DOE

MARKET RESEARCH STUDY

HYDROGEN FUEL CELLS IN FARM EQUIPMENT

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1.0 INTRODUCTION

Farm equipment is a sizeable business—globally and in the United States. It has been estimated that the global farm tractor market will increase from approximately $41.5 billion in 2020 to $50.5 billion in 2025.[1] While farm tractors are an established market, there has been interest in exploring alternatively powered tractors using sources such as biofuels, methane, and hydrogen fuel cells. There have been a few farm equipment prototypes using hydrogen fuel cells; however, there are no hydrogen fuel cell powered tractors currently available for purchase.

Presently, diesel is the most commonly used agricultural fuel, and is an integral part of the agricultural landscape. This trend holds up across farms of varying sizes and tractors spanning several power levels. The purpose of this report is to highlight the potential opportunities and challenges for hydrogen fuels cells used in farm tractors. This is addressed though a detailed look at the U.S. farm tractor market, agricultural fuels, and the current state of hydrogen fuel cell-powered farm tractors.

1.1 METHODOLOGY

Both secondary and primary market research methods were used to identify emerging markets for hydrogen fuel cell tractors. Secondary market research made use of information from two subscription databases (BCC Research and MarketsandMarkets) as well as publicly available information. To gain a perspective on the promise for hydrogen fuel cell powered farm tractors, primary research was used to reach out to several points of contact in multiple stakeholder groups—including farmers, those affiliated with farm associations or agriculture-related associations, associations focusing on farm equipment, farm equipment dealers, and associations for farm equipment dealers—to gauge interest in hydrogen fuel cell tractors and zero-emission tractors, more generally. In total, 124 people were involved in this outreach effort. Throughout this report, the results of the primary market research are interspersed and discussed without attribution.

Table 1: Primary Market Research

Group	Contacted	Received Feedback	Response Rate
Farmers and Farm Associations	104	20	19%
Farm Equipment Manufacturing Associations	5	2	40%
Farm Equipment Dealers and Related Associations	15	4	27%
Total	**124**	**26**	**21%**

2.0 Farm Tractor Market

2.0 FARM TRACTOR MARKET

Farmers in the U.S. are facing some specific challenges, including a growing population, a reduction in arable land, and a shortage of labor. As a result of these issues, farmers are relying heavily on farming equipment, particularly tractors in the <30 HP 31-70 HP power output segments.[2] The average cost of a tractor in the U.S. ranges from approximately $9,000 to $150,000 (though they can cost more). Tractor output typically correlates with price (a more powerful tractor will generally have a higher cost). This section provides an overview of the global and U.S. markets for farm tractors, with a focus on segmenting this market by tractor power output. Market size and growth statistics are provided, in terms of both the dollar value of the market and the volume of units sold.

Table 2: Tractor Pricing in the U.S., 2020[3]

Tractor Output (HP)	Price Range (USD)
<30 HP	$9,000-11,000
30-75	$25,000-50,000
75-100 HP	$50,000-70,000
>100 HP	$75,000-150,000

Another challenge facing farmers worldwide is the need to decrease the release of greenhouse gas emissions due to the use of diesel fuel in farm equipment. Alternative fuel sources are therefore being considered for use in farm equipment including the use of hydrogen fuel cell technology in tractors – the workhorse of contemporary farms. The purpose of this report is to explore the current market for farm equipment and consider the use of alternatives.

The market for farm equipment is usually represented in both dollars and power output. According to a 2020 report by MarketsandMarkets, the U.S. market for farm tractors is expected to increase from approximately $7.039 billion in 2020 to $8.580 billion in 2025, with a CAGR of 4% from 2020-2025.[4] With respect to units, the U.S. market for tractors is forecast to increase from roughly 251,400 units in 2020 to 292,700 units in 2025, with a CAGR of 3.1%.[5]

Table 3: U.S. Farm Tractor Market, by Power Output (USD Million)[6]

Power Output	2018	2019	2020	2023	2025	CAGR (2020-2025)
<30 HP	133.3	139.7	144.4	157.3	164.6	2.7%
31-70 HP	59.7	61.2	63.0	69.7	74.2	3.3%
71-130 HP	26.9	27.2	28.0	31.4	33.9	3.9%
131-250 HP	11.9	12.2	12.4	14.2	15.5	4.5%
>250 HP	3.7	3.8	3.6	4.0	4.6	5.0%
Total	**235.4**	**244.0**	**251.4**	**276.7**	**292.7**	**3.0%**

Table 4. U.S. Farm Tractor Market, by Power Output (USD Million)[7]

Power Output	2018	2019	2020	2023	2025	CAGR (2020-2025)
<30 HP	1,233	1,297	1,344	1,479	1,554	2.9%
31-70 HP	1,469	1,510	1,560	1,743	1,862	3.6%
71-130 HP	1,592	1,614	1,669	1,894	2,047	4.2%
131-250 HP	1,615	1,666	1,692	1,948	2,124	4.7%
>250 HP	783	808	775	871	993	5.1%
Total	**6,693**	**6,895**	**7,039**	**7,935**	**8,580**	**4.0%**

Growth in the farm equipment market, which includes tractors, implements, and other types of farm equipment is driven by increasing farm mechanization across the globe as well as favorable government policies for agricultural growth. However, challenges such as the degradation of soil fertility, unpredictable shifts in climate patterns, and the need for better operational output are driving farmers to choose increasingly mechanized methods of farming for enhanced productivity and performance. As such, the global market for farm tractors is expected to increase from approximately $41.520 billion in 2020 to $50.545 billion in 2025, with a compound annual growth rate (CAGR) of 4% from 2020-2025.[8] With respect to units, the global market for tractors is forecast to increase from roughly 2,196,000 units in 2020 to 2,555,000 units in 2025, with a CAGR of 3.1%.[9] The global tractor market is segmented by power output, with segments aligning with the following power output categories: <30 HP, 31-70 HP, 71-130 HP, 131-250 HP, and >250 HP.

Table 5. Global Farm Tractor Market, by Power Output ('000 Units)[10]

Power Output	2018	2019	2020	2023	2025	CAGR (2020-2025)
<30 HP	968	872	848	909	956	2.4%
31-70 HP	967	1,036	1,023	1,122	1,201	3.3%
71-130 HP	231	217	213	239	259	4.0%
131-250 HP	103	100	97	110	119	4.1%
>250 HP	17	16	16	18	20	4.9%
Total	**2,285**	**2,241**	**2,196**	**2,398**	**2,555**	**3.1%**

Table 6: Global Farm Tractor Market, by Power Output (USD Million)

Power Output	2018	2019	2020	2023	2025	CAGR (2020-2025)
<30 HP	5,361	4,946	4,868	5,303	5,603	2.9%
31-70 HP	13,161	13,939	13,867	15,420	16,692	3.8%
71-130 HP	9,740	9,252	9,134	10,346	11,238	4.2%
131-250 HP	11,057	10,944	10,687	12,156	13,183	4.3%
>250 HP	3,203	3,097	2,964	3,429	3,829	5.3%
Total	**42,522**	**42,178**	**41,520**	**46,655**	**50,545**	**4.0%**

2.1 TRACTOR MARKET SUPPY CHAIN

For R&D firms working on the development of hydrogen technology for potential application in farm equipment, it is important to understand the tractor supply chain which encompasses component suppliers, original equipment manufacturers (OEMs), dealers, and customers.

Component suppliers can include suppliers of engines, tires, hydraulic control and hitch systems, transmission gears, and steering mechanisms. Major component suppliers include companies such as Cummins, Deutz, FPR Industrial, Carraro, YTO France, ZF TRW, Daedong, and Yanmar. Major tractor manufacturers include **John Deere, Mahindra & Mahindra, AGCO, CLAAS, Zetor Tractors, Kubota, TAFE, SDF Group, and Yanmar.** Dealers play a role in selling both tractors and implements and farmers would represent the customer and end-user. **Dealers play an important role in the supply chain, as they act as an intermediary between tractor OEMs and farmers**. These dealers have an opportunity to educate farmers when it comes to new technology, how to best use the equipment, and how to select the product most suitable for their focus area(s). Agro-dealers are regarded as the "best source of information on product acceptance, pricing, quality, competition, market conditions, and input demand."[11] Farmers establish relationships with dealers to learn more about the equipment that is best suited for their crops, and to procure that equipment. **The interactions between dealers and farmers often flow back to OEMs, enabling OEMs to develop machinery that will meet customer needs and specifications**.[12]

Component Suppliers	OEMs	Dealers	Customers
Example Components: • Engines • Tires • Hydraulic control and hitch systems • Transmission gears • Steering mechanisms **Example Companies:** • Cummins Deutz • FPR Industrial • Carraro • YTO France • ZF TRW • Daedong • Yanmar	**Example OEMs:** • John Deere • Mahindra & Mahindra • AGCO • CLAAS • Zetor Tractors • Kubota • TAFE • SDF Group • Yanmar	• Tractors • Implements **Example Dealers:** • SEMA Equipment • Farol • Baldwin Tractor & Equipment • RDO John Deere • Titan Machinery Case IH New Holland • Brandt Holdings John Deere	Farmers

Figure 1. Tractor Market Supply Chain, (MarketsandMarkets)[13]

3.0 Installed Base of U.S. Farm Tractors

3.0 INSTALLED BASE OF U.S. FARM TRACTORS

Farm tractors represent a major investment for working farms and are maintained and used for years. In considering an eventual transition in the U.S. to tractors using alternative fuels or alternative sources of power, one must consider the size of the installed base, by size of farm – as well as the life of a farm tractor. This section provides information on several aspects of the tractor landscape, ranging from power level to lifecycle.

3.1 TRACTOR STATISTICS FROM THE CENSUS OF AGRICULTURE

The U.S. Department of Agriculture (USDA) released the most recent *Census of Agriculture* (the *2017 Census of Agriculture*) in April 2019. The *Census of Agriculture* looks at the number of tractors and segments this data by horsepower, as well as by farm size. The following table looks at the number of tractors in use on U.S. farms, segmented by power level.

Table 7. Number of Tractors on U.S. Farms, by Power Level (USDA)[14]

Tractor Horsepower Segment	Number of Tractors on U.S. Farms (2017)
Less than 40 horsepower	995,918 tractors
40-99 horsepower	1,795,589 tractors
100 horsepower	1,246,592 tractors
Total number of tractors	**4,038,099 tractors**

The *Census of Agriculture* also estimates the number of tractors, by both power level and farm size. The following tables look at the farm size segmentation for the total number of tractors and the number of tractors in each horsepower segment.

