicle performance requirements for tasks typical of 1000 acres or more farms in Eastern South Dakota, as determined from review of literature.

	Heavy Tillage[1]	Medium Field Work[2]	Light Field Work[3]	Livestock Production[4]	General Utility[5]
Power Range (Drawbar Horsepower)	165-175	75-85	30-40	45-55	10-20
Speed Range (mph)	3-6	3-15	3-15	1-15	1-6
Draft (lbs)	6540-18,065	820-11,260	70-4670	700-10,000	100-1500
Torque(ft-lbs at PTO)		170-525	136-292	350-780	225
Lift (lbs)			1500	1000-2500	1500
Operating Duration					
Time (hrs)	8-12	5-12	4-12	2-8	3-8
Energy (hp-hrs)	1700	680	280	250	82.5
Annual Operating					
Time (hrs)	475	680	535	700-1000	70
Energy (hp-hrs)	80,750	54,400	18,725	42,500	1050

1. Tasks include moldboard plowing, chisel plowing and field cultivating.
2. Tasks include disking, fertilizing, silage chopping, combining, baling and hauling heavy loads.
3. Tasks include seeding, windrowing, light hauling, mowing, raking, dragging, spraying, stalk chopping, planting, row cultivating and corn picking.
4. Tasks include grinding, loader work, sewage handling, livestock moving and snow moving.
5. Tasks include operating augers and elevators, digging post holes, moving machinery and hauling rock.

6. Productive capacity: This is the product of implement size and speed and is given in units such as acres per hour.

7. Allowable noise level: Limits have been established at levels that will not cause hearing loss. Noise level may safely go as high as 115 dB A if exposure is limited to fifteen minutes per day. For an eight hour duration, 90 dB A is allowed (OSHA, 1978).

8. Pollution problems: This parameter would be difficult to quantify in meaningful terms. Problems with vehicle pollutants are particularly acute when the vehicle is operated inside farm buildings. In any case, the electric vehicle, being virtually pollution free, could easily satisfy any pollution standards.

9. Weight range: It was assumed that conventional tractors are already near the upper weight limit in terms of pounds of weight per square inch of tire bearing area since soil compaction may be a problem, in some cases, with conventional tractors. Therefore the range of weight per unit area values was determined to be that of vehicles just large enough to accomplish the specific task. Values range from 7.0 to 13.6 psi.

10. Safety requirements: Vehicle task requirements for safe operation include: uncluttered operator's position; shields, steps, and handholds; rear fenders; conveniently located controls; starter safety switch; adequate

lighting; protective non-skid surfaces on controls; and electrical systems standard safety precautions (ASAE, 1980).

11. Acceptable maintenance time: This was the time that could reasonably be spent performing maintenance and adjustments on the tractor without causing production losses. These timeliness figures were developed from information provided by the U.S. Crop and Livestock Reporting Service (Kepner, 1978). When the annual operating time for a task was low, the matrix entry for acceptable maintenance time indicated that there was no shortage of time to perform task-related maintenance on the tractor.

12. Physical size: The wheelbase and treadwidth range were given, in inches, for the average of those tractors in the power range required to perform the task on the given farm size.

13. Maneuverability: The turning radius, in inches, was noted for the average tractor described in (12) above.

14. Annual time available to perform task: These values were based on climatic information (Lytle, 1980) and the crop being produced (Durland, 1980), and were recorded as hours per year.

<u>Farm Research Values</u>

The second method of determining vehicle performance task requirements was to research farm tasks currently performed by farm operators in the Brookings, South Dakota, area to determine the method of task completion. A matrix containing vehicle performance criteria for all tasks was constructed for each tractor on each of seventeen farms (Figure 3). The list of performance parameters was slightly different from that given for the literature review method of determining task requirements. The list is as follows:

1. Productive capacity: This is the product of speed and implement size, given in units such as acres per hour. This is a function of the power range for the given task.

2. Power range: Actual farm data give task power requirements ranging from 5 to 140 hp. This compares with the 10 to 175 hp range from the literature review method. The discrepancy probably results from the difference in size of the large farms used in the two methods. For the first method, a large farm size of 3000 acres was assumed, while the average size of the five large Brookings, South Dakota, area farms studied was 1650 acres.

3. Speed range: Farm operators reported a range of speed requirements for tasks performed from zero to twenty miles per hour. This compares with a speed range of from zero to fifteen miles per hour from the first method.

4. Draft, torque, or lift: Draft, torque, or lift values are functions of the power range and speed, and thus agree closely with those of the first method for medium farms and are slightly smaller than the first method results

for large farms.

5. Operating duration required: Daily operating durations given by farm operators ranged from one to sixteen hours. This exceeded the one to twelve hour operating duration range from the literature review method, however operating durations in excess of twelve hours were reported by only two farm operators.

6. Annual operating time required: These values are functions of farm size and productive capacity. Analysis of farm operator data resulted in annual operating times ranging from 1 to 1004 hours depending on the task. This compares favorably with the annual operating time range of from 45 to 1000 hours from the literature review method of determining vehicle performance task requirements.

Tables 5 and 6 summarize the five important vehicle performance parameters: power range; speed range; draft, torque, or lift; operating duration required; and annual operating time required. These values were obtained from the farmer interviews and were tabulated by task groups in the same manner as were the results of the literature review method (Tables 3 and 4). Analysis of the two sets of vehicle performance requirements shows general agreement of the results from both methods of determining task requirements. The farm interview data for power range and speed range covered a wider range of values than did the literature review data, but the averages of each of the ranges

TABLE 5

Principal vehicle performance requirements for performing tasks determined from medium (200-1000 acres) farms near Brookings, South Dakota.

	Heavy Tillage[1]	Medium Field Work[2]	Light Field Work[3]	Livestock Production[4]	General Utility[5]
Power Range (Drawbar Horsepower)	66-125	18-116	5-79	10-115	9-25
Speed Range (mph)	2.5-6	0-20	0-17.6	0-18	0-15
Draft (lbs)	1500-10,375	450-9524	70-5156	80-16,000	500-3500
Torque(ft-lbs at PTO)	720-827	145-584	49-770	97-778	49-249
Lift (lbs)			1000-3000	1000-2500	2500
Operating Duration Time (hrs)	2-14	2-13	1-14	1/6-10	1-8
Energy(hp-hrs) (average)	916.1	471.0	234.7	138.0	67.8
Energy(hp-hrs) (range)	360-1392	69-1287.5	20-754	3.7-632.5	30-160
Annual Operating Time (hrs) (average)	106.8	149.5	199.4	622.1	73.6
Annual Operating Time (hrs) (range)	40-189	66.2-292	78.6-295.5	15-1172	5-244
Energy (hp-hrs) (average)	9528	10,448	7589	23,556	1078
Energy (hp-hrs) (range)	2387-21,803	3834-26,017	2064-12,178	555-49,777	75-3265

1. Tasks include moldboard plowing, chisel plowing and field cultivating.
2. Tasks include disking, fertilizing, silage chopping, combining, baling and hauling heavy loads.
3. Tasks include seeding, windrowing, light hauling, mowing, raking, dragging, spraying, stalk chopping, planting, row cultivating and corn picking.
4. Tasks include grinding, loader work, sewage handling, livestock moving and snow moving.
5. Tasks include operating augers and elevators, digging post holes, moving machinery and hauling rock.

TABLE 6

Principal vehicle performance requirements for performing tasks determined from large (over 1000 acres) farms near Brookings, South Dakota.

	Heavy Tillage[1]	Medium Field Work[2]	Light Field Work[3]	Livestock Production[4]	General Utility[5]
Power Range (Drawbar Horsepower)	15-135	35-140	12-93	6-137	8-25
Speed Range (mph)	3.5-9	2.5-18	0-18	0-18	0-15
Draft (lbs)	2409-11,593	350-8727	70-6054	213-20,000	240-3745
Torque(ft-lbs at PTO)	1206-1284	170-729	146-778	90-1381	97-243
Lift (lbs)			1000-1500	1000-3800	2000
Operating Duration Time (hrs)	2-15	1-16	2-16	1/2-12	1-8
Energy(hp-hrs) (average)	1007.9	850.3	316.6	381.9	53.8
Energy(hp-hrs) (range)	52.5-1600	49-1525	48-930	9-1350	30-160
Annual Operating Time (hrs) (average)	177.8	261.1	348.4	987.6	174.2
Annual Operating Time (hrs) (range)	107-297	147-575	158-744	50-2395	0-631
Energy(hp-hrs) (average)	20,282	25,366	12,944	58,519	1096
Energy(hp-hrs) (range)	13,224-29,144	8927-58,337	4256-26,761	4760-175,048	1135-1705

1. Tasks include moldboard plowing, chisel plowing and field cultivating.
2. Tasks include disking, fertilizing, silage chopping, combining, baling and hauling heavy loads.
3. Tasks include seeding, windrowing, light hauling, mowing, raking, dragging, spraying, stalk chopping, planting, row cultivating and corn picking.
4. Tasks include grinding, loader work, sewage handling, livestock moving, and snow moving.
5. Tasks include operating augers and elevators, digging post holes, moving machinery and hauling rock.

exhibited a mean difference of less than twenty per cent. Draft, torque, or lift values, as functions of power range, compared in a similar manner. Operating duration ranges were wider for farm interview data than for literature review data, but average values were nearly identical. Average daily energy requirements from both methods were nearly the same. Annual operating times and energy requirements from the farm interviews were less than those from the literature review method for the three field task groups. This is probably due to recent improvements in field task management practices. Annual operating times and energy requirements from both methods are similar for the livestock production and general utility task groups.

7. Noise level: These values are the subjective ratings on a scale of one to ten given by the farm operators for each tractor used. One implies a very quiet tractor at the operator's position and ten corresponds to a very loud tractor at the operator's position. Farmers' responses covered the whole range from one to ten.

8. Weight range required: The calculations to produce these values were based on the characteristics of existing tractors. The numbers recorded were weight per unit of tire bearing area, given in pounds per square inch. It was assumed that existing tractors are already in the upper portion of the allowable weight per unit area range.

9. Allowable maintenance time required: These values represent the average daily time spent for maintenance and adjustments on the tractor used to perform the task. Maintenance times varied from two to thirty minutes per day.

10. Time available: This parameter remains unchanged from the results of the literature review method, since it is primarily dependent upon climatic and crop factors.

11. Physical size: Wheelbase and treadwidth range are given in inches for the tractor used to perform the task.

12. Turning radius: This is given in inches and is the minimum for the tractor, without using brakes, that currently performs the task. Both physical size and turning radius of existing tractors are considered adequate by farm operators.

The foregoing list of twelve vehicle performance task requirements appears to include any necessary information to describe the parameters involved in performing a given task. The five most important parameters were quantified and summarized by task groups for the literature review method (Tables 3 and 4) and for the farm interview method (Tables 5 and 6).

Electric Vehicle Capabilities

Preliminary analysis of electric vehicle capabilities indicates that electric vehicles could equal or exceed performance capabilitites of conventional tractors in all areas except operating duration and weight range.

Electric vehicles have been used to deliver milk in England for over forty years. The United States Postal Service has a large number of electric vehicles in its fleet. Electric automobiles were in existence in the first decade of this century. Modern electric cars have highway cruising speeds and can travel distances of one hundred miles or more on a single charge. Battery powered fork lifts and tow trucks are widely used in industry and warehouses. Coal miners use low profile electric vehicles to load coal into conveyor systems.

Electric vehicles may be manufactured with a wide range of motor sizes. Most railroad locomotives are propelled by electric motors. In some areas electric trains are common for commuter transit systems. Large power shovels do open pit mining powered by electric motors. While these three types of vehicles are not battery powered, it is apparent that electric motors and associated control systems can handle far more power than is currently needed on South Dakota farms.

There are virtually no polluting emissions from electric vehicles. This feature could be especially important for operation inside farm buildings. At the same time electric vehicles would produce much less noise pollution than conventional tractors. For intermittent use tasks an electric vehicle would be switched off no matter how short the period of non-use, during which time it would be completely silent and pollution-free. Conventional tractors are usually left running during short idle periods. Although noise may not be a serious problem, many tractor engines emit excessive pollutants at low speeds because of a fuel-air mixture designed for efficient operation at rated engine speeds.

Electric vehicles are not as susceptible to fuel shortages as are petroleum powered tractors. Electricity is generated from a variety of energy sources including hydroelectric potential, nuclear fuel, coal, and solar radiation, as well as petroleum. The nature of agricultural production in the United States requires that many of the tasks must be performed within a very limited length of time. If developments in foreign countries resulted in a cutoff of imported oil to the United States at a critical time for agriculture, the resulting delay in performing certain tasks could be economically disastrous. Since most of the electricity in agricultural regions is produced from sources other than oil, electric vehicles would have a more stable energy supply. In addition, charging of the battery set or sets could be done late at night during off-peak electric power demand times. This would provide savings for the farm operator and the electric power supplier.

Electric vehicles require less maintenance than conventional gas or diesel powered vehicles. In a series of actual on-the-job comparisons between electric and petroleum powered vehicles in England, maintenance costs ranged from 32 to 42 per cent less for the electric vehicles (Harrow et al., 1979).

The study of fork lifts, tow trucks, automobiles, and delivery trucks indicates that electric vehicles can be made to meet the same physical size and turning radius limitations as conventional vehicles. It is reasonable to assume that electric tractors need not be any more cumbersome than conventional tractors.

Capabilities for electric vehicles at the present time appear adequate to meet all of the vehicle performance requirements except operating time or weight range. Either of these two parameters may be satisfied, but at the expense of the other. This is because the energy density of present day batteries is too low to allow batteries with sufficient energy content for all farm tasks without excessive vehicle weights. The lead-acid batteries available today have energy densities of 18 to 19 watt-hours per pound (Electric Vehicle Council, 1980). The proposed electric vehicle designs for 1981 indicate, for instance, that the battery required to operate a 25 hp electric tractor for four hours, using the efficiencies and depth of discharge listed in the design, would weigh 8500 pounds (Table 7). Extra weight is considered a disadvantage for field tasks because of soil compaction (Gill and Vanden Berg, 1967), but for certain livestock production and general utility tasks, the extra weight may be an advantage. Battery technology advancements are projected to include the availability of nickel-iron batteries with energy densities of 32 watt-hours per pound or more by 1990 (Electric Vehicle Council, 1980). Referring to the proposed electric vehicle designs, and using the efficiencies and depth of discharge therein, the battery required to operate a 25 hp electric tractor for four hours in 1990 would weigh only 4175 pounds or 51 per cent less than today's lead-acid battery (Table 8).

If the weight range maximums are considered to be those of conventional tractors, in terms of weight per unit bearing area, then electric vehicles could not meet this requirement unless additional bearing area was provided. Total tractor weight must also be considered as a factor in soil compaction.

When considering electric vehicle capabilities and studying the proposed designs for 1981 and 1990, it should be noted that batteries were sized for four hours of continuous operation at full rated power. If the task performed required less than full rated power or less than continuous operation, the effective energy density of the battery would increase and operating time would be extended. It

TABLE 7

Electric Vehicle Hypothetical Designs for 1981

A. 15 HP[1]

PTO:		540 rpm standard
Hydraulics:		Optional, 2000 psi, 6 gpm
Motor:		15 hp compound wound d.c., with speed and reversing control
Battery:		
	Type:	Lead-acid (19 wh/lb)
	Size:	97.3 kwh rated[2], 5100 lbs.
	Cost:	$9,730
	Life:	500 cycles
Transmission:		8-speed standard shift (4 gears plus high-low)[3]
Clutch:		Standard disk type[4]
Drive:		Two Wheel
Vehicle Weight:		7000 lbs.

B. 25 HP[1]

PTO:		540 rpm standard
Hydraulics:		Standard, 2000 psi, 6 gpm
Motor:		25 hp compound wound d.c., with speed and reversing control
Battery:		
	Type:	Lead-acid (19 wh/lb)
	Size:	162.1 kwh rated[2], 8500 lbs.
	Cost:	$16,210
	Life:	500 cycles
Transmission:		8 speed standard shift (4 gears plus high-low)[3]
Clutch:		Standard disk type[4]
Drive:		Two wheel
Vehicle weight:		10,500 lbs.

C. 40 HP[1]

PTO:		540 rpm standard
Hydraulics:		Standard, 2000 psi, 6 gpm
Motor:		40 hp compound wound d.c., with speed and reversing control
Battery:		
	Type:	Lead-acid (19 wh/lb)
	Size:	259.4 kwh rated[2], 13,600 lbs.
	Cost:	$25,940
	Life:	500 cycles

TABLE 7 (continued)

Transmission:	8 speed standard shift, (4 gears plus high-low)[3]
Clutch:	Standard disk type [4]
Drive:	Four wheel, 20" to 26" wheels depending on weight distribution and traction requirements, crab steering
Vehicle Weight:	17,800 lbs.

1. Vehicle components sized to deliver rated hp at the PTO for 4 continuous duty hours.

2. Rated capacity is calculated assuming 90% motor efficiency, 71% battery discharge efficiency, 80% depth of discharge, 90% controller efficiency and 4 hours of operation at rated hp.