Table 8. All U.S. Tractors, Segmented by Farm Size (USDA)[15]

Farm Size (Acres)	Total Number of Tractors
1 to 9 acres	212,197
10 to 49 acres	712,362
50 to 69 acres	211,134
70 to 99 acres	275,381
100 to 139 acres	287,774
140 to 179 acres	238,990
180 to 219 acres	176,595
220 to 259 acres	146,523
260 to 499 acres	531,239
500 to 999 acres	473,543
1,000 to 1,999 acres	368,622
2,000 or more acres	403,739
Total	**4,038,099**

Table 9. U.S. Tractors Less Than 40 HP, Segmented by Farm Size (USDA)[16]

Farm Size (Acres)	Total Number of Tractors
1 to 9 acres	119,257
10 to 49 acres	300,643
50 to 69 acres	69,255
70 to 99 acres	81,210
100 to 139 acres	75,152
140 to 179 acres	55,731
180 to 219 acres	37,417
220 to 259 acres	29,233
260 to 499 acres	88,679
500 to 999 acres	62,156
1,000 to 1,999 acres	40,067
2,000 or more acres	37,118
Total	**995,918**

Table 10: U.S. Tractors in the 40-99 HP Range, Segmented by Farm Size (USDA)[17]

Farm Size (Acres)	Total Number of Tractors
1 to 9 acres	78,207
10 to 49 acres	351,085
50 to 69 acres	116,672
70 to 99 acres	152,268
100 to 139 acres	160,500
140 to 179 acres	127,958
180 to 219 acres	93,736
220 to 259 acres	74,995
260 to 499 acres	247,619
500 to 999 acres	179,615
1,000 to 1,999 acres	110,743
2,000 or more acres	102,191
Total	**1,795,589**

Table 11: U.S. Tractors in the 100+ HP Range, Segmented by Farm Size (USDA)[18]

Farm Size (Acres)	Total Number of Tractors
1 to 9 acres	14,733
10 to 49 acres	60,634
50 to 69 acres	25,207
70 to 99 acres	41,903
100 to 139 acres	52,122
140 to 179 acres	55,301
180 to 219 acres	45,442
220 to 259 acres	42,295
260 to 499 acres	194,941
500 to 999 acres	231,772
1,000 to 1,999 acres	217,812
2,000 or more acres	264,430
Total	**1,246,592**

3.2 AVERAGE LIFETIME OF A TRACTOR

The U.S. Department of Agriculture's *2017 Census of Agriculture* looks at the number of U.S. tractors—in total and segmented by horsepower range—and further segments this data based on tractors manufactured prior to 2013 and tractors manufactured from 2013-2017. The following table outlines this data. On average, approximately 12% of tractors in use are from the previous four years, with a vast majority of U.S. tractors in use (88%) being more than four years old.

Table 12: U.S. Tractors, Segmented by Manufacturing Date (USDA)[19]

Tractor Type	Total Number	Number of Tractors Manufactured from 2013-2017	Number of Tractors Manufactured Prior to 2013
All Tractors	**4,038,099**	**470,722 (12%)**	**3,567,377 (88%)**
< 40 HP Tractors	995,918	98,566 (10%)	897,352 (90%)
40-99 HP Tractors	1,795,589	191,415 (11%)	1,604,174 (89%)
100+ HP Tractors	1,246,592	180,741 (14%)	1,065,851 (86%)

In terms of lifespan, the average useful life of a tractor is typically measured in hours. Farm tractors are often used from 100-600 hours per year, depending on the farm, with the average hard-working tractor logging approximately 500 hours annually.[20,21] The average useful life of most tractors is approximately 12,000 hours, though estimates and lifetimes can vary substantially depending on how a tractor is used and maintained.[22] Other sources have indicated that well-maintained tractors average about 8,000-10,000 engine hours before requiring more (unscheduled) maintenance. Both compact tractors with diesel engines and gas engine tractors average 6,000-8,000 hours.[23] According to the Iowa State University Ag Decision Maker, the estimated economic life is 10-12 years for most farm machines and 15 years for tractors.[24]

3.2 FUELS COMMONLY USED IN FARM TRACTORS

There are a number of fuels that are used in farm tractors, including diesel, kerosene, gasoline, LP gas, and tractor-fuel/distillate/TVO.[25] Diesel is the type of fuel most commonly used in tractors.

In September 2014, a team from Idaho National Laboratory published a report titled "Agricultural Industry Advanced Vehicle Technology: Benchmark Study for Reduction in Petroleum Use." According to this report, "nearly all modern tractors used in commercial agriculture are powered with diesel fuel."[26] The report explores alternative fuels and the process of replacing diesel with alternative fuels. An OEM survey was conducted, noting that the availability of alternative fuels was the highest barrier, in terms of alternative fuels reducing petroleum consumption in the agricultural equipment segment. The same OEM survey stated that cost ranked highest as a barrier to the further adoption of alternative fuels. Other noteworthy barriers to adoption include distribution and production, customer perception and acceptance, engine technology, and energy density (on-machine storage capacity). Biodiesel was discussed as a direct substitute for petroleum diesel, as no engine modifications are required for the use of biodiesel. Ethanol is a direct substitute for petroleum gasoline fuel. Hydrogen fuel cells are discussed, relative to tractors. The first fuel cell tractor was prototyped by Allis Chalmers in 1959. While this tractor was twice as efficient, compared to typical tractors at that time, the Allis Chalmers AC D-12 never made it to mainstream production. About a decade ago, a more modern hydrogen fuel cell tractor was developed by New Holland. Their NH2 working prototype was capable of 79 kW, or 106 HP. This tractor uses no petroleum-based fuel, and it emits only water vapor, but the availability of hydrogen fuel and the distribution infrastructure needed posed as significant barriers to the widespread adoption of this technology.[27] Natural gas fueled tractors have also been developed. There are two options for using natural gas as a diesel replacement in tractors—either as pure natural gas or as part of a dual fuel system. The natural gas would need to be used as either compressed natural gas (CNG) or liquefied natural gas (LNG). Some examples of natural gas tractors that have been developed include the Steyr Profi 4135 (a dedicated natural gas tractor), a 135-hp methane-powered research tractor from New Holland (which can also run on diesel fuel) called the T6.140 Methane Power tractor, and the T133 from Valtra (which runs entirely on diesel or as a dual-fuel system with 83% natural gas and 17% diesel).[28]

According to a paper titled "Modeling Non-Road Agricultural Tractor Emissions in Central Texas," in 2012 the Capital Area Council of Governments (CAPCOG)—an organization representing 10 counties in Central Texas—and Eastern Research Group (ERG) conducted a regional survey of tractor operators in order to obtain detailed data on tractor usage and engine characteristics. As part of the survey, these groups gathered data on different types of tractors in use by survey respondents. The following table outlines the horsepower range for the various tractor models and the percentage of tractors in each category that use diesel fuel, gasoline, or LPG (liquified petroleum gas).

Table 13: Fuel Type Distribution by Tractor HP Grouping[29]

HP Range	Diesel (%)	Gas (%)	LPG (%)
< 40 HP	69.0%	26.3%	4.7%
40-99 HP	90.2%	8.3%	1.5%
100+ HP	100.0%	0.0%	0.0%

Diesel fuel accounts for a majority of fuel used in farm tractors. However, gas and LPG are also used to a lesser extent—and these fuels are more commonly used in smaller tractors that are less than 40 HP. In terms of the amount of fuel used, on the basis of farm size, there are a few sources that address this topic.

Fuels represented a little under 5% of the total of selected farm production expenses in 2017, down from 2007.[30] The definition and figures are based on the *2017 Census of Agriculture,* and include gasolines, fuels, and oils with expenses including the cost of all gasoline, diesel, natural gas, LP gas, motor oil, and grease products for the farm during 2017. These expenses exclude fuel for personal use of automobiles by the family and others, fuel used for cooking and heating the farmhouse, and any other use outside of farm work on the operation.[31]

Table 14. Gasoline, Fuels, and Oils Purchased by Farms, Segmented by Farm Production Expenses: 2017 and 2012 (USDA)[32]

	2012		2017	
	Farms	**Expenses ($1,000)**	**Farms**	**Expenses ($1,000)**
Total	**1,987,747**		**1,921,692**	
Farms with expenses of				
$ to $999	890,927	345,709	925,276	335,393
$1,000 or more	640,319	1,441,430	596,693	1,312,064
$5,000 or more	165,939	1,107,717	156,790	1,049,101
$10,000 or more	154,232	2,378,613	137,508	2,080,039
$25,000 or more	72,414	2,482,956	57,541	1,951,406
$50,000 or more	63,916	8,816,762	47,884	6,746,118

The *2017 Census of Agriculture* also looks at the number of U.S. farms that purchase gasoline, fuels, and oils and the amount spent on gasoline, fuels, and oils, segmenting this information by farm size. These expenses include the cost of all gasoline, diesel, natural gas, LP gas, motor oil, and grease products for the farm in a single year (2017).[33]

Table 15: Number of U.S. Farms Purchasing Gasoline, Fuels, and Oils and Dollar Amount Spent on Gasoline, Fuels, and Oils Per Farm Size Segment (USDA)[34]

Farm Size	Number of U.S. Farms that Purchase Gasoline, Fuels, and Oils	Collective Amount Spent on Gasoline, Fuels, and Oils
1 to 9 acres	243,392	$405,304,000
10 to 49 acres	541,260	$997,401,000
50 to 69 acres	127,223	$284,887,000
70 to 99 acres	153,343	$380,092,000
100 to 139 acres	141,665	$402,368,000
140 to 179 acres	109,521	$373,096,000
180 to 219 acres	71,222	$298,327,000
220 to 259 acres	54,895	$259,782,000
260 to 499 acres	177,554	$1,239,272,000
500 to 999 acres	130,428	$1,750,619,000
1,000 to 1,999 acres	86,599	$2,218,136,000
2,000 or more acres	84,590	$4,864,837,000
Total	**1,921,692**	**$13,474,121,000**

While the average cost of fuel will vary according to fuel type, region, and date (among possibly other factors), one could obtain an estimated or average fuel cost and use this figure to further estimate the average amount of fuel used per farm. For example, in 2017, the average annual cost of gasoline was $2.53 and the average annual cost of diesel was $2.65.[35] With an average fuel cost of $2.60 per gallon in 2017, one could take the collective amount spent on gasoline, fuels, and oils on U.S. farms ($13,474,121,000), divide that by the number of farms (1,921,692), and then divide that by the average cost per gallon of fuel ($2.60) to get an estimated 2,697 gallons of fuel per farm on an annual basis.

In October 2019, the California Air Resources Board published a report titled "Analysis of California's Diesel Agricultural Equipment Inventory According to Fuel Use, Farm Size, and Equipment Horsepower." This report looks at the amount of fuel consumed, by farm size. For example, a 50- to 100-acre farm is estimated to use approximately 40 gallons of fuel per acre, annually.

Table 16: Farm Size Range, in Acres (CARB)[36]

Farm Size Groupings
0 to 15 acres
15 to 50 acres
50 to 100 acres
100 to 250 acres
250 to 500 acres
500 to 1,000 acres
Over 1,000 acres

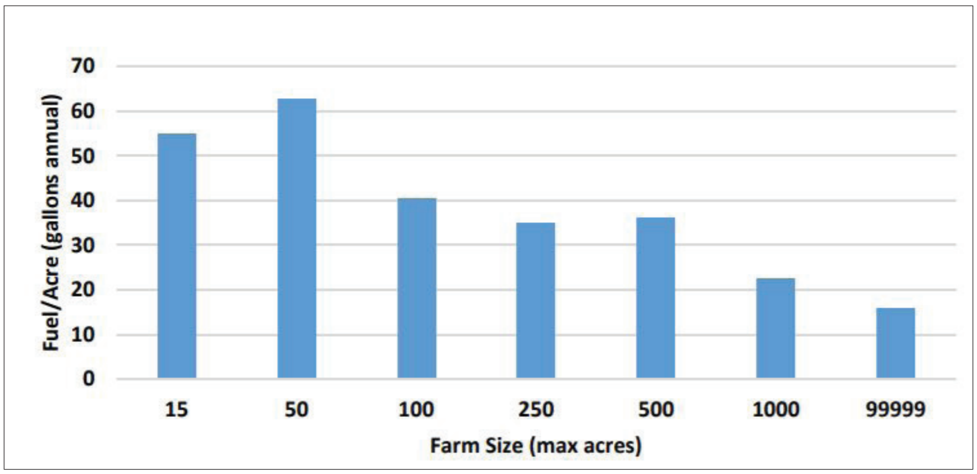


Figure 2: Fuel Use Per Acre, by Farm Size (Maximum Acres) (CARB)

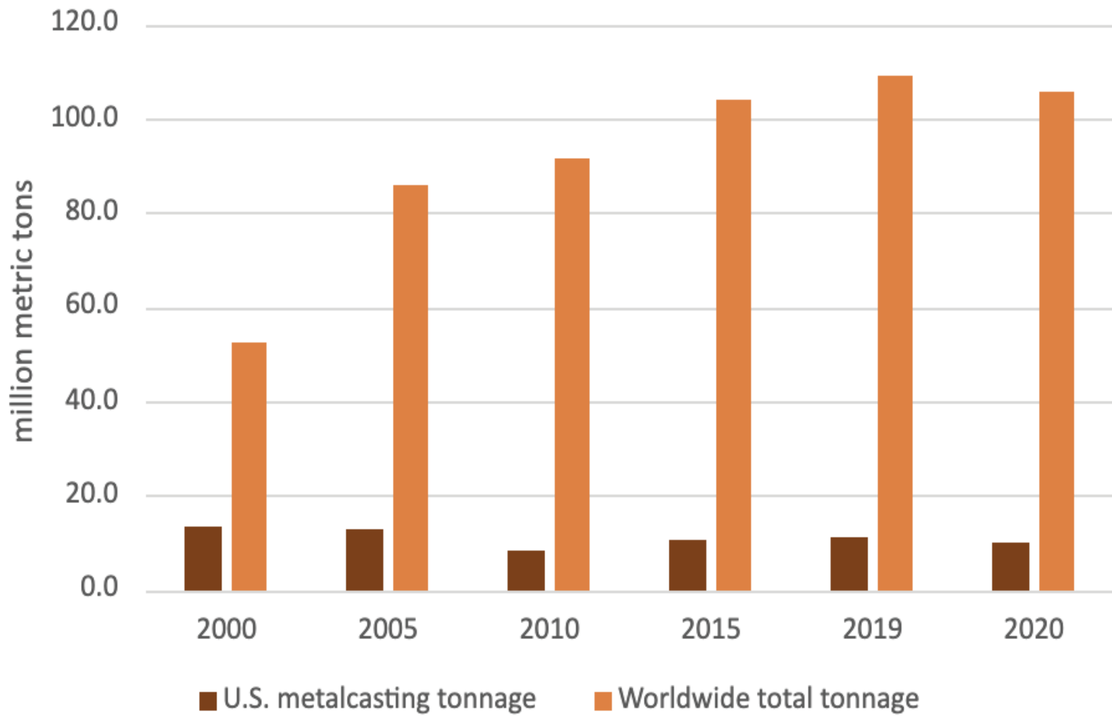


Figure 3: Fuel Use According to Farm Size (CARB)[37]

Iowa State University Extension and Outreach has provided guidance to help those in the agricultural segment to estimate farm machinery costs, and these costs include fuels. According to this source, average fuel consumption (in gallons per hour) for farm tractors on a year-round basis (without reference to any specific implement) can be estimated using the following equations (power takeoff/PTO):

- 0.060 x maximum PTO horsepower for gasoline engines
- 0.044 x maximum PTO horsepower for diesel engines[38]

From what the research has suggested, nearly all tractors above 100 HP run on diesel fuel (aside from what may be a few select prototypes and innovative models). If you were to take 0.044 and multiply that figure by 100 (assuming a 100 HP tractor), you would have 4.4 gallons of fuel being used per hour. Tractors are often used from 100-600 hours per year. With this in mind, it could be estimated that a tractor of this horsepower level would use approximately 440 to 2,640 gallons of fuel per year.

When looking at diesel specifically, the table 17 contains estimates of the average quantity of diesel fuel required for farm field operations. The estimates include only the fuel required for actual field work and do not account for machine preparation or travel to and from the field.

Table 17: Approximate Diesel Fuel Required for Field Operations[39]

Field Operation	Diesel Gallons Per Acre	Field Operation	Diesel Gallons Per Acre
Fertilization		Harvesting	
Spreading dry fertilizer, bulk cart	0.15	Mower	0.03
Anhydrous ammonia (30-inch spacing)	0.55	Mower-conditioner, PTO	0.55
		Self-propelled windrower	0.45
Tillage		Rake	0.25
Shredding cornstalks	0.45	Baler	0.40
Moldboard plow	1.70	Forage harvester	
Subsoiler/ripper	1.70	Green forage	0.85
Disk-chisel plow	1.30	Haylage	1.15
Chisel plow	1.10	Corn Silage	3.25
Offset disk	0.85	High-moisture ground ear corn	1.70
Tandem disk, plowed field	0.65	Forage blower	
Tandem disk, tilled field	0.55	Green forage	0.30
Tandem disk, cornstalks	0.45	Haylage	0.25
Field cultivate, plowed field	0.70	Corn silage	1.25
Field cultivate, tilled field	0.65	High-moisture ground ear corn	0.40
Seedbed conditioner	0.90	Combine, soybeans	1.00
		Combine, corn	1.45
Planting (30-inch rows)		Hauling, field plus 1/2 mile on gravel road	
Planter, seed only, tilled seedbed	0.40	Green forage	0.30
Plant with fertilizer and pesticide attachments, tilled seedbed		Haylage	0.20
	0.55	Corn silage	1.25
Till-planter	0.55	Corn grain	0.20
No-till planter	0.45	Soybeans	0.08

Grain drill	0.30	Hauling, add following values to those above for each additional mile on gravel road	
Broadcast seeder	0.15		
Air drill	0.70	Green forage	1.15
		Haylage	0.20
Weed Control (30-inch rows)		Corn silage	0.80
Sprayer, trailer type	0.10	Corn grain	0.15
Rotary hoe	0.20	Soybeans	0.05
Row-crop cultivator	0.40		

In looking at diesel use on U.S. farms from a high-level perspective, the U.S. Energy Information Administration (EIA) provides annual data on the sales of distillate fuel oil (diesel) by end use (farms represent an end use category). In 2019, approximately 3,451,746,000 gallons of distillate fuel oil were purchased by farm consumers.[40]

Table 18: Sales of Distillate Fuel Oil in the Farm Segment (EIA)[41]

Year	Amount of Distillate Fuel Oil Purchased by Farm Consumers
2014	3,209,391,000
2015	3,248,791,000
2016	3,457,677,000
2017	3,435,842,000
2018	3,466,434,000
2019	3,451,746,000

Farm equipment is a contributor of greenhouse gas emissions in the United States. In April 2021, the U.S. Environmental Protection Agency (EPA) published the “Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-2019.” This report states that in 2019, approximately 39.7 $MMTCO_2$-Eq of CO_2 was attributed to fuel combustion in the agricultural segment (including from motorized farm equipment, such as tractors). Also in 2019, an additional 0.1 $MMTCO_2$-Eq of CH_4 emissions and 1.1 $MMTCO_2$-Eq in N_2O emissions were attributed to agricultural equipment (which includes equipment such as tractors and combines, as well as fuel consumption from trucks that are used off-road in agriculture). In 2019, fuel combustion in the agricultural segment accounted for at least 40.9 $MMTCO_2$-Eq of greenhouse gas emissions in the United States.

Table 19: Greenhouse Gas Emissions Linked to U.S. Agricultural Fuel Combustion and Equipment (U.S. EPA) (in MMTCO$_2$-Eq)[42]

Emission Type	2015	2016	2017	2018	2019
CO_2[1]	41.1	40.2	39.8	39.8	39.7
CH_4[2]	0.1	0.1	0.1	0.1	0.1
N_2O[3]	1.1	1.1	1.1	1.1	1.1
Total	**42.3**	**41.4**	**41.0**	**41.0**	**40.9**

The EPA covers greenhouse gas emissions linked to agricultural fuel combustion and equipment separately from other agriculture sector emissions. In terms of the broader impact of farms on greenhouse gas emissions, the EPA reports that agriculture sector emissions totaled 628.6 MMTCO$_2$-Eq in 2019.[43]

Table 20: Emissions from Agriculture (U.S. EPA) (in MMTCO$_2$-Eq)[44]

Gas/Source	1990	2005	2015	2019
CO_2 – Urea Fertilization	2.4	3.5	4.7	5.3
CO_2 – Liming	4.7	4.3	3.7	2.4
CH_4 – Enteric Fermentation	164.7	169.3	166.9	178.6
CH_4 – Manure Management	37.1	51.6	57.9	62.4
CH_4 – Rice Cultivation	16.0	18.0	16.2	15.1
CH_4 – Field Burning of Agricultural Residues	0.4	0.4	0.4	0.4
N_2O – Agricultural Soil Management	315.9	313.4	348.5	344.6
N_2O – Manure Management	14.0	16.4	17.5	19.6
N_2O – Field Burning of Agricultural Residues	0.2	0.2	0.2	0.2
Total	**553.3**	**577.1**	**616.1**	**628.6**

1 This is CO_2 from fossil fuel combustion in the agriculture segment. In 2019, about 39.7 MMTCO$_2$-Eq was attributed to fossil fuel combustion in the agricultural segment, and this accounted for 0.6% of total (gross) emissions for that year.

2 This is CH_4 from non-road agricultural equipment—which includes equipment such as tractors and combines, as well as fuel consumption from trucks that are used off-road in agriculture.

3 This is N_2O from non-road agricultural equipment—which includes equipment such as tractors and combines, as well as fuel consumption from trucks that are used off-road in agriculture.

3.4 ON-SITE FUELING

When considering the transition from diesel to hydrogen, an important consideration is the distribution method. Agricultural fuels appear to be supplied to farms through a network of fuel suppliers and distributors. These suppliers are often regionally focused, and some provide additional services such as remote fuel tank monitoring. Remote monitoring-based delivery schedules are identified as a way to reduce greenhouse gasses since it can cutdown on transportation fuels and reduces waste. While diesel dominates the agricultural fuel space and delivery options, several suppliers also offer other types of fuel deliveries such as biofuels, propane, and gasoline.

In June 2015, the U.S. Environmental Protection Agency Office of Emergency Management published a report titled, *Oil Storage on U.S. Farms: Risks and Opportunities for Protecting Surface Waters*. While dated, this report appears to provide the most recently available statistics. This report was prepared in response to a provision included in the Water Resources Reform and Development Act (WRRDA) of 2014 which called for the EPA to conduct a study to determine the aggregate aboveground oil storage capacity threshold for farms subject to the Spill Prevention Control and Countermeasure (SPCC) regulation.