3. No reverse gear is needed, the motor can be reversed.

4. Clutch serves primarily as an emergency disconnect and facilitates shifting while moving.

TABLE 8

Electric Vehicle Hypothetical Designs for 1990

A. 25 HP[1]		
PTO:		540 rpm standard
Hydraulics:		Standard, 2000 psi, 6 gpm
Motor:		25 hp, reversing, compound wound d.c., speed control optional
Battery:		
	Type:	Nickel-iron (32 wh/lb)
	Size:	133.0 kwh rated[2], 4175 lbs.
	Cost:	$9,310
	Life:	2000 cycles
Transmission[3]:		Continuously Variable Transmission, (CVT)
Clutch:		None needed
Drive:		Two wheel
Vehicle Weight:		7000 lbs.
B. 40 HP[1]		
PTO:		540 rpm standard
Hydraulics:		Standard, 2000 psi, 6 gpm
Motor:		40 hp, 3 phase synchronous with phase converter, reversing, no speed control required
Battery:		
	Type:	Nickel-iron (32 wh/lb)
	Size:	201.6 kwh rated[4], 6325 lbs.
	Cost:	$14,113
	Life:	2000 cycles
Transmission[3]:		CVT
Clutch:		None needed
Drive:		Four wheel with 20" to 26" wheels, crab steering
Vehicle Weight:		11,500 lbs.
C. 60 HP[1]		
PTO:		540 rpm standard
Hydraulics:		Standard, 2000 psi, 6 gpm
Motor:		60 hp, 3 phase synchronous with phase converter, reversing, no speed control required
Battery:		
	Type:	Nickel-iron (32 wh/lb)
	Size:	302.4 kwh rated[4], 9475 lbs.
	Cost:	$21,169
	Life:	2000 cycles

TABLE 8 (continued)

Transmission[3]:	CVT
Clutch:	None needed
Drive:	Four wheel with 24" to 30" wheels, articulated steering
Vehicle weight:	17,000 lbs.

1. Vehicle components sized to deliver rated hp at the PTO for 4 continuous duty hours.

2. Rated capacity is calculated assuming 90% motor efficiency, 82% battery discharge efficiency, 80% depth of discharge, 95% controller efficiency and 4 hours of operation at rated hp.

3. Ratios variable across entire speed range, direct drive, no reverse needed.

4. Rated capacity is calculated assuming 95% motor efficiency, 82% battery discharge efficiency, 80% depth of discharge, 95% controller efficiency and 4 hours of operation at rated hp.

should be noted that if the electric vehicles were designed such that the battery set could be easily removed and replaced, then one extra battery set would allow eight hours or more of operation each day.

Feasibility of Electric Vehicles

Electric vehicles can meet or exceed most task requirements for agriculture; therefore the assessment of technical and economic feasibility of electric vehicles in agriculture hinges on relatively few performance criteria.

Technical Feasibility

Technical feasibility of electric vehicles in agriculture is determined by the degree to which the task requirements can be met by electric vehicle capabilities. The most basic of the vehicle task requirements is the power range. Speed, draft, torque, lift, and productive capacity are all functions of the available power at the motor output. The second basic requirement is the operating time, considered both on a daily and an annual basis. The corresponding electric vehicle capability depends on the two basic parameters: power and operating duration. These two parameters may be combined into a single energy term, namely horsepower-hours. Comparison between task energy requirement and electric vehicle energy capability determines the feasibility of the electric vehicle to perform the task. This comparison, on both daily and annual bases, indicates the percentage of the required work the electric vehicle is capable of performing in the time under consideration.

The first two methods of comparing the task requirements with electric vehicle capabilities involve consideration of requirements and capabilities on a daily basis. Analysis of farm interview data yielded average daily energy requirements for each task group on each farm (Table A-1). Tables A-2, A-3, and A-4 depict the percentage of the average energy requirement in each of the five task groups that could be met by each of the four proposed electric vehicle sizes. The most conservative estimate of electric vehicle feasibility was constructed using the average daily energy requirement for each task group and considering only those electric vehicles with power capability equal to or greater than the average power requirement as given by each farmer cooperator (Table A-2). This effectively depicts the percentages of each farmer cooperator's work requirement that could be accomplished by an electric vehicle if the farmer made no management changes. That is, the time to do each task remains the same, the types of tasks remain the same, and the farmer works full days on a specific task.

The second comparison of task energy requirements and electric vehicle energy capabilities is similar to the first except that it shows feasibility percentages for electric vehicle sizes with less power than the average requirement. This assumes that the farmer could adjust speed or implement size so that the task could be done with less power (Table A-3). The daily energy requirement was not changed.

The third method of comparing task requirements with electric vehicle capabilities considers energy requirements and capabilities on an annual basis. This most optimistic estimate of electric vehicle feasibility was constructed considering the total annual energy requirement for each task group. The annual electric vehicle capability was calculated by multiplying the daily capability for each electric vehicle size by 150 days for the field work task groups or by 300 days for the livestock and general utility task groups (Table A-4). This assumes that the farmer cooperator would adjust work schedules to maximize utilization of the electric vehicle. For instance if there are normally twenty days per year during which disking could be performed based on timeliness studies, but this is typically done by the farmer cooperator in five days, Table A-4 assumes that the farmer will disk for part of twenty days to make optimal use of the electric vehicle.

It should be noted that if the electric vehicle is designed in such a way that the battery set could be easily changed, then one extra battery set would double the daily operating time. This would double all of the feasibility percentages (Tables A-2, A-3, and A-4). None of these tables alone accurately portrays the potential for replacing farm tractors with electric vehicles. Realistically the farmer cooperators could make some management changes to accomodate electric vehicles, but it would not be reasonable to try to utilize all available field days for each task where a substantial yield penalty results from delays. Tables A-2 and A-4 define a range of feasibilities, and the practical replacement potential of conventional farm tractors by electric vehicles is within this range. By assuming a battery change during the day, the upper and lower limits of the range are doubled.

When farm size and type were considered, the data indicated that a large percentage of the tractor work requirement on medium farms (200 - 1000 acres) with livestock operations could be completed with electric vehicles (Table A-3). For instance, a 40 hp electric vehicle on the average of such farms could do 18 per cent of the heavy field work, 34 per cent of the medium field work, 72 per cent of the light field work, or 100 per cent of the livestock and general utility work, calculated on the basis of daily energy requirements. The percentages averaged one-fourth lower for large farms (over 1000 acres) with livestock operations (Table A-3).

Economic Feasibility

Comprehensive comparisons of economic and energy efficiencies between electric and conventional farm tractors are difficult. A macro-scale study would involve costs and efficiencies all the way from the ultimate energy source to the agricultural work accomplished. The important point to consider when determining the extent of economic and energy efficiency studies is that electricity has a number of sources such as coal, nuclear fuels, hydro-electric potential, geothermal heat, and solar radiation in addition to petroleum. These additional sources of electricity are more abundant and less susceptible to foreign interruptions than is petroleum. For these reasons the energy efficiency analyses contained herein are limited to on-the-farm efficiencies. Economic feasibility of electric vehicles was studied from the farmer's perspective, and is based on costs and efficiencies realized by the farm operator.

On-the-farm energy efficiencies of electric vehicles compare favorably with those of the most fuel efficient diesel tractors marketed today. State-of-the-art battery powered electric tractors could be 33 per cent efficient at converting electricity to PTO (power take-off) shaft output. Projected advances could bring this to 54 per cent by 1990, while the average fuel efficiency was only 30 per cent for the ten most fuel efficient diesel tractors tested at the Nebraska Tractor Test facility up through 1979 (Ewing, 1980). The range of efficiencies for diesel tractors currently in use on farms is from 20 to 30 per cent.

From the proposed electric vehicle designs, it is evident that the initial cost of an electric vehicle would probably be equal to the cost of a comparable conventional tractor plus the cost of the battery set. The operating and maintenance costs must be lower for the electric vehicle to be economically attractive and the analysis may be described as determining how quickly an electric vehicle can repay its additional initial cost with operating and maintenance cost savings. Using energy cost inflation scenarios for 1980 and 1990 (Table 1) and assuming a linear increase in energy costs for the years in between, Figure 4 compares operating costs by showing the ratio of diesel fuel costs to electric costs per unit of useful work output. First, no improvements in electric vehicle component efficiencies were considered, and second, the improvements listed in the proposed 1990 electric vehicle designs (Table 8) were included. The lower line in each graph indicates the ratio of energy costs, if the conditions for the electric pessimistic energy cost inflation scenario (Table 1) hold true; the upper line indicates the cost ratio, if the electric optimistic scenario (Table 1) is correct. The most likely fuel cost ratio falls between the first two and is also shown on the graphs. By 1990 an improved electric vehicle would probably operate from 38 to 62 per cent more economically than a conventional