SPCC applies to a farm that: “Stores, transfers, uses, or consumes oil or oil products, such as diesel fuel, gasoline, lube oil, hydraulic oil, adjuvant oil, crop oil, vegetable oil, or animal fat; and stores more than 2,500 U.S. gallons in aboveground containers; and could reasonably be expected to discharge oil to waters of the United States or adjoining shorelines, such as interstate waters, intrastate lakes, rivers, and streams.”[45]

In 2008 EPA estimated that approximately 150,000 farms may have sufficient aggregate oil storage capacity to be subject to the SPCC requirements (based on greater than 1,320 gallons aggregate aboveground oil storage capacity at the time). However, this figure is an estimate – neither EPA nor USDA gather information on oil storage quantities or handling practices on farms. Although national data on oil storage are not available, the USDA compiles data on fuel expenditures, which provide some insight on uses of diesel, gasoline, and other oils on U.S. farms.[46] These fuel expenditure figures, as analyzed by EPA, estimates that 81-96 percent of U.S. farms store less than 2,500 gallons of oil on site (either in aboveground or underground containers), and only a very small fraction of farms – less than about 1 percent – store more than 20,000 gallons of oil. This is based on the USDA expenditure information and a review of tank registration data as well as by anecdotal information compiled by EPA.[47]

As noted previously, EPA estimated that there were approximately 150,000 farms subject to the SPCC rule in 2008, these figures were then updated using new information. Although there is considerable variability across farms, the fuel expenditure data compiled and analyzed by EPA suggest that 81 to 89 percent of U.S. farms have an aggregate storage capacity below 1,320 gallons of oil, 81 to 96 percent have less than 2,500 gallons, and 92 to 99 percent have less than 6,000 gallons. An estimated 99 to 99.9 percent of farms have aggregate storage capacity below 20,000 gallons.[48]

Table 21: Number and Aggregate Storage Capacity of Farms by Economic Class in 2013[49]

		$10M or more	$5M to $9.99M	$3M to $4.99M	$1M to $2.99 M	$500,000 to $999,999	$275,000 to $499,999	$100,000 to $274,999	Less than $100,000
Number of farms		**2,643**	**6,926**	**11,979**	**70,235**	**68,887**	**80,408**	**156,421**	**1,697,970**
Estimated average aggregate storage capacity (gallons/farm)	*Low*[1]	26,105	13,609	7,246	4,069	2,340	1,652	898	154
	High[1]	87,570	44,522	25,160	14,116	7,876	5,551	2,920	463

Based on 2013 data from USDA on fuel expenditures by fuel type and by farms in different revenue categories (USDA NASS, personal communication).

[1] Range represents different assumptions of the number of fuel deliveries. For low bound (smaller storage capacity), EPA assumed 2 deliveries for gasoline and 4 deliveries for diesel per year; for high bound (greater storage capacity), EPA assumed 1 delivery each for gasoline and diesel per year.

Table 22: Distribution of farms by aggregate storage capacity range in 2013[50]

			1,320-2,500 gallons	2,500-6,000 gallons	6,000-10,000 gallons	10,000-20,000 gallons	20,000 gallons or higher
	Less than 1,320 gallons						
Number of farms	*Low*[1]	1,854,391	149,295	70,235	11,979	6,926	2,643
	High[1]	1,697,970	02	236,829	68,887	70,235	21,548
% of farms	*Low*[1]	88.5%	7.1%	3.4%	0.6%	0.3%	0.1%
	High[1]	81.0%	0.0%	11.3%	3.3%	3.4%	1.0%

Based on 2013 data from USDA on fuel expenditures by fuel type and by farms in different revenue categories (USDA NASS, personal communication).

[1] Range represents different assumptions of the number of fuel deliveries. For low bound (smaller storage capacity), EPA assumed 2 deliveries for gasoline and 4 deliveries for diesel; for high bound (greater storage capacity), EPA assumed 1 delivery each for gasoline and diesel.

[2] USDA provides average annual fuel expenditures by economic class. As shown in Exhibit 9 above, the estimated average aggregate storage capacities for farms with expenditures in the two smallest fuel expenditure categories fall either below (463 gallons) or above (2,920 gallons) the 1,320- to 2,500-gallon range.

Per the 2015 EPA report on on-site farm oil storage, characteristics of on-farm fuel storage included bulk storage container types, fuel types, container sizes, location, and distribution within the farm facility (e.g., central vs. satellite oil storage areas), and frequency of fuel deliveries. This report included research from pasts studies on storage and a combination of primary and secondary research.[51]

According to a 2006 report, in which a number of farmers were interviewed, it was confirmed that commonly sized fuel storage tanks (1,000 gallons) are typically refilled three to four times per year, and that larger tanks (7,000 to 10,000 gallons) require less frequent deliveries — typically one per year. Based on this delivery frequently it may be estimated that fuel demand for larger farms (with larger storage tanks) may be 14,000 to 20,000 gallons per tank per year. However, at the other end of the spectrum, about ten percent of farmers have oil deliveries 10 to 15 times per year and typically have tanks of 500 gallons or less, or high fuel consumption. It was also reported that most farms receive delivery to their 500-gallon tanks weekly during the peak season.[23]

3.4.1 FUEL COOPERATIVES

Agricultural cooperatives (co-ops) have been a part of the agricultural fuel supply landscape since the 1920s. These fuel cooperatives provide a range of services which typically include fuel supply and distribution, but some incorporate wholesale, refining, and even exploration and production of petroleum to help provide lower cost fuels to the cooperative members. These cooperatives may be local or regional with local groups tending to focus on retailing and farm facility delivery and larger, regional groups handling other aspects of agricultural petroleum supply.[52]

The January 2021 USDA Rural Development Service Report on agricultural cooperatives reports that there were 1,779 agricultural cooperatives in 2019, which is 27 fewer than in 2018. This decrease was primarily attributed to mergers among cooperatives and some dissolutions. Of the 1,779 co-ops, 1,516 operate within 1 state, the other 263 operate in 2 or more states. In terms of type, there were 931 marketing co-ops, 759 supply co-ops, and 89 service co-ops in 2019 – petroleum products are distributed through supply co-ops. These agriculture co-ops operated 7,587 branch and other locations in 2019, and including headquarters, had 9,366 locations.[53]

Petroleum co-op sales were the highest of all supplies, at 26.9 billion in 2019, and were down very slightly from 2018.[54] The following tables present information on co-op petroleum sales, number of co-ops, and co-op memberships.

Table 23: Combined Income Statement, U.S. Ag Co-ops, 2019 and 2018[55]

	2019	2018	Difference	Change
	Billion $	*Billion $*	*Million $*	**Percent**
Supplies sold (gross sales): Crop protectants	8.119	8.941	(821.9)	**(9.19)**
Feed	11.759	11.859	(99.3)	**(0.84)**
Fertilizer	13.632	13.367	265.1	**1.98**
Petroleum	**26.885**	**26.886**	**(1.0)**	**(0.00)**
Seed	5.576	5.861	(285.8)	**(4.88)**
Other supplies	5.070	4.814	256.3	**5.32**
Total supplies	71.041	71.728	(686.6)	**(0.96)**
Total gross revenue	195.957	198.061	(2,103.8)	**(1.06)**
Cost of goods sold	173.641	175.946	(2,305.7)	**(1.31)**
Gross margin	22.316	22.113	203.9	**0.92**
Service and other operating income	5.248	4.272	976.0	**22.85**
Gross revenue	**27.564**	**26.384**	**1,179.8**	**4.47**

Table 24: Data used in trend analysis, U.S. ag co-ops, 2010 to 2019[56]

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Number of cooperatives										
Marketing	1,215	1,222	1,206	1,195	1,114	1,079	1,040	1,010	961	931
Supply and service	1,099	1,063	1,032	991	992	968	913	861	845	848
Total	2,314	2,285	2,238	2,186	2,106	2,047	1,953	1,871	1,806	1,779
Number of memberships *(millions)*										
Marketing	0.737	0.846	0.652	0.655	0.627	0.591	0.584	0.604	0.594	0.677
Supply & service	1.498	1.434	1.463	1.321	1.368	1.330	1.317	1.286	1.295	1.222
Total	2.235	2.280	2.115	1.976	1.995	1.921	1.901	1.890	1.889	1.900
Net sales of selected supplies *(billion $)*										
Petroleum	***16.450***	***20.330***	***23.360***	***24.400***	***25.600***	***21.390***	***17.031***	***16.963***	***19.037***	***18.905***
Feed	8.590	10.490	11.840	12.720	10.800	9.932	9.032	8.938	9.905	9.932
Fertilizer	9.370	11.940	14.190	14.020	16.300	12.326	10.425	9.884	10.438	10.714
Crop protectants	5.640	6.600	7.190	7.330	7.500	7.315	6.377	6.970	6.208	5.599
Seed	2.630	2.900	3.270	3.360	3.400	3.188	3.373	3.507	3.689	3.443

Table 25: Net Sales of Petroleum & U.S. Ag Co-ops, by State, 2019[57]

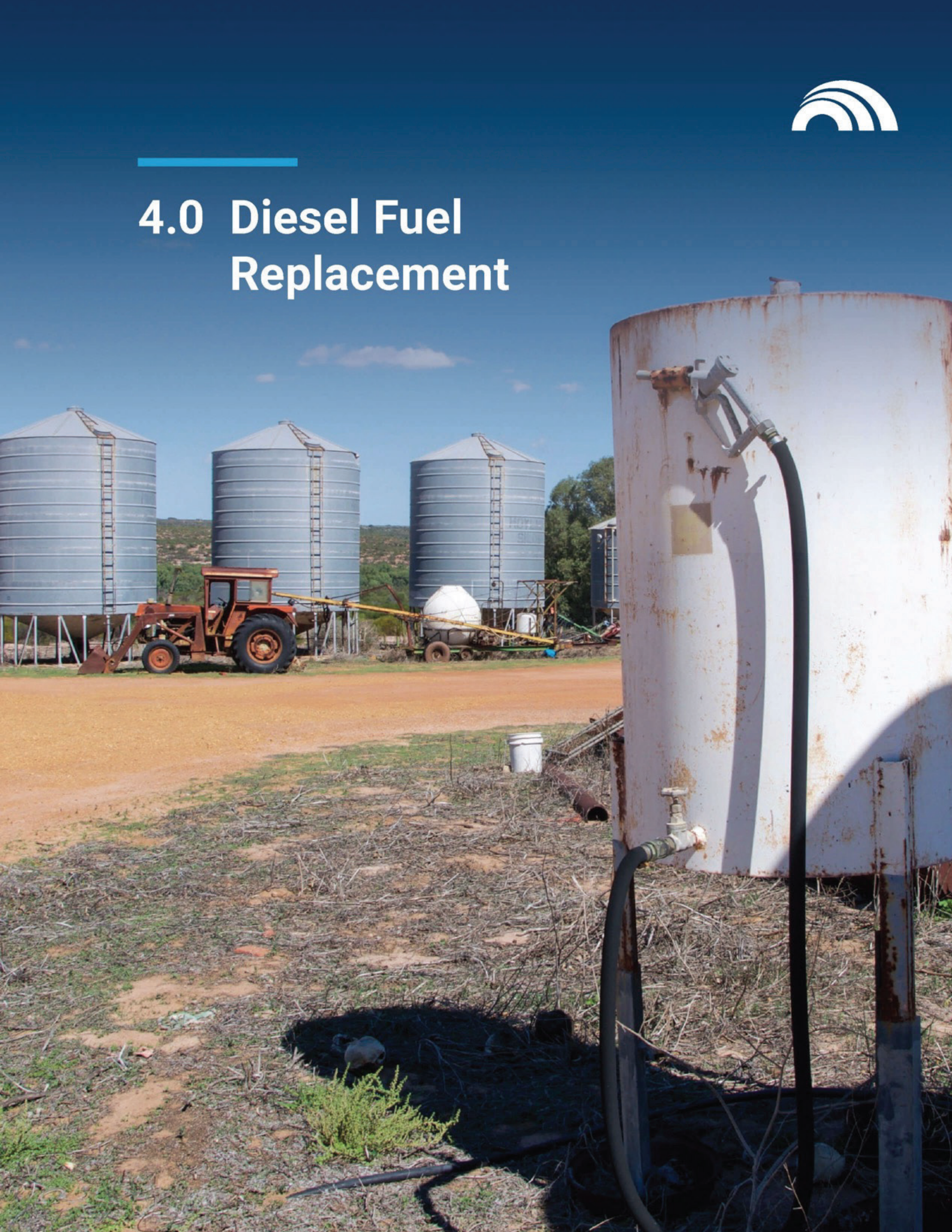
ITEM	AK	AL	AR	AZ	CA	CO	CT	DE
Petroleum	--	23.045	248.377	3.608	22.360	385.489	5.565	20.682
Co-ops in State (no.)	11	59	47	26	127	45	11	11
ITEM	**FL**	**GA**	**HI**	**IA**	**ID**	**IL**	**IN**	**KS**
Petroleum	40.415	28.827	-	1,978.375	198.478	1,844.805	1,003.850	1,092.130
Co-ops in State (no.)	42	31	14	106	41	114	53	106
ITEM	**KY**	**LA**	**MA**	**MD**	**ME**	**MI**	**MN**	**MO**
Petroleum	130.650	13.342	1.450	77.369	10.579	349.282	1,611.877	1,435.597
Co-ops in State (no.)	46	44	15	27	30	67	200	85
ITEM	**MS**	**MT**	**NC**	**ND**	**NE**	**NH**	**NJ**	**NM**
Petroleum	11.883	652.951	35.636	1,462.829	1,083.962	2.448	2.328	2.293
Co-ops in State (no.)	59	63	28	142	65	13	24	22
ITEM	**NV**	**NY**	**OH**	**OK**	**OR**	**PA**	**RI**	**SC**
Petroleum	0.530	40.343	621.093	385.232	197.177	17.377	0.087	8.509
Co-ops State (no.)	14	63	62	70	48	41	9	15
ITEM	**SD**	**TN**	**TX**	**UT**	**VA**	**VT**	**WA**	**WI**
Petroleum	773.721	153.402	352.793	13.633	269.693	-	575.963	1,292.856
Co-ops in State (no.)	93	73	175	25	59	14	75	94
ITEM	**WV**	**WY**	**DC**	**FOREIGN1**				
Petroleum	20.928	100.333	-	301.186				
Co-ops doing State (no.)	23	23	6	16				

NOTE: Some co-ops do business in several States, so the sum of the State number of co-ops doing business in the States will not be equal to the total number of U.S. ag co-ops (1,779).

1 Sourced from outside the 50 States and DC.

2 Service receipts and other income includes service income, other operating income, patronage, non-operating income.

4.0 Diesel Fuel Replacement



4.0 DIESEL FUEL REPLACEMENT

Today the agricultural fuel landscape includes traditional farm fuels, such as diesel, but also includes alternative fuel and energy sources. While diesel is the mostly commonly used agricultural fuel, many alternatives have been proposed and introduced into this community. Presently, hybrid and methane-powered engines are the most likely replacements for diesel fuel in tractors and other agricultural applications.

In terms of hydrogen fuel cell powered tractors, efforts to develop and sell hydrogen tractors appear to be on the research and pilot scale. However, future applications for hydrogen in tractors and agriculture include enabling technologies such as on-farm solar systems used to produce hydrogen with an electrolyzer, the production of hydrogen from animal wastes, for use in heating systems, or in a fuel cell to provide power for lighting and ventilation. The conversion of farm vehicles and generators to fuel cells to utilize on-farm hydrogen is a potential future application area but does not appear to be a near-term target. In addition to powering tractors, some see other potential applications for on-farm hydrogen use such as replacing propane gas used by farmers to dry products such as potatoes, onions, and carrots.

One recent case study in a French vineyard reports: "Battery electric and hydrogen fuel cell tractors have the potential to reduce CO_2 emissions of vineyards, if the electricity used to drive them is produced from sustainable sources." The report goes on to note that battery systems are very efficient, but hydrogen systems are more compact and lighter. Factors to consider when looking at the options depend on local infrastructure, available space, and future development of costs.

4.1 CHALLENGES

While some experts note that there is interest in hydrogen fuel cell technology for tractors and other agricultural applications, these experts also indicate that there are limits to the technology that may inhibit its growth and applicability to this space. For example, storage and distribution pose challenges to hydrogen use along with concerns regarding the safety of the technology. One idea to address these challenges includes developing solutions that allow farmers to produce energy on-site for use in tractors. Additional technology gaps that need to be addressed are the energy loss issues associated with converting electricity into hydrogen – this process, at present, can cause with approximately 25% energy loss. Moreover, the field is in a very nascent state with the majority of efforts still in the R&D stage, much more work is needed before the technology is in a state making it ready for large scale on-site farm use.

4.2 POLICIES & INCENTIVES

Government policies and incentives are a common driver for technology shifts in agriculture, energy, and other industries. The findings below provide information on some existing U.S. policies for agricultural equipment and clean energy.

The U.S. Government is providing incentives for farms to consider alternative fuels. Clean Agriculture is a voluntary program that promotes the reduction of diesel exhaust emissions from agricultural equipment and vehicles by encouraging proper operations and maintenance by farmers, ranchers, and agribusinesses, use of emissions-reducing technologies, and use of cleaner fuels. Clean Construction and Clean Agriculture are part of the U.S. Environmental Protection Agency's Diesel Emissions Reduction Act (DERA) Program, which offers funding for clean diesel construction and agricultural equipment projects. EPA offers funding, as appropriated annually by Congress, for projects that reduce emissions from existing diesel engines. EPA's *Clean Agriculture* also provides information on strategies for reducing emissions from older engines, including idle-reduction practices that save money and fuel while reducing emissions.

In 2015 the U.S. Department of Agriculture's (USDA) Building Blocks for Climate Smart Agriculture and Forestry, which is a plan designed to help farmers, ranchers, forestland owners, and rural communities respond to climate change. This plan is made up of 10 "building blocks," which span a range of technologies and practices to reduce greenhouse gas (GHG) emissions, increase carbon storage, and generate clean renewable energy. While the plan focuses on more energy efficient farm equipment (among other efforts) the focus appears to be on biofuels as opposed to hydrogen fuel cells.

4.3 ZEV FARM EQUIPMENT

Several states such as California, Michigan, Wisconsin, Colorado, and others have signed a multi-state action plan for Zero Emission Vehicles (ZEV), which does not specifically mention targets for agricultural equipment, but does include agriculture in its discussion of contributions to greenhouse gasses. The table below lists the targets by state for ZEV in the action plan.

Table 26. State Greenhouse Gas Emission Targets

States have committed to ambitious GHG reduction goals, typically resulting in 80% reductions by 2050.	2020	2030	2050
CALIFORNIA	0% Below 1990 levels	40% Below 1990 levels	80% Below 1990 levels
CONNECTICUT	10% Below 1990 levels	45% Below 2001 levels	80% Below 2001 levels
MARYLAND	25% Below 2006 levels	40% Below 2006 levels	90% Below 2006 levels
MASSACHUSETTS	25% Below 1990 levels		80% Below 1990 levels
NEW JERSEY	0% Below 1990 levels		80% Below 2006 levels
NEW YORK		40% Below 1990 levels	80% Below 1990 levels
OREGON	10% Below 1990 levels		75% Below 1990 levels
RHODE ISLAND	10% Below 1990 levels	45%* Below 1990 levels	80% Below 1990 levels
VERMONT**	10% Below 1990 levels	50%*** Below 1990 levels	75% Below 1990 levels

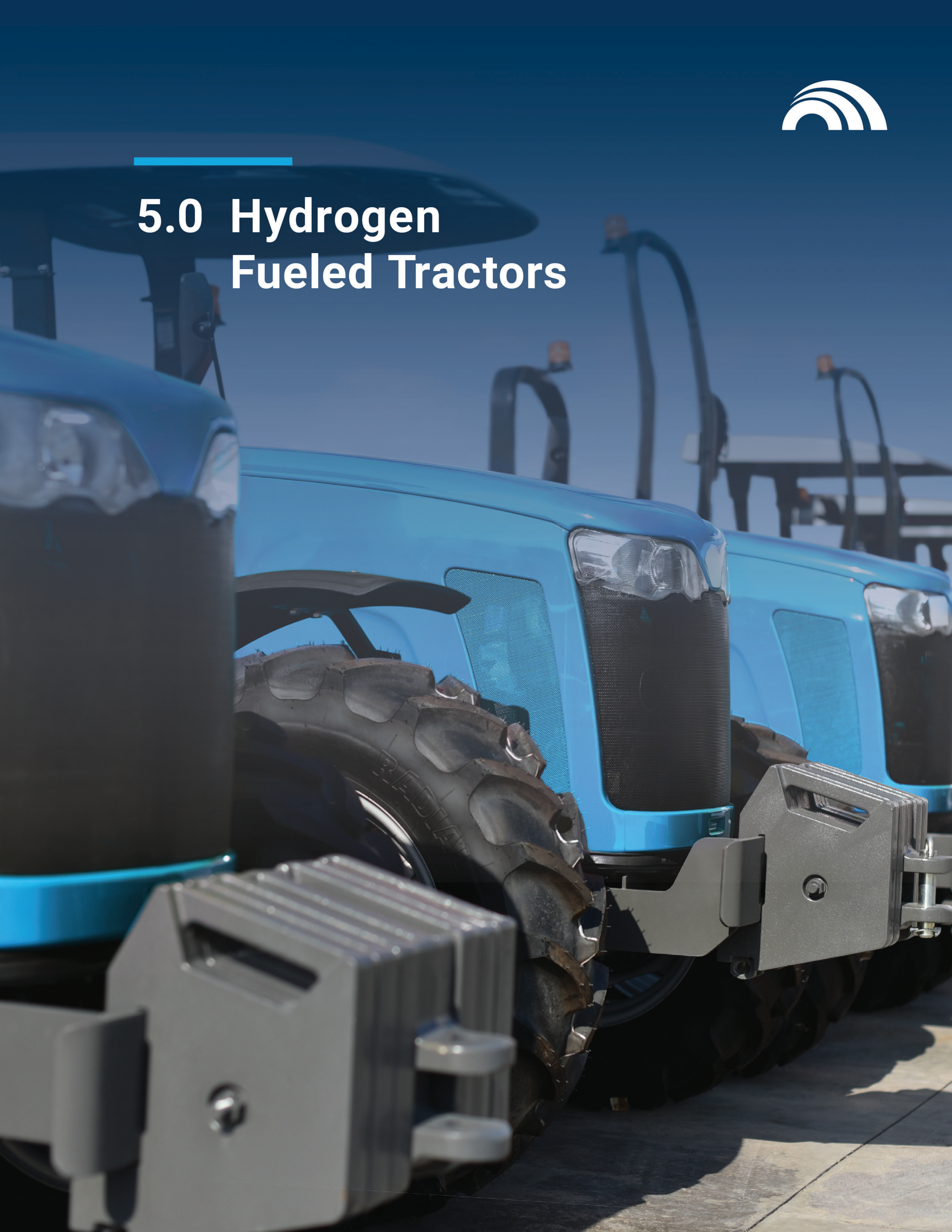
** Rhode Island target date 2035*

*** Vermont Statutory goals (shown above) were established by Executive Order in 2005 and passed into law in 2006. The Comprehensive Energy Plan (CEP) goals established in 2016 set Vermont's goals at 40% below 1990 levels by 2030 and 80% to 95% below 1990 levels by 2050. *** Vermont target date 2028*

These states also are working independently with state regulations, policies, and incentives to meet these targets.

On the Federal level, Clean Construction and Clean Agriculture are voluntary programs that are part of the U.S. Environmental Protection Agency's Diesel Emissions Reduction Act (DERA) Program, which offers funding for clean diesel construction and agricultural equipment projects. This is a voluntary program working to reduce diesel emissions in agriculture and construction equipment, which includes encouraging proper operations and maintenance, use of emissions-reducing technologies, and use of cleaner fuels.