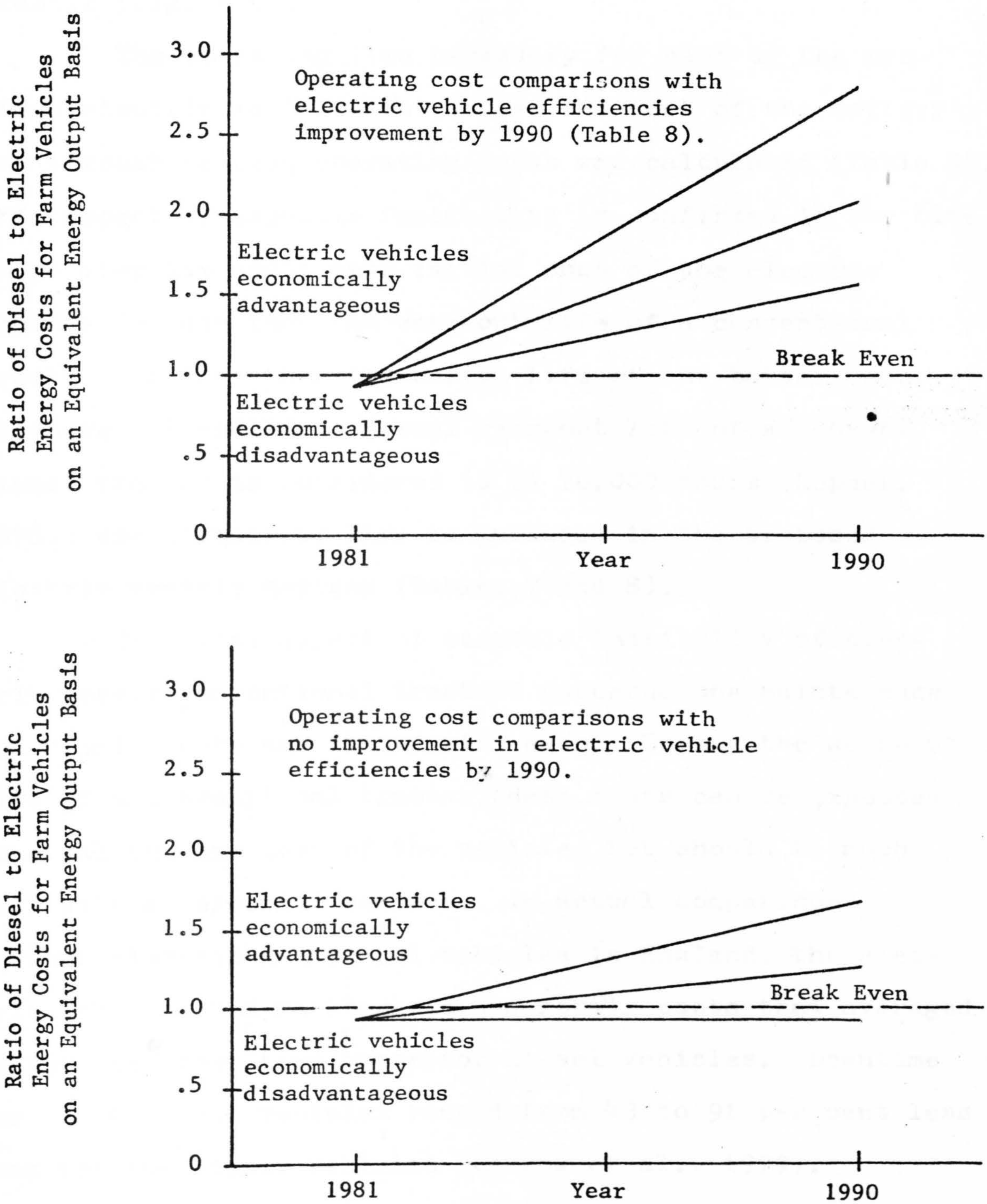

Figure 4. Comparisons of energy operating costs between electric and conventional vehicles for three energy cost inflation scenarios

tractor (Figure 4).

The operating time necessary for each of the proposed electric vehicles to recover the cost of the battery set through reduced operating costs was calculated (Table 9). This aspect of economic feasibility is confirmed if the time to recover the additional initial cost of the electric vehicle is less than the wear-out life of a conventional tractor, or less than the useful life of the battery set, whichever is smaller. Normal wear-out life of a conventional tractor is considered to be 10,000 hours (Kepner, 1978); useful battery life is included in the proposed electric vehicle designs (Tables 7 and 8).

The final aspect of economic feasibility of electric versus conventional tractors concerns the maintenance and repair costs associated with each. During the wear-out life of a conventional tractor these costs can be expected to equal the new cost of the vehicle, but should be much less with an electric vehicle. In actual comparisons between electric and diesel vehicles in England, the electric vehicles had maintenance and repair costs that averaged 36 per cent less than those for diesel vehicles. Downtime for the electric vehicles ranged from 43 to 91 per cent less than for the diesel vehicles (Harrow et al., 1979).

Electric vehicles seem to be feasible for the medium and large farms having livestock operations involved in this study. Since these types of farm operations make up nearly

TABLE 9

Operating Time Required for Proposed Electric Vehicles to Recover the Cost of a Battery Set Through Energy Cost Savings Compared with Conventional Tractors

Year	Energy Cost Inflation Scenario	Vehicle Size (hp)	Cost of Battery Set	Operating Time to Recover Battery Cost (hours)
1981[1]	Present Costs[3]	15	$ 9,730	Negative
		25	$ 16,210	Negative
		40	$ 25,940	Negative
1990[1]	Electric Pessimistic[4]	25	$ 9,310	Negative
		40	$ 14,113	Negative
		60	$ 21,169	Negative
	Most Likely[5]	25	$ 9,310	16,915
		40	$ 14,113	16,027
		60	$ 21,169	16,044
	Electric Optimistic[6]	25	$ 9,310	7,566
		40	$ 14,113	7,168
		60	$ 21,169	7,172
1990[2]	Electric Pessimistic[4]	25	$ 9,310	9,777
		40	$ 14,113	8,452
		60	$ 21,169	8,456
	Most Likely[5]	25	$ 9,310	6,067
		40	$ 14,113	5,425
		60	$ 21,169	5,427
	Electric Optimistic[6]	25	$ 9,310	4,729
		40	$ 14,113	4,330
		60	$ 21,169	4,331

1. Electric vehicle efficiencies currently attainable (Table 7)
2. Electric vehicle efficiencies projected for 1990 (Table 8)
3. Electricity $0.036/kwh; Diesel $1.172/gal.
4. 34% increase electricity; 34% increase diesel; real terms
5. 34% increase electricity; 63% increase diesel; real terms
6. No increase electricity; 63% increase diesel; real terms

three-fourths of all farms in eastern South Dakota, it appears that electric vehicles could be practical replacements for many of the lower-powered internal combustion engine tractors in this state. Considering that the electric vehicle advantages of improved energy efficiency, lower fuel costs, less expensive maintenance, quiet and pollution-free operation, and reduced downtime are independent of location, it seems that electric vehicles may be feasible in a large segment of United States agriculture. Finally, when the reliability of electric vehicle energy sources is considered, along with technological goals for electric vehicle advances beyond this decade, the electric vehicle in agriculture seems almost a certainty.

CONCLUSIONS

Vehicle performance task requirements were identified and quantified for agricultural tasks on farms typical of eastern South Dakota. Information was collected in two ways; first, general information was obtained through analysis of previous research, and second, specific task requirement information was determined through extensive data collection on seventeen farm operations near Brookings, South Dakota.

Electric vehicle capabilities were defined for the present and projected for 1990 based on industry and government goals and predictions. State-of-the-art electric vehicles could be 33 per cent efficient at converting farm electricity to PTO shaft power and projected 1990 vehicles could be 55 per cent efficient. This compares with a 30 per cent energy conversion efficiency for the ten most fuel efficient tractors tested at the Nebraska Tractor Test Facility.

Electric vehicles technically could replace 12 to 100 per cent of agricultural vehicle fuel use by utilizing one 60 HP electric tractor per farm. On the average of the medium (200 - 1000 acres) farms studied, electric vehicles could perform up to 27 per cent of the heavy tillage, up to 52 per cent of the medium field work, 40 to 100 per cent of the light field work, and up to 100 per cent of the livestock production and general utility work. On the average large (over 1000 acres) farm with livestock studied, electric vehicles could perform up to 25 per cent of the heavy tillage, up to 34 per cent of the medium field work, 45 to 67 per cent of the light field work, and 13 to 61 per cent of the livestock production and general utility work.

Electric vehicles are not currently economical, assuming no special rates for electricity, but it appears that economic feasibility will be attainable by 1990. Operating costs for electric vehicles could be up to 35 per cent less than those for conventional vehicles by 1990 if no improvements were made in electric vehicle component efficiencies. If the efficiencies predicted by the Department of Energy are realized by 1990, electric vehicles will have operating costs from 37 to 62 per cent less than those for conventional vehicles.

Factors such as reduced rates for off-peak electricity, battery technology breakthroughs, or sharp curtailments of petroleum availability could lead to immediate economic feasibility for electric vehicles.

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APPENDIX

TABLE A-1

Power and Energy Requirements for Seventeen Grain and Livestock Farms Near Brookings, South Dakota

Farmer	Farm Size and Type	Task Group	Power Range (HP)		Daily Operating Duration (Hrs)		Daily Energy Requirement (HP-HR/Day)	
			Range	Ave.	Range	Ave.	Range	Ave.
A	Medium with Livestock	Heavy[1]	71-83	77.0	5-10	8.8	622-710	666.3
		Medium[2]	34-60	45.3	2-6	4.2	74-288	188.1
		Light[3]	17-49	33.8	3-10	7.4	80-480	260.6
		Livestock[4]	25-82	39.5	1-4	2.2	28-205	87.4
		Utility[5]	9-17	13.7	2-5	3.3	31-68	44.3
B	Medium with Livestock	Heavy[1]	77	77.0	12	12.0	924	924.0
		Medium[2]	31-70	49.4	3-12	6.9	136-840	379.0
		Light[3]	15-64	33.0	4-12	6.9	60-588	257.1
		Livestock[4]	10-55	34.1	1/6-8	3.1	3-296	103.3
		Utility[5]	15-23	19.0	2-6	3.5	46-75	60.5
C	Medium with Livestock	Heavy[1]	116	116.0	10-14	11.0	1160-1392	1276.0
		Medium[2]	45-116	72.0	6-8	7.7	360-928	557.7
		Light[3]	15-64	37.0	4-10	6.7	76-576	253.8
		Livestock[4]	25-70	49.8	1-10	4.4	25-531	243.5
		Utility[5]	15	15.0	3-4	3.5	52-53	52.5

TABLE A-1 (Continued)

Farmer	Farm Size and Type	Task Group	Power Range (HP)		Daily Operating Duration (Hrs)		Daily Energy Requirement (HP-HR/Day)	
			Range	Ave.	Range	Ave.	Range	Ave.
D	Medium with Livestock	Heavy[1]	71-79	73.7	5-10	9.2	532-790	677.5
		Medium[2]	18-76	47.0	2-10	5.9	72-760	322.1
		Light[3]	8-79	33.5	3-10	7.5	44-510	252.6
		Livestock[4]	23-79	41.6	2-6	3.2	46-192	123.6
		Utility[5]	20-23	22.5	2-4	3.0	46-80	63.0
E	Medium with Livestock	Heavy[1]	87-93	91.0	10-14	11.3	930-1209	1032.0
		Medium[2]	29-97	65.3	4-10	7.5	203-970	497.2
		Light[3]	5-58	24.0	2-14	8.8	20-754	248.3
		Livestock[4]	20-60	36.8	1-8	3.4	20-296	123.2
		Utility[5]	15	15.0	4-6	5.0	60-90	75.0
F	Medium with Livestock	Heavy[1]	89-110	99.5	9-10	9.8	845-1100	972.8
		Medium[2]	51-115	65.8	4-8	7.0	204-920	475.8
		Light[3]	13-74	32.6	4-11	7.2	97-592	232.9
		Livestock[4]	14-115	52.7	1/2-6	1.8	14-633	135.5
		Utility[5]	10-15	12.5	1-8	4.5	15-80	47.5

TABLE A-1 (Continued)

Farmer	Farm Size and Type	Task Group	Power Range (HP)		Daily Operating Duration (Hrs)		Daily Energy Requirement (HP-HR/Day)	
			Range	Ave.	Range	Ave.	Range	Ave.
G	Medium with Livestock	Heavy[1]	89	89.0	12	12.0	1068	1068.0
		Medium[2]	29-82	59.3	2-12	6.8	94-984	463.8
		Light[3]	12-64	28.2	1-13	7.0	30-455	195.1
		Livestock[4]	23-51	37.0	3-5	4.0	69-255	155.0
		Utility[5]	20-25	22.5	2-3	2.5	50-60	55.0
H	Medium with Livestock	Heavy[1]	75-82	79.0	4-12	7.8	360-820	618.3
		Medium[2]	23-78	44.0	2-10	6.8	69-624	316.7
		Light[3]	10-50	24.9	2-12	6.2	35-500	170.3
		Livestock[4]	20-60	37.8	1-10	3.6	20-440	146.0
		Utility[5]	15	15.0	4-5	4.5	67-68	67.5
I	Medium with Livestock	Heavy[1]	88	88.0	12-13	12.5	1100	1100.0
		Medium[2]	38-103	70.6	2-13	8.9	100-1288	713.7
		Light[3]	14-40	22.0	2-13	5.4	35-500	155.3
		Livestock[4]	11-90	49.0	1-6	2.8	30-402	146.7
		Utility[5]	15	15.0	4-5	4.5	67-68	67.5

TABLE A-1 (Continued)

Farmer	Farm Size and Type	Task Group	Power Range (HP)		Daily Operating Duration (Hrs)		Daily Energy Requirement (HP-HR/Day)	
			Range	Ave.	Range	Ave.	Range	Ave.
J	Medium with Livestock	Heavy[1]	66-76	72.7	10	10.0	660-760	726.7
		Medium[2]	32-76	56.8	10-12	10.4	320-836	598.4
		Light[3]	12-55	29.5	6-12	9.3	72-550	286.8
		Livestock[4]	10-58	33.4	1-6	4.2	10-232	154.1
		Utility[5]	20	20.0	8	8.0	160	160.0
K	Medium with Livestock	Heavy[1]	93-125	107.0	2-11	6.8	372-1313	767.5
		Medium[2]	46-110	75.6	4-10	7.2	211-1045	593.1
		Light[3]	17-44	30.8	2-10	4.4	48-380	147.3
		Livestock[4]	20-55	40.3	1-6	3.1	40-200	126.6
		Utility[5]	12-20	15.7	1-5	3.2	30-54	45.5
Averages for Medium Farms with Livestock		Heavy[1]	66-125	88.2	2-14	10.1		893.6
		Medium[2]	18-116	59.2	2-13	7.2		464.2
		Light[3]	5-79	29.9	1-14	7.0		223.6
		Livestock[4]	10-115	41.1	1/6-10	3.3		140.4
		Utility[5]	9-25	16.9	1-8	4.1		67.1

TABLE A-1 (Continued)

Farmer	Farm Size and Type	Task Group	Power Range (HP)		Daily Operating Duration (Hrs)		Daily Energy Requirement (HP-HR/Day)	
			Range	Ave.	Range	Ave.	Range	Ave.
L	Large with Livestock	Heavy[1]	15-118	79.3	2-10	5.4	52-756	454.1
		Medium[2]	47-89	62.2	3-10	6.1	171-711	391.9
		Light[3]	19-47	32.3	3-10	6.8	77-423	223.8
		Livestock[4]	40	40.0	2-4	3.0	120	120.0
		Utility[5]	8-20	14.0	1-7	3.8	30-48	39.0
M	Large with Livestock	Heavy[1]	135	135.0	10	10.0	1350	1350.0
		Medium[2]	120-135	127.5	10	10.0	1200-1350	1275.0
		Light[3]	34-84	54.7	2-12	7.6	150-840	403.3
		Livestock[4]	32-135	72.2	1-10	6.7	88-1350	543.4
		Utility[5]	20	20.0	2-8	5.0	40-160	100.0
N	Large with Livestock	Heavy[1]	69-128	98.5	4-15	8.3	276-1600	938.0
		Medium[2]	35-140	74.1	1-12	5.9	49-1470	580.4
		Light[3]	12-32	36.5	4-16	7.7	48-480	214.7
		Livestock[4]	25-121	69.1	1/2-10	4.5	18-837	351.6
		Utility[5]						

TABLE A-1 (Continued)

Farmer	Farm Size and Type	Task Group	Power Range (HP)		Daily Operating Duration (Hrs)		Daily Energy Requirement (HP-HR/Day)	
			Range	Ave.	Range	Ave.	Range	Ave.
O	Large with Livestock	Heavy[1]	118-128	123.3	6-10	9.3	1024-1240	1148.0
		Medium[2]	48-132	79.4	2-12	6.7	98-1518	601.9
		Light[3]	15-93	45.2	3-12	8.0	52-930	403.5
		Livestock[4]	6-135	70.0	1-12	4.2	9-1236	346.7
		Utility[5]	10-25	16.7	3-5	4.2	45-113	70.0
Averages for Large Farms with Livestock		Heavy[1]	15-135	109.0	2-15	8.3		972.5
		Medium[2]	35-140	85.8	1-12	7.2		712.3
		Light[3]	12-93	42.2	2-16	7.5		311.3
		Livestock[4]	6-135	62.8	1/2-12	4.6		340.4
		Utility[5]	8-25	12.7	1-8	3.3		52.3
P	Medium No Livestock	Heavy[1]	97	97.0	12	12.0	1164	1164.0
		Medium[2]	29-93	59.7	4-12	8.3	116-837	545.7
		Light[3]	18-64	38.0	5-12	8.3	90-640	356.5
		Livestock[4]	37	37.0	3	3.0	111	111.0
		Utility[5]	19	19.0	4	4.0	76	76.0

TABLE A-1 (Continued)

Farmer	Farm Size and Type	Task Group	Power Range (HP)		Daily Operating Duration (Hrs)		Daily Energy Requirement (HP-HR/Day)	
			Range	Ave.	Range	Ave.	Range	Ave.
Q	Large No Livestock	Heavy[1]	108-128	116.0	8-12	10.0	1024-1344	1149.3
		Medium[2]	122-128	125.0	9-16	11.3	1280-1525	1402.5
		Light[3]	15-58	40.8	6-10	8.0	90-464	338.0
		Livestock[4]	137	137.0	4	4.0	548	548.0
		Utility[5]	20	20.0	3	3.0	60	60.0
Averages for All 17 Farms		Heavy[1]	15-135	95.2	2-15	9.8		943.1
		Medium[2]	18-140	69.4	1-16	7.5		582.6
		Light[3]	5-93	33.9	1-16	7.2		258.8
		Livestock[4]	6-137	51.6	1/6-12	3.6		209.7
		Utility[5]	8-25	16.2	1-8	3.9		63.7

1. Tasks include moldboard plowing, chisel plowing, and field cultivating.
2. Tasks include disking, fertilizing, silage chopping, combining, baling and hauling heavy loads.
3. Tasks include seeding, windrowing, light hauling, mowing, raking, dragging, spraying, stalk chopping, planting, row cultivating, and corn picking.
4. Tasks include grinding, loader work, sewage handling, livestock moving, and snow moving.
5. Tasks include operating augers and elevators, digging post holes, moving machinery, and hauling rock.
6. Medium farms are 200 to 1000 acres; large farms are over 1000 acres.