5.0 Hydrogen Fueled Tractors



5.0 HYDROGEN FUELED TRACTORS

Hydrogen fuel tractors have generated interest for years; however, they have not become a commercially available option for farmers. This section explores companies and R&D efforts to develop tractors and equipment using alternative fuels, and hydrogen-fueled tractors, more specifically. Research has been conducted in an effort to determine if there are any hydrogen-fueled tractors currently being sold and, if so, the unit volume that has been sold to date. While there does not appear to be a commercially available hydrogen tractor on the market today, there are some demonstration projects that have been completed. In addition, the Swedish company, PowerCell, has also provided hydrogen fuel cells to an undisclosed American tractor manufacturer.

5.1 CNH INDUSTRIAL / NEW HOLLAND

New Holland (parent company CNH Industrial) is well-known for its NH2 experiment which developed a tractor running on hydrogen, introduced in 2009 with a concept tractor at the SIMA machinery show in Paris, France. As described by the company, "[the] tractor uses a hydrogen-diesel fuel mix to enhance power and reduce emissions. The engine can run on 100 percent diesel or a diesel-hydrogen mix. Hydrogen is injected and mixed with air during the piston intake stroke. As with all diesel engines, diesel is injected near top dead center of the compression stroke and compression heat ignites the combined fuels. The greenhouse gasses coming out the stack are significantly reduced."[58]

However, the concept was short-lived, and the company shifted focus to a methane model. According to reports, the effective working range was limited to about two to three hours, which made the shift to a methane concept tractor much more practical.[59]

Parent company CNH Industrial is a leading global capital goods company engaged in the design, production, marketing, sale, and financing of agricultural and construction equipment, trucks, commercial vehicles, buses and specialty vehicles for firefighting, defense, and other uses, as well as engines, transmissions and axles for those vehicles and engines for marine and power generation applications. The company's agricultural equipment is sold under the New Holland Agriculture and Case IH brands, as well as the STEYR, Kongskilde and Överum brands in Europe and the Miller brand, primarily in North America and Australia. Its agriculture segment designs, manufactures and distributes a full line of farm machinery and implements, including two-wheel and four-wheel drive tractors, crawler tractors (Quadtrac®), combines, cotton pickers, grape and sugar cane harvesters, hay and forage equipment, planting and seeding equipment, soil preparation and cultivation implements, and material handling equipment.[60] No mention of hydrogen-related work is mentioned in investor materials or on the company website as of searches carried out in April and early May 2021.

5.2 POWERCELL

In December 2020 PowerCell Sweden AB received an order for two MS-100 fuel cell systems from an undisclosed global U.S. agriculture equipment manufacturer. The systems will be used to test an electrification of tractors using fuel cells and hydrogen and will be delivered during the fourth quarter 2020 and the first quarter 2021 respectively. The company's MS-100 fuel cell system has been developed for an electrification of vehicles within the off-road segment such as handling equipment, construction equipment and various other types of vehicles, including agriculture equipment.[61] In April 2021 the company received a follow-on order for two more 100 kW fuel cell systems for further tests of electrification of tractors using fuel cells and hydrogen that will be delivered during the fourth quarter 2021.[62]

PowerCell was founded in 2008 as an industrial spin-out from the Volvo Group. Its products run on pure or reformed hydrogen and generate electricity and heat without any other emissions than water. The company received a major order in April 2019 Robert Bosch GmbH through a joint development and licensing agreement - the order specifies PowerCell's S3 type fuel cell stacks and it worth approximately one million euros. Under this agreement Bosch secured the right to offer the new version of the S3 fuel cell stacks exclusively in cars, trucks, and buses. The joint series production of the PEM fuel cell is to start "no later than 2022" according to earlier statements.[63]

5.3 NATIONAL INSTITUTE OF AGRO-MACHINERY INNOVATION AND CREATING (CHIAIC)

China's first hydrogen fuel-cell electric tractor was launched in mid-2020 by the National Institute of Agro-machinery Innovation and Creation (CHIAIC) in Luoyang in the central province of Henan. According to reports, "the tractor has a main permanent-magnet, synchronous mid-motor, and independent electric lifting and steering motors. The hydrogen fuel cell operates when the vehicle is underloaded, while under heavy load, the lithium battery will add further power supply. With 5G technology, ET504-H is able to monitor the real-time running status of the vehicle as well as the surrounding working environment, which will effectively improve the reliability of the operation."[64]

5.4 CUMMINS

While the company has yet to specifically identify a hydrogen fuel cell tractor, it is a leading tractor producer and in late 2020 the company laid out an aggressive strategy for hydrogen. The company already has more than 2,000 fuel cell installations across a variety of on-and off-highway applications and is looking to expand these offerings. However, at present, farm tractors have not been specifically identified as a target.[65]

5.5 JCB

JCB is an English company that produces a variety of heavy machinery and vehicles for several verticals, including agriculture. The company has two plants on four continents and more than 750 dealers around the world. In a recent interview a company member reported that, “The beauty of hydrogen in an agricultural situation is that it closely replicates what you do already in terms of quick and not too frequent refueling. Agricultural kit is quite complicated but theoretically it is possible that we will see hydrogen powered off-road equipment in a decade or maybe a little longer.”[66]

5.6 ITM POWER

At the 2019 Renewable in Agriculture Conference representatives from ITM Power, which makes electrolyser systems for Hydrogen generation, mentioned that there are many smaller scale options for farm including small scale electrolysers and fuel cell farm vehicles. Additionally, company presentations note that, “Hydrogen fuel cell electric vehicles are better suited to agribusiness demands than battery electric.” It also discusses how it could address some of the common challenges with hydrogen for agriculture. “Production cost reduced and fixed via use of integrated hydrogen energy system including transport.” However, these discussions do not provide a concrete timeline for platform development or integration, especially with hydrogen tractors.[67]

5.7 SCHMEUECKER DEMONSTRATION FARM

One example of an operating hydrogen tractor and farm may be found in Iowa and was developed by a farmer who initially worked at NASA’s JPL. The tractor developed is described as, “The John Deere 7810 tractor is outfitted with a 9.4-liter OX Power engine based on a Ford 460 cu-in V-8 design. It runs on hydrogen gas or a mixture of hydrogen and ammonia gases. The tractor tanks are fueled by first bleeding hydrogen from the storage tanks and after the tank pressures have been equalized, the tractor pump is used. A commercial ammonia pump is used to fuel the tractor ammonia tank from the ammonia storage tank.”[68] The tractor was developed in conjunction with the Hydrogen Engine Center (HEC) in Algona, Iowa.

6.0 Tractor Manufacturers

6.0 TRACTOR MANUFACTURERS

While the previous section looks at hydrogen-powered tractors and companies working in that space, this section identifies and discusses top tractor manufacturers, with a specific focus on top tractor manufacturers serving the U.S. farms. For companies looking to develop hydrogen-fueled tractors (or enabling technologies), it is important to understand the current competitive landscape for tractor manufacturers and be familiar with the existing offerings in traditional diesel machines and the interest areas of leading players.

6.1 LEADING COMPANIES IN THE GLOBAL FARM EQUIPMENT MARKET

In August 2020, MarketsandMarkets published a report covering the global farm equipment market. Farm tractors account for a significant portion of this market. The global farm equipment market is consolidated, with the top five players accounting for roughly 80% of the total market share. Leading companies include John Deere, CNH, Kubota, AGCO, Yanmar, CLAAS, Mahindra & Mahindra, SDF Group, and Bucher Group, among others.

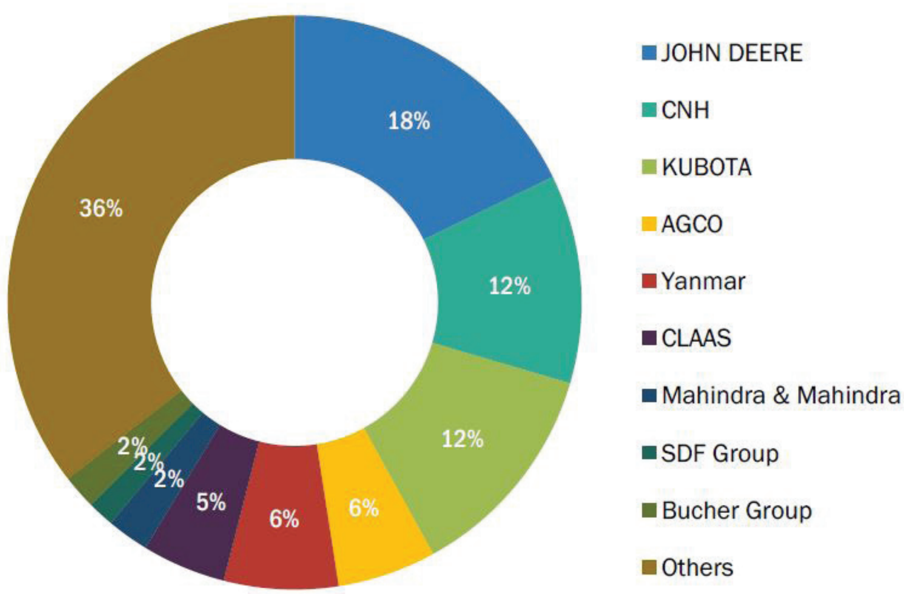


Figure 4: Global Farm Equipment Market Share Analysis (2019)

(MarketsandMarkets)[69]

6.2 LEADING COMPANIES IN THE U.S. AND CANADIAN TRACTOR MARKET

A June 2018 presentation titled "Partners in Power: How Propane Industry Investments Led to Tractors Powered by Propane and Natural Gas," given by Cinch Munson—Senior VP for Business Development with the Propane Education and Research Council, featured the following figure. This figure highlights the market share of key players in the U.S. and Canadian tractor market.

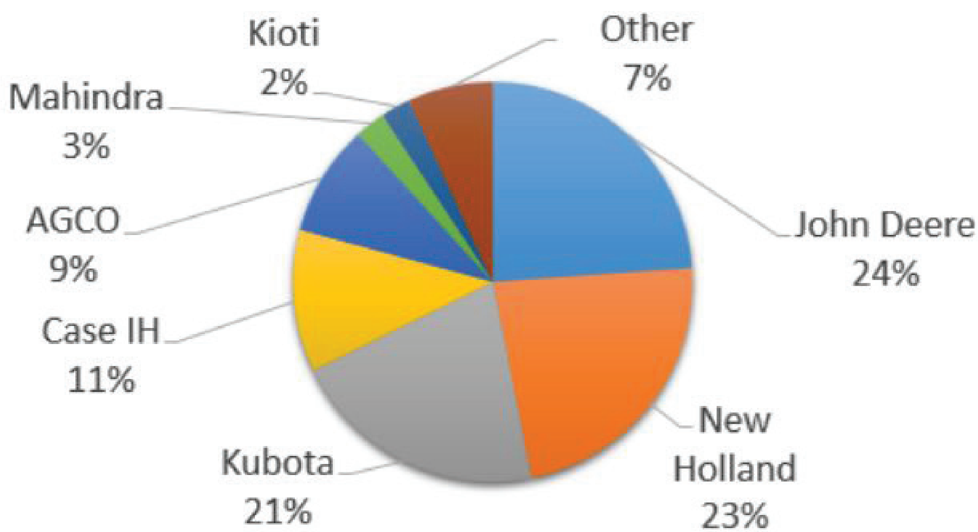


Figure 5: Market Share of Top Tractor Manufacturers, Canada, and U.S.[70]

6.2.1 JOHN DEERE

Deere & Company, along with its subsidiaries, are collectively referred to as John Deere. John Deere operates through three primary business segments: agriculture and turf, construction and forestry, and financial services. The agriculture and turf segment manufactures and distributes a line of agriculture and turf equipment and related service parts—this includes:

- Large, medium, and utility tractors
- Tractor loaders
- Combines
- Cotton pickers
- Cotton strippers
- Sugarcane harvester
- Harvesting front-end equipment

- Sugarcane loaders and pull-behind scrapers
- Tillage, seeding, and application equipment
- Hay and forage equipment
- Turf and utility equipment such as riding lawn equipment, golf course equipment, utility vehicles, and commercial mowing equipment
- Outdoor power products
- Implements, integrated agricultural solutions, and precision technologies[71]

According to John Deere's most recent Annual Report, global competitors in the agriculture and turf segment include AGCO Corporation, CLAAS, CNH Industrial, Kubota Tractor Corporation, Mahindra, and The Toro Company, as well as other regional and local competitors. Within the U.S. and Canada, the company markets products to approximately 1,981 dealers—about 1,544 of which sell agricultural equipment. Outside of the U.S. and Canada, John Deere agricultural equipment is sold to distributors and dealers for resale in over 100 countries.[72]

Environmental matters around the world are having an impact on John Deere. The European Union's Stage V Regulation (parts of this regulation went into effect in 2019 and 2020) applies to non-road diesel engines across different power categories for machines used in agriculture (and other applications, such as construction, materials handling, industrial use, and generator applications). Government agencies around the world are enacting similar laws in order to reduce off-road engine emissions. India's Bharat Stage IV Regulation is another example. This regulation is scheduled to go into effect in 2021. These standards will support the reduction of particulate and NOx emissions. To meet these standards and regulations, John Deere plans to make significant investments in the development of new engine technologies and after-treatment systems. While the company is focusing on innovations that will enable their products to comply with emissions regulations, these technical improvements will add to the cost of their products.[73]

The following table provides 2020 revenue data for the various geographic and product line segments of John Deere's agriculture and turf segment. Of note, U.S. revenue for the agriculture and turf segment was $11.948 billion. The large agriculture product segment includes sales of tractors with more than 200 HP and associated attachments, combines, cotton pickers, cotton strippers, and sugarcane harvesters, among other types of heavy-duty agricultural equipment. The small agriculture product segment includes net sales of medium and utility tractors with less than 200 HP—as well as hay and forage equipment, balers, mowers, and related attachments and parts.[74]

Table 27: Breakdown of Revenue in John Deere's Agriculture and Turf Segment (2020)[75]

Segment	Revenue
Primary Geographic Markets	
United States	$11,948,000,000
Canada	$990,000,000
Western Europe	$3,764,000,000
Central Europe and CIS	$1,391,000,000
Latin America	$2,236,000,000
Asia, Africa, Australia, New Zealand, and the Middle East	$2,441,000,000
Total	**$22,770,000,000**
Major Product Lines	
Large Agriculture	$11,387,000,000
Small Agriculture	$8,102,000,000
Turf	$2,390,000,000
Financial Products	$106,000,000
Other	$785,000,000
Total	**$22,770,000,000**

In terms of more innovative tractor models, John Deere seems to be focusing mainly on electric tractors. In 2016, the company presented their first fully electric tractor, called SESAM—Sustainable Energy Supply for Agricultural Machinery. More recently, in 2019, John Deere announced the development of a high-performance, autonomous fully electric tractor, GridCON. This electric cable-powered tractor provides up to 400 HP (300 kW) of power. Based on a John Deere 6210R tractor, the autonomous machine uses a cable connection from the field border to the machine, which transfers power continuously at over 300 kW. Compared to a battery-powered equivalent, the prototype electric tractor offers a 50% reduction in machine and operating costs.[76]A 100 kW electric motor feeds an IVT transmission and there is another outlet for implements powered by a 200kW electric motor. A drum fixed to the tractor carries up to 1,000 meters of cable.[77]

6.2.2 CNH INDUSTRIAL (CASE IH AND NEW HOLLAND)

CNH Industrial is a global company that employs more than 63,000 people in 67 manufacturing plants and 56 research and development centers in 180 countries. CNH Industrial encompasses 12 brands:

- Case IH Agriculture
- STEYR Traktoren
- Case Construction
- New Holland Agriculture
- New Holland Construction
- IVECO
- IVECO Astra
- IVECO Bus
- HeuliezBus
- Magirus
- IVECO Defense Vehicles
- FPT Powertrain Technologies[78]

Case IH Agriculture and New Holland Agriculture are the brands most closely tied to the tractor market. Collectively, CNH Industrial is engaged in the design, production, and sale of agricultural and construction equipment, trucks, commercial vehicles, buses and specialty vehicles for firefighting, defense, and other uses, engines, transmissions, and axels for the vehicles they provide, as well as for marine and power generation applications. According to the most recent Annual Report for CNH Industrial, the company primarily operates through five core segments: agriculture, construction, commercial and specialty vehicles, powertrain, and financial services. The company's agriculture segment designs and manufactures a full line of farm machinery and implements, including both two-wheel and four-wheel drive tractors, crawler tractors, combines, cotton pickers, grape and sugar cane harvester, hay and forage equipment, planting and seeding equipment, soil preparation and cultivation implements, and material handling equipment. Agricultural equipment is sold under the New Holland Agriculture and Case IH brands, as well as the STEYR, Kongskilde, and Overum brands in Europe, and the Miller brand in North America and Australia.[79]

The agriculture segment primarily caters to operators of dairy, livestock, and row crop producing farms, as well as independent contractors that provide services to these farms. Row crop farmers typically purchase tractors in the mid-to-upper end of the HP range, while dairy and livestock farmers more often use tractors in the mid-to-lower HP range. Agricultural equipment manufacturers are subject to continuous changes in engine emission regulations and restrictions in this area. These regulations and standards require frequent changes in engine technology, which require increasing R&D investment and may raise the equipment price. Each geographic market may have its own unique emissions regulations, which can further complicate the situation, as CNH attempts to meet global product needs and standards.[80]

According to CNH Industrial's most recent Annual Report, their main competitors in the agricultural equipment market include Deere & Company (John Deere), AGCO, Claas, Argo Tractors, the Same Deutz Fahr Group, and Kubota Tractor Corporation. While new generations of tractors have a number of common mechanical components, each brand and product have different features, colors, interior and exterior styling, warranty terms, technology offerings, and model designations. The agriculture segment of CNH Industrial sells and distributes products through approximately 2,500 dealers and distributors, with over 6,500 points of sale. CNH purchases a number of materials, parts and components from third-party suppliers—they had about 4,102 global direct material suppliers, as of 2020.[81]

CNH Industrial reported total revenue of $26.032 billion in 2020. That year, the agriculture segment of CNH Industrial accounted for $10.923 billion in revenue (42% of the company's total revenue).[82] From a geographic perspective, approximately $6.142 billion (or 23.6% of total revenue) comes from North America. CNH Industrial reported revenue of $3.794 billion for the North American agricultural segment in 2020.[83]

Case IH Agriculture provides a full line of tractors, from 30-682 HP. Their tractors still run on diesel fuel, but the company is focusing on engine efficiency. Case IH has partnered with FPT Industrial, an engine manufacturer, to include high-horsepower engines that meet the Tier 4B emissions standard and reduce fuel consumption by an average of 10%.[84]

New Holland also provides a comprehensive line of tractors for the agricultural segment, ranging from 22-682 HP. In 2009, New Holland produced a prototype tractor that was powered by a hydrogen fuel cell, the NH2. This hydrogen fuel cell tractor was based on the company's T6000 tractor, but instead of a standard diesel combustion engine, it featured two electric motors—one to provide power to traction and another that provided power to power train operations and auxiliaries. The NH2 was able to run for about 1.5-2 hours on a single hydrogen tank, with the fuel cell generating approximately 106 HP.[85] New Holland created its first propane fueled tractor prototype in 2012 and in 2013 the company presented its first T6 Methane Power tractor prototype.[86] In 2016, New Holland prototyped a third-generation Alternative Fuels Tractor that was available with biomethane, methane, biopropane, and propane fuel options, reducing greenhouse gas emissions by approximately 80%. The prototype featured the cassis of a T6 with comparable horsepower and torque, but with multiple alternative fuel options. This prototype was capable of reducing fuel costs by 20-40% and it also meets Tier 4 Final standards.[87] Most recently, New Holland has released a methane-powered tractor, which is currently available for purchase. The New Holland T6 Methane Power is the first 100% methane powered production tractor.[88]

6.2.3 KUBOTA

Kubota Group is headquartered in Japan, with 188 companies in the group and 128 of those companies are outside of Japan. The group operates in over 120 countries and has 41,027 employees. In North America, Kubota Group has 35 companies, employing 5,542 people. Kubota tractors are used around the world in agricultural settings and the total tractor production volume is more than 4 million units worldwide (cumulative).[89] Their farm and industrial machinery segment encompasses tractors, as well as implements, combine harvesters, rice transplanters, and utility vehicles.

The farm and industrial machinery segment accounted for 81.9% of the company's total annual revenue in fiscal year 2019. Total revenue for Kubota Group was 1,920.0 billion yen (approximately $17.554 billion[4]) in fiscal year 2019 and total revenue for the farm and industrial machinery segment was 1,572.6 billion yen (approximately $14.378 billion[5]) that same year. From a geographic perspective, the North American segment of Kubota Group generated 679.1 billion yen (approximately $6.2 billion[6]) in fiscal year 2019, accounting for a 35.4% share of the company's total revenue.[90]

Kubota Group is supporting more environmentally friendly initiatives in many of their business segments, including farm and industrial machinery. With respect to tractors, they are aiming to reduce the number of parts, reducing environmentally hazardous substances contained in paint, reducing fuel consumption by improving loading efficiency in product transportation, reducing fuel consumption by introducing an energy-saving mode, conforming to exhaust gas regulations, and reducing noise and vibration. With respect to more eco-friendly engines, the company is reducing fuel consumption by improving combustion efficiency and reducing losses, accepting bio diesel/gasoline, conforming to exhaust gas regulations, reducing noise and vibration, and reducing RoHS-designated substances.[91]

Kubota is active in the U.S. market, with Kubota Corporation introducing its first tractor to the U.S. in the late 1960s. Kubota Tractor Corporation (KTC) was formed in 1972. In the U.S., Kubota currently offers a line of lawn mowers, utility vehicles, construction equipment, agriculture tractors, and hay equipment.[92] Major Kubota facilities in the U.S. include:

- Kubota Tractor Corporation (headquartered in Grapevine, TX)
- Kubota Credit Corporation, USA (headquartered in Grapevine, TX)
- Kubota Manufacturing of America (headquartered in Gainesville, GA)
- Kubota Industrial Equipment (headquartered in Jefferson, GA)

4 Estimate is based on the Japanese Yen/US Dollar exchange rate on May 6, 2021.
5 Estimate is based on the Japanese Yen/US Dollar exchange rate on May 6, 2021.
6 Estimate is based on the Japanese Yen/US Dollar exchange rate on May 6, 2021.