TABLE A-2

Percentages of Daily Energy Requirements That Could be Met by Proposed Electric Vehicles with No Changes in Task Requirements or Tractor Capabilities

Farmer	Farm Size[6] and Type	Task Group	Daily Energy Requirement (hp-hrs)	Proposed Vehicle Size 15hp[7]	25hp[7]	40hp[7]	60hp[7]
A	Medium with Livestock	Heavy[1]	666.3	0%	0%	0%	0%
		Medium[2]	188.1	0%	0%	0%	100+%
		Light[3]	260.6	0%	0%	62%	92%
		Livestock[4]	87.4	0%	0%	100+%	100+%
		Utility[5]	44.3	100+%	100+%	100+%	100+%
B	Medium with Livestock	Heavy[1]	924.0	0%	0%	0%	0%
		Medium[2]	379.9	0%	0%	0%	63%
		Light[3]	257.1	0%	0%	62%	93%
		Livestock[4]	103.3	0%	0%	100+%	100+%
		Utility[5]	60.5	0%	100+%	100+%	100+%
C	Medium with Livestock	Heavy[1]	1276.0	0%	0%	0%	0%
		Medium[2]	557.7	0%	0%	0%	0%
		Light[3]	253.8	0%	0%	63%	95%
		Livestock[4]	243.5	0%	0%	0%	99%
		Utility[5]	52.5	100+%	100+%	100+%	100+%

TABLE A-2 (Continued)

Farmer	Farm Size[6] and Type	Task Group	Daily Energy Requirement (hp-hrs)	Proposed Vehicle Size 15hp[7]	25hp[7]	40hp[7]	60hp[7]
D	Medium with Livestock	Heavy[1]	677.5	0%	0%	0%	0%
		Medium[2]	322.1	0%	0%	0%	75%
		Light[3]	252.6	0%	0%	63%	95%
		Livestock[4]	123.6	0%	0%	0%	100+%
		Utility[5]	63.0	0%	100+%	100+%	100+%
E	Medium with Livestock	Heavy[1]	1032.0	0%	0%	0%	0%
		Medium[2]	497.2	0%	0%	0%	0%
		Light[3]	248.3	0%	40%	64%	97%
		Livestock[4]	123.2	0%	0%	100+%	100+%
		Utility[5]	75.0	80%	100+%	100+%	100+%
F	Medium with Livestock	Heavy[1]	972.8	0%	0%	0%	0%
		Medium[2]	475.8	0%	0%	0%	0%
		Light[3]	232.9	0%	0%	69%	100+%
		Livestock[4]	135.5	0%	0%	0%	100+%
		Utility[5]	47.5	100+%	100+%	100+%	100+%

TABLE A-2 (Continued)

Farmer	Farm Size[6] and Type	Task Group	Daily Energy Requirement (hp-hrs)	Proposed Vehicle Size			
				15hp[7]	25hp[7]	40hp[7]	60hp[7]
G	Medium with Livestock	Heavy[1]	1068.0	0%	0%	0%	0%
		Medium[2]	463.8	0%	0%	0%	52%
		Light[3]	195.1	0%	0%	82%	100+%
		Livestock[4]	155.0	0%	0%	100+%	100+%
		Utility[5]	55.0	0%	100+%	100+%	100+%
H	Medium with Livestock	Heavy[1]	618.3	0%	0%	0%	0%
		Medium[2]	316.7	0%	0%	0%	76%
		Light[3]	170.3	0%	59%	94%	100+%
		Livestock[4]	146.0	0%	0%	100+%	100+%
		Utility[5]	67.5	89%	100+%	100+%	100+%
I	Medium with Livestock	Heavy[1]	1100.0	0%	0%	0%	0%
		Medium[2]	713.7	0%	0%	0%	0%
		Light[3]	155.3	0%	64%	100+%	100+%
		Livestock[4]	146.7	0%	0%	0%	100+%
		Utility[5]	67.5	89%	100+%	100+%	100+%

TABLE A-2 (Continued)

Farmer	Farm Size[6] and Type	Task Group	Daily Energy Requirement (hp-hrs)	Proposed Vehicle Size 15hp[7]	25hp[7]	40hp[7]	60hp[7]
J	Medium with Livestock	Heavy[1]	726.7	0%	0%	0%	0%
		Medium[2]	598.4	0%	0%	0%	40%
		Light[3]	286.8	0%	0%	56%	84%
		Livestock[4]	154.1	0%	0%	100+%	100+%
		Utility[5]	160.0	0%	63%	100%	100+%
K	Medium with Livestock	Heavy[1]	767.5	0%	0%	0%	0%
		Medium[2]	593.1	0%	0%	0%	0%
		Light[3]	147.3	0%	0%	100+%	100+%
		Livestock[4]	126.6	0%	0%	0%	100+%
		Utility[5]	45.5	100+%	100+%	100+%	100+%
Averages for Medium Farms with Livestock		Heavy[1]	893.6	0%	0%	0%	0%
		Medium[2]	464.2	0%	0%	0%	52%
		Light[3]	223.6	0%	0%	72%	100+%
		Livestock[4]	140.4	0%	0%	0%	100+%
		Utility[5]	67.1	0%	100+%	100+%	100+%

TABLE A-2 (Continued)

Farmer	Farm Size[6] and Type	Task Group	Daily Energy Requirement (hp-hrs)	Proposed Vehicle Size 15hp[7]	25hp[7]	40hp[7]	60hp[7]
L	Large with Livestock	Heavy[1]	454.1	0%	0%	0%	0%
		Medium[2]	391.9	0%	0%	0%	0%
		Light[3]	223.8	0%	0%	71%	100+%
		Livestock[4]	120.0	0%	0%	100+%	100+%
		Utility[5]	39.0	100+%	100+%	100+%	100+%
M	Large with Livestock	Heavy[1]	1350.0	0%	0%	0%	0%
		Medium[2]	1275.0	0%	0%	0%	0%
		Light[3]	403.3	0%	0%	0%	60%
		Livestock[4]	543.4	0%	0%	0%	0%
		Utility[5]	100.0	0%	100%	100+%	100+%
N	Large with Livestock	Heavy[1]	938.0	0%	0%	0%	0%
		Medium[2]	580.4	0%	0%	0%	0%
		Light[3]	214.7	0%	0%	75%	100+%
		Livestock[4]	351.6	0%	0%	0%	0%
		Utility[5]	--				

TABLE A-2 (Continued)

Farmer	Farm Size[6] and Type	Task Group	Daily Energy Requirement (hp-hrs)	Proposed Vehicle Size 15hp[7]	25hp[7]	40hp[7]	60hp[7]
O	Large with Livestock	Heavy[1]	1148.0	0%	0%	0%	0%
		Medium[2]	601.9	0%	0%	0%	0%
		Light[3]	403.5	0%	0%	0%	59%
		Livestock[4]	346.7	0%	0%	0%	0%
		Utility[5]	70.0	0%	100+%	100+%	100+%
Averages for Large Farms with Livestock		Heavy[1]	972.5	0%	0%	0%	0%
		Medium[2]	712.3	0%	0%	0%	0%
		Light[3]	311.3	0%	0%	0%	77%
		Livestock[4]	340.4	0%	0%	0%	0%
		Utility[5]	52.3	100+%	100+%	100+%	100+%
P	Medium No Livestock	Heavy[1]	1164.0	0%	0%	0%	0%
		Medium[2]	545.7	0%	0%	0%	44%
		Light[3]	356.5	0%	0%	45%	67%
		Livestock[4]	111.0	0%	0%	100+%	100+%
		Utility[5]	76.0	0%	100+%	100+%	100+%

TABLE A-2 (Continued)

Farmer	Farm Size[6] and Type	Task Group	Daily Energy Requirement (hp-hrs)	Proposed Vehicle Size 15hp[7]	25hp[7]	40hp[7]	60hp[7]
Q	Large No Livestock	Heavy[1]	1149.3	0%	0%	0%	0%
		Medium[2]	1402.5	0%	0%	0%	0%
		Light[3]	338.0	0%	0%	0%	71%
		Livestock[4]	548.0	0%	0%	0%	0%
		Utility[5]	60.0	0%	100+%	100+%	100+%
Averages for All 17 Farms		Heavy[1]	943.1	0%	0%	0%	0%
		Medium[2]	582.6	0%	0%	0%	0%
		Light[3]	258.8	0%	0%	62%	93%
		Livestock[4]	209.7	0%	0%	0%	100+%
		Utility[5]	63.7	0%	100+%	100+%	100+%

1. Tasks include moldboard plowing, chisel plowing, and field cultivating.
2. Tasks include disking, fertilizing, silage chopping, combining, baling and hauling heavy loads.
3. Tasks include seeding, windrowing, light hauling, mowing, raking, dragging, spraying, stalk chopping, planting, row cultivating, and corn picking.
4. Tasks include grinding, loader work, sewage handling, livestock moving, and snow moving.
5. Tasks include operating augers and elevators, digging post holes, moving machinery, and hauling rock.
6. Medium farms are 200 to 1000 acres; large farms are over 1000 acres.
7. Horsepower ratings are based on continuous duty capabilities for four hours with no battery change.

TABLE A-3

Percentages of Daily Energy Requirements That Could Be Met by Proposed Electric Vehicles if Tractor Power May be Reduced

Farmer	Farm Size[6] and Type	Task Group	Daily Energy Requirement (hp-hrs)	Proposed Vehicle Size 15hp[7]	25hp[7]	40hp[7]	60hp[7]
A	Medium with Livestock	Heavy[1]	666.3	9%	15%	25%	36%
		Medium[2]	188.1	32%	53%	85%	100+%
		Light[3]	260.6	23%	38%	62%	92%
		Livestock[4]	87.4	69%	100+%	100+%	100+%
		Utility[5]	44.3	100+%	100+%	100+%	100+%
B	Medium with Livestock	Heavy[1]	924.0	6%	11%	17%	26%
		Medium[2]	379.9	16%	26%	42%	63%
		Light[3]	257.1	23%	39%	62%	93%
		Livestock[4]	103.3	58%	97%	100+%	100+%
		Utility[5]	60.5	99%	100+%	100+%	100+%
C	Medium with Livestock	Heavy[1]	1276.0	5%	8%	13%	19%
		Medium[2]	557.7	11%	18%	29%	43%
		Light[3]	253.8	24%	39%	63%	95%
		Livestock[4]	243.5	25%	41%	66%	99%
		Utility[5]	52.5	100+%	100+%	100+%	100+%

TABLE A-3 (Continued)

Farmer	Farm Size[6] and Type	Task Group	Daily Energy Requirement (hp-hrs)	Proposed Vehicle Size 15hp[7]	25hp[7]	40hp[7]	60hp[7]
D	Medium with Livestock	Heavy[1]	677.5	9%	15%	24%	35%
		Medium[2]	322.1	19%	31%	50%	75%
		Light[3]	252.6	24%	40%	63%	95%
		Livestock[4]	123.6	49%	81%	100+%	100+%
		Utility[5]	63.0	95%	100+%	100+%	100+%
E	Medium with Livestock	Heavy[1]	1032.0	6%	10%	16%	23%
		Medium[2]	497.2	12%	20%	32%	48%
		Light[3]	248.3	24%	40%	64%	97%
		Livestock[4]	123.2	49%	81%	100+%	100+%
		Utility[5]	75.0	80%	100+%	100+%	100+%
F	Medium with Livestock	Heavy[1]	972.8	6%	10%	16%	25%
		Medium[2]	475.8	13%	21%	34%	50%
		Light[3]	232.9	26%	43%	69%	100+%
		Livestock[4]	135.5	44%	74%	100+%	100+%
		Utility[5]	47.5	100+%	100+%	100+%	100+%

TABLE A-3 (Continued)

Farmer	Farm Size[6] and Type	Task Group	Daily Energy Requirement (hp-hrs)	Proposed Vehicle Size 15hp[7]	25hp[7]	40hp[7]	60hp[7]
G	Medium with Livestock	Heavy[1]	1068.0	6%	9%	15%	22%
		Medium[2]	463.8	13%	22%	34%	52%
		Light[3]	195.1	31%	51%	82%	100+%
		Livestock[4]	155.0	39%	65%	100+%	100+%
		Utility[5]	55.0	100+%	100+%	100+%	100+%
H	Medium with Livestock	Heavy[1]	618.3	10%	16%	26%	39%
		Medium[2]	316.7	19%	32%	51%	76%
		Light[3]	170.3	35%	59%	94%	100+%
		Livestock[4]	146.0	41%	68%	100+%	100+%
		Utility[5]	67.5	89%	100+%	100+%	100+%
I	Medium with Livestock	Heavy[1]	1100.0	5%	9%	15%	22%
		Medium[2]	713.7	8%	14%	22%	34%
		Light[3]	155.3	39%	64%	100+%	100+%
		Livestock[4]	146.7	41%	68%	100+%	100+%
		Utility[5]	67.5	89%	100+%	100+%	100+%

TABLE A-3 (Continued)

Farmer	Farm Size[6] and Type	Task Group	Daily Energy Requirement (hp-hrs)	Proposed Vehicle Size 15hp[7]	25hp[7]	40hp[7]	60hp[7]
J	Medium with Livestock	Heavy[1]	726.7	8%	14%	22%	33%
		Medium[2]	598.4	10%	17%	27%	40%
		Light[3]	286.8	21%	35%	56%	84%
		Livestock[4]	154.1	39%	65%	100+%	100+%
		Utility[5]	160.0	38%	63%	100%	100+%
K	Medium with Livestock	Heavy[1]	767.5	8%	13%	21%	31%
		Medium[2]	593.1	10%	17%	27%	40%
		Light[3]	147.3	41%	68%	100+%	100+%
		Livestock[4]	126.6	47%	79%	100+%	100+%
		Utility[5]	45.5	100+%	100+%	100+%	100+%
Averages for Medium Farms with Livestock		Heavy[1]	893.6	7%	11%	18%	27%
		Medium[2]	464.2	13%	22%	34%	52%
		Light[3]	223.6	27%	45%	72%	100+%
		Livestock[4]	140.4	43%	71%	100+%	100+%
		Utility[5]	67.1	89%	100+%	100+%	100+%

TABLE A-3 (Continued)

Farmer	Farm Size[6] and Type	Task Group	Daily Energy Requirement (hp-hrs)	Proposed Vehicle Size 15hp[7]	25hp[7]	40hp[7]	60hp[7]
L	Large with Livestock	Heavy[1]	454.1	13%	22%	35%	53%
		Medium[2]	391.9	15%	26%	41%	61%
		Light[3]	223.8	27%	45%	71%	100+%
		Livestock[4]	120.0	50%	83%	100+%	100+%
		Utility[5]	39.0	100+%	100+%	100+%	100+%
M	Large with Livestock	Heavy[1]	1350.0	4%	7%	12%	18%
		Medium[2]	1275.0	5%	8%	13%	19%
		Light[3]	403.3	15%	25%	40%	60%
		Livestock[4]	543.4	11%	18%	29%	44%
		Utility[5]	100.0	60%	100%	100+%	100+%
N	Large with Livestock	Heavy[1]	938.0	6%	11%	17%	26%
		Medium[2]	580.4	10%	17%	28%	41%
		Light[3]	214.7	28%	47%	75%	100+%
		Livestock[4]	351.6	17%	28%	46%	68%
		Utility[5]	--				

TABLE A-3 (Continued)

Farmer	Farm Size[6] and Type	Task Group	Daily Energy Requirement (hp-hrs)	Proposed Vehicle Size 15hp[7]	25hp[7]	40hp[7]	60hp[7]
O	Large with Livestock	Heavy[1]	1148.0	5%	9%	14%	21%
		Medium[2]	601.9	10%	17%	27%	40%
		Light[3]	403.5	15%	25%	40%	59%
		Livestock[4]	346.7	17%	29%	46%	69%
		Utility[5]	70.0	86%	100+%	100+%	100+%
Averages for Large Farms with Livestock		Heavy[1]	972.5	6%	10%	16%	25%
		Medium[2]	712.3	8%	14%	22%	34%
		Light[3]	311.3	19%	32%	51%	77%
		Livestock[4]	340.4	18%	29%	47%	71%
		Utility[5]	52.3	100+%	100+%	100+%	100+%
P	Medium No Livestock	Heavy[1]	1164.0	5%	9%	14%	21%
		Medium[2]	545.7	11%	18%	29%	44%
		Light[3]	356.5	17%	28%	45%	67%
		Livestock[4]	111.0	54%	90%	100+%	100+%
		Utility[5]	76.0	79%	100+%	100+%	100+%

TABLE A-3 (Continued)

Farmer	Farm Size[6] and Type	Task Group	Daily Energy Requirement (hp-hrs)	Proposed Vehicle Size 15hp[7]	25hp[7]	40hp[7]	60hp[7]
Q	Large No Livestock	Heavy[1]	1149.3	5%	9%	14%	21%
		Medium[2]	1402.5	4%	7%	11%	17%
		Light[3]	338.0	18%	30%	47%	71%
		Livestock[4]	548.0	11%	18%	29%	44%
		Utility[5]	60.0	100%	100+%	100+%	100+%
Averages for All 17 Farms		Heavy[1]	943.1	6%	11%	17%	25%
		Medium[2]	582.6	10%	17%	27%	41%
		Light[3]	258.8	23%	39%	62%	93%
		Livestock[4]	209.7	29%	48%	76%	100+%
		Utility[5]	63.7	94%	100+%	100+%	100+%

1. Tasks include moldboard plowing, chisel plowing, and field cultivating.
2. Tasks include disking, fertilizing, silage chopping, combining, baling and hauling heavy loads.
3. Tasks include seeding, windrowing, light hauling, mowing, raking, dragging, spraying, stalk chopping, planting, row cultivating, and corn picking.
4. Tasks include grinding, loader work, sewage handling, livestock moving, and snow moving.
5. Tasks include operating augers and elevators, digging post holes, moving machinery, and hauling rock.
6. Medium farms are 200 to 1000 acres; large farms are over 1000 acres.
7. Horsepower ratings are based on continuous duty capabilities for four hours with no battery change.

TABLE A-4

Percentages of Annual Energy Requirements That Could be Met by Proposed Electric Vehicles for Typical Eastern South Dakota Farms[1]

Farmer	Farm Size[6] and Type	Task Group	Annual Energy Requirement	Proposed Vehicle Size 15hp[2]	25hp[2]	40hp[2]	60hp[2]
A	Medium with Livestock	Field Tasks[3]	16,042	56%	94%	100+%	100+%
		Livestock & Utility Tasks[4]	15,911	100+%	100+%	100+%	100+%
		Total[5]	31,953	56%	94%	100+%	100+%
B	Medium with Livestock	Field Tasks[3]	22,319	40%	67%	100+%	100+%
		Livestock & Utility Tasks[4]	15,643	100+%	100+%	100+%	100+%
		Total[5]	37,962	47%	79%	100+%	100+%
C	Medium with Livestock	Field Tasks[3]	35,613	25%	42%	67%	100+%
		Livestock & Utility Tasks[4]	22,405	80%	100+%	100+%	100+%
		Total[5]	58,018	31%	52%	83%	100+%
D	Medium with Livestock	Field Tasks[3]	34,000	26%	44%	71%	100+%
		Livestock & Utility Tasks[4]	41,725	43%	72%	100+%	100+%
		Total[5]	75,725	24%	40%	63%	95%
E	Medium with Livestock	Field Tasks[3]	27,153	33%	55%	88%	100+%
		Livestock & Utility Tasks[4]	33,076	54%	91%	100+%	100+%
		Total[5]	60,229	29%	50%	80%	100+%

TABLE A-4 (Continued)

Farmer	Farm Size[6] and Type	Task Group	Annual Energy Requirement	Proposed Vehicle Size 15hp[2]	25hp[2]	40hp[2]	60hp[2]
F	Medium with Livestock	Field Tasks[3]	23,841	38%	63%	100+%	100+%
		Livestock & Utility Tasks[4]	49,997	36%	60%	96%	100+%
		Total[5]	73,838	24%	41%	65%	98%
G	Medium with Livestock	Field Tasks[3]	22,919	39%	65%	100+%	100+%
		Livestock & Utility Tasks[4]	9,220	100+%	100+%	100+%	100+%
		Total[5]	32,139	56%	93%	100+%	100+%
H	Medium with Livestock	Field Tasks[3]	24,331	37%	62%	99%	100+%
		Livestock & Utility Tasks[4]	24,615	73%	100+%	100+%	100+%
		Total[5]	48,946	37%	61%	98%	100+%
I	Medium with Livestock	Field Tasks[3]	33,361	27%	45%	72%	100+%
		Livestock & Utility Tasks[4]	21,305	84%	100+%	100+%	100+%
		Total[5]	54,666	33%	55%	88%	100+%
J	Medium with Livestock	Field Tasks[3]	26,815	34%	56%	90%	100+%
		Livestock & Utility Tasks[4]	28,285	64%	100+%	100+%	100+%
		Total[5]	55,100	33%	54%	87%	100+%
K	Medium with Livestock	Field Tasks[3]	43,627	21%	34%	55%	82%
		Livestock & Utility Tasks[4]	32,260	56%	93%	100+%	100+%
		Total[5]	75,887	24%	40%	63%	95%

TABLE A-4 (Continued)

Farmer	Farm Size[6] and Type	Task Group	Annual Energy Requirement	Proposed Vehicle Size 15hp[2]	25hp[2]	40hp[2]	60hp[2]
Averages for Medium Farms with Livestock		Field Tasks[3]	28,184	32%	53%	85%	100+%
		Livestock & Utility Tasks[4]	26,767	67%	100+%	100+%	100+%
		Total[5]	54,951	33%	55%	87%	100+%
L	Large with Livestock	Field Tasks[3]	44,611	20%	34%	54%	81%
		Livestock & Utility Tasks[4]	5,895	100+%	100+%	100+%	100+%
		Total[5]	50,506	36%	59%	95%	100+%
M	Large with Livestock	Field Tasks[3]	64,946	14%	23%	37%	55%
		Livestock & Utility Tasks[4]	59,719	30%	50%	80%	100+%
		Total[5]	124,665	14%	24%	38%	58%
N	Large with Livestock	Field Tasks[3]	40,883	22%	37%	59%	88%
		Livestock & Utility Tasks[4]	47,660	38%	63%	100+%	100+%
		Total[5]	88,543	20%	34%	54%	81%
O	Large with Livestock	Field Tasks[3]	99,726	9%	15%	24%	36%
		Livestock & Utility Tasks[4]	176,753	10%	17%	27%	41%
		Total[5]	276,479	6%	11%	17%	26%
Averages for Large Farms with Livestock		Field Tasks[3]	62,541	14%	24%	38%	58%
		Livestock & Utility Tasks[4]	72,507	25%	41%	66%	99%
		Total[5]	135,048	13%	22%	36%	53%

TABLE A-4 (Continued)

Farmer	Farm Size[6] and Type	Task Group	Annual Energy Requirement	Proposed Vehicle Size 15hp[2]	25hp[2]	40hp[2]	60hp[2]
P	Medium No Livestock	Field Tasks[3]	20,764	43%	72%	100+%	100+%
		Livestock & Utility Tasks[4]	1,163	100+%	100+%	100+%	100+%
		Total[5]	21,927	82%	100+%	100+%	100+%
Q	Large No Livestock	Field Tasks[3]	42,794	21%	35%	56%	84%
		Livestock & Utility Tasks[4]	8,050	100+%	100+%	100+%	100+%
		Total[5]	50,844	35%	59%	94%	100+%
Averages for All 17 Farms		Field Tasks[3]	36,691	24%	41%	65%	98%
		Livestock & Utility Tasks[4]	34,922	52%	86%	100+%	100+%
		Total[5]	71,613	25%	42%	67%	100+%

1. Based on analysis of field practice records and fuel records for 17 Brookings, South Dakota, farms in 1979 and average weather records.
2. Horsepower ratings are based on continuous duty capabilities for four hours with no battery change.
3. Includes heavy, medium, and light field work, and assumes 150 work days per year.
4. Includes livestock and general utility tasks, and assumes 300 work days per year.
5. Includes all five task groups, and assumes 300 work days per year.
6. Medium farms are 200 to 1000 acres; large farms are over 1000 acres.

TABLE A-5

Farmers Cooperating in This Study

1. Morris Apland RR1
Bruce, South Dakota

2. Arlen Berwald
Estelline, South Dakota Toronto

3. Jerry Hayden RR2
Brookings, South Dakota

4. James Hegg
Bruce, South Dakota

5. Terry Hill RR2
Brookings, South Dakota

6. Don Larson RR3 auctioneer
Brookings, South Dakota

7. Greg Nelson
Aurora, South Dakota

8. Wayne Ness
Toronto, South Dakota

9. Jerry Oines RR3
Brookings, South Dakota

10. Marvin Rentsch
Bruce, South Dakota RR1

11. David Rusten
White, South Dakota

12. Palmer Skovlund RR
Bruce, South Dakota

13. Charles Slocum
Aurora, South Dakota

14. Robert and Eric Sterud RR3
Brookings, South Dakota

TABLE A-5 (continued)

15. Ivan Sundal
Brookings, South Dakota

16. Larry Vander Wal
Brookings, South Dakota

17. Mason Wheeler
Aurora, South Dakota