- Kubota Engine of America (headquartered in Lincolnshire, IL)
- Kubota Credit Corporation, USA (headquartered in Grapevine, TX)[93]

Kubota Tractor Corporation (KTC) is the leading U.S. marketer and distributor of Kubota tractors, machinery, and farm equipment. Kubota equipment is sold and serviced in the U.S. through a network of more than 1,100 authorized dealers. These dealers are supported by the KTC corporate headquarters and four division offices (located in Lodi, CA; Fort Worth, TX; Groveport, OH; and Suwanee, GA). KTC has a North American Distribution Center located in Edgerton, KS.[94] Kubota Tractor Corporation offers a line of farm tractors, ranging from about 65-200 HP. In addition to tractors for the agricultural segment, the company also offers residential and commercial tractors.[95]

Kubota is aiming to reduce carbon emissions from its farming and construction equipment by 30%, between 2020 and 2030. As Europe has imposed strict regulations related to diesel fuel, Kubota has introduced electric versions of mini excavators and compact tractors, which would be suitable for park maintenance (among other applications). The electric versions will be manufactured in Japan or Germany beginning in 2023. Kubota is also looking to develop tractor models powered by hydrogen fuel cells, as well as those powered by biofuels. The company's ultimate goal is to achieve company-wide carbon net neutrality by 2050.[96]

In January 2020, Kubota released prototypes of their electric tractors and electric compact construction machinery (small excavators). These models continue to be under development and Kubota is planning to conduct demonstration experiments and look more carefully at user needs. The prototype tractor was electrically powered, using a lithium ion battery. It offers a maximum output that is equivalent to the output of a compact tractor with a diesel engine and the tractor is suitable for applications such as park maintenance, fertilizer application, and transportation.[97] Kubota was conducting tests of the tractor in France, beginning in 2020, with plans to launch the electrical tractors and electrical construction machinery following the series of experiments and evaluations.[98]

Also in 2020, Kubota unveiled a futuristic looking tractor that is autonomous, equipped with artificial intelligence, and it is 100% electrically powered using a combination of lithium-ion batteries and solar batteries.[99] This tractor has been referred to as the "Dream Tractor," the "X-Tractor," or the "X Tractor-Cross Tractor."

6.2.4 AGCO

AGCO is a company that designs, manufactures, and distributes agricultural solutions—including tractors, combine harvesters, hay and forage equipment, application equipment, seeding and tillage equipment, implements and attachments, protein production systems, and solutions for smart farming, grounds care, and grain storage. This U.S. company is headquartered in Duluth, GA, with a presence in Africa, Asia, Australia, Europe, South America, and the Middle East.

ACGO's major tractor brands include Challenger, Fendt, Massey Ferguson, and Valtra. Challenger's tractor product line is comprised of high horsepower row crop tractors (396-517 HP), track tractors (380-673 HP), special application tractors (500-600 HP), and articulated 4W drive tractors (500-600 HP).[100] Fendt has heavier involvement in the European tractor market. Their line of tractors ranges from 91-495 HP.[101] Massey Ferguson provides a comprehensive line of tractors, ranging from 20-400 HP.[102] Valtra is a leading manufacturer and service provider in the Nordic countries and one of the more popular brands in Latin America. They manufacture tractors in Finland and Brazil. Valtra tractors are sold in over 75 countries, worldwide. Their line of tractors ranges from 75-405 HP.[103]

In their most recent Annual Report, AGCO notes that their top competitors on a global scale are Deere & Company (John Deere) and CNH Industrial. The company primarily distributes products through a network of independent dealers and distributors, including 785 dealers and distributors in Europe, 1,820 in North America, 245 in South America, and 400 throughout the rest of the world. While the number of North American dealers and distributors is significantly larger compared to those in other regions, North American dealers and distributors only accounted for 24% of net sales in 2020, whereas the 785 dealers and distributors in Europe accounted for 57% of net sales.[104]

AGCO manufactures and assembles products at 443 different locations around the world. Their AGCO Power engines division produces diesel engines, gears, and generating sets. The diesel engines manufactured are used in some of AGCO's tractors, combines and sprayers, and the engines are also sold to third parties. AGCO Power's focus is on manufacturing off-road engines in the 75-600 HP range.[105] As with other companies in this market, AGCO has invested a significant amount in engineering and applied research, with the goal of improving product quality and performance while also complying with government safety and emissions regulations.[106] The engines manufactured by AGCO meet the emission standards set by European, Brazilian, and U.S. regulatory authorities, including the U.S. Environmental Protection Agency (EPA) and different state authorities. In the U.S. market, AGCO has to obtain government environmental approvals in order to import their products and these approvals can be challenging or time consuming to obtain. Compliance with environmental and safety regulations has increased the complexity of their operations, which translates to greater product cost.[107]

According to AGCO's Annual Report, they are investing in R&D activities to support advanced technology development and continuous improvements in vehicle engine and transmission efficiency. Their research efforts are also focusing on "alternative fuel solutions as well as the acceleration of electrification, natural gas, hybrid technology and fuel cell alternatives."[108] AGCO is piloting a fully electric Fendt tractor with potential use in livestock, greenhouse farming, specialty crop farming, and municipal applications. They are hoping to advance this technology and develop battery-powered equipment which can be used in other agricultural applications.[109] The Fendt e100 Vario is an all-electric compact tractor that features 50 kW power output, and it can operate for up to 5 hours under realistic operating conditions. The tractor leverages a 650 V high-capacity lithium-ion battery with a capacity of about 100 kWh. The battery s charged using a standard CEE outdoor socket or through a supercharging option with direct voltage. With a standard

CCS type 2 plug, the battery can be recharged up to 80% in 40 minutes. The Fendt e100 Vario was used for the first time in 2018, with a limited number of tractors produced. They were initially used on selected farms and local municipalities.[110]

AGCO reported global net sales of just under $9.15 billion in 2020, with North America accounting for $2.175 billion in sales for that year and the U.S. accounting for nearly $1.782 billion in net sales. Global net sales from tractors totaled $5.272 billion in 2020, with $692 million in tractor net sales for North America.[111]

According to AGCO, high horsepower tractors ranging from 140-650 HP are typically used on large acreage farms for row crop production, soil cultivation, planting, land leveling, seeding, and commercial hay operations. Utility tractors are generally in the 40-130 HP range, and they are typically used on small- and medium-sized farms and in specialty agricultural industries (dairy, livestock, orchards, and vineyards). Compact tractors are those under 40 HP. These are often used on small farms and in specialty agricultural industries—as well as for landscaping and residential uses. Collectively, tractors accounted for a 57% share of AGCO's net sales in 2020.[112]

6.2.5 CLAAS

CLAAS is a German company that operates globally, providing agricultural equipment such as tractors, combines, forage harvesters, balers, hay tools, and precision farming solutions. Their line of tractors includes the XERION 5000-4000 (435-530 HP 4WD tractor), the AXION 900 series/AXION 960-920 (320-440 HP), and the AXION 800 series/ AXION 880-810 (200-285 HP).[113] In the United States, CLAAS has two sales companies—CLAAS of America in Columbus, IN and CLAAS of America in Omaha, NE. They have a product company, CLAAS of Omaha, in Omaha, NE, as well as a financing company (CLAAS Financial Services) in San Francisco, CA.[114]

The CLAAS Group generated net sales of 4.042 billion euros in 2020. A vast majority of their net sales tied back to Germany, France, and the rest of Europe. "Other countries" (aside from Germany, France, those in Western Europe, and those in Central and Eastern Europe) accounted for 788.4 million euros in net sales for 2020, accounting for 19.6% of the company's total net sales for the year.[115]

Of note is CLAAS's involvement in EKoTech. In 2011, agricultural equipment and construction machinery manufacturers came together and started working on strategies to reduce harmful emissions in Europe. The German agricultural equipment industry initiated the EKoTech research project in 2016, partnering with universities, scientific institutions, and the German Mechanical Engineering Industry Association (VDMA). The goal of EKoTech was to cut carbon emissions in agricultural equipment. Their benchmark is a 40% reduction in emissions from 1990 levels, by 2030. The EKoTech effort first looked at ways to improve the engine and overall operating efficiency. Currently, and moving forward, EKoTech is focusing on alternative energy sources and drive concepts—including biodiesel, fuel cells, and the use of electric motors. Many of the manufacturers with involvement in EKoTech are exploring these areas. Dr. Eberhard Nacke is responsible for innovation at CLAAS, he has managed the EKoTech project, and he is tasked with implementing the EKoTech findings at CLAAS.[116]

6.2.6 MAHINDRA

Mahindra Group, headquartered in India, is a group of over 150 companies employing over 250,000 people in over 100 countries around the world. Mahindra Group is involved in a number of industry segments, including farm equipment. Companies within the Mahindra Group's farm equipment segment include Mahindra Tractors, Swaraj Tractors, Mahindra USA (Tractors), Mahindra Yueda (Yancheng) Tractor Company – Jinma Tractors, Gromax Agri Equipment, and Mahindra Tractor Implements. Mahindra USA is a U.S. based company within the Mahindra Group that focuses on tractor and agricultural equipment sales in the United States. Mahindra USA is headquartered in Houston, TX.

In fiscal year 2020, Mahindra Group reported $19.5 billion in total group revenue. Farm equipment accounted for 15% of this total revenue (approximately $2.925 billion in farm equipment revenue for the year).[117] Their tractors typically range from 15 to >100 HP. In India, they sell across three primary brands—Mahindra, Swaraj, and Trakstar. Globally they company sells across brands such as Mahindra, Mitsubishi, and Erkunt.[118] Mahindra has reported sales of over 200,000 units annually and over 2.1 million tractors sold.[119]

Mahindra USA provides sub-compact (19.4-24 HP), compact (24-25.9 HP), compact utility (25.9-65 HP), and utility (43-125 HP) tractors for the agricultural segment. Mahindra is ranked third in the U.S. market in the <100 HP tractor category.[120]

6.2.6 YANMAR

Yanmar Group is a Japanese company that operates in the U.S. as Yanmar America Corporation (headquartered in Adairsville, GA). Yanmar America has approximately 253 employees. Yanmar is a supplier of Yanmar brand industrial and marine diesel engines, diesel generators, micro cogeneration and gas heat pup energy system solutions, compact construction equipment, and compact utility tractors. With respect to their tractor product line, Yanmar provides the SA Series (22-24 HP and recommended for farms with less than 25 acres), the YT2 Series (35 HP and recommended for farms with 10-50 acres), and the YT3 Series (47-59 HP and recommended for farms with 25 acres or more).[121] As with Mahindra, Yanmar's focus is on smaller tractors that are less than 100 HP.

In 2021, it was announced that International Tractors Limited (ITL) developed the advanced Solis Hybrid 5015 tractor in collaboration with Yanmar Agribusiness. The 50 HP Solis Hybrid 5015 tractor optimizes traditional diesel engine power by combining it with electric energy to deliver performance that is like that offered by a 60 HP tractor. This hybrid tractor comes with a lithium-ion battery and an advanced motor to reduce pollution.[122]

7.0 Fuel Cell Supply Chain

7.0 FUEL CELL SUPPLY CHAIN

Supply chains help individuals better understand and study the needs in an area such as farm tractors by taking other connected systems and parties into account. For example, tractor manufacturers may not be vertically integrated and may look to suppliers for components to power their platforms. This section provides an overview of the fuel cell supply chain, focusing on the different steps and components in the supply chain and key stakeholders in the various segments.

7.1 SUPPLY CHAIN OVERVIEW

In September 2019, E4tech Ltd in partnership with Ecorys and Strategic Analysis Inc. prepared a report for the Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2 JU), titled "Study on Value Chain and Manufacturing Competitiveness Analysis for Hydrogen and Fuel Cells Technologies." This report includes diagrams that outline the fuel cell supply chain.

New Holland Agriculture previously developed the NH_2 hydrogen fuel cell powered tractor. This hydrogen fuel cell tractor was powered by Andromeda fuel cell stacks supplied by Nuvera Fuel Cells. These PEM fuel stacks contained 384 cells and produced 124 kW of power.[123] PEM fuel cells (PEMFC) are being developed primarily for transportation applications and it appears that this would include agricultural tractors.

The report from E4tech, Ecorys, and Strategic Analysis Inc. outlines the critical components of PEMFCs. Critical components of a PEM fuel cell include the supported catalyst, membrane, membrane electrode assemblies, gas diffusion layer, PEMFC stack, PEMFC system, coated plate materials, membrane support, ionomer, bipolar plates, air handling and recirculation, the H_2 sensor, power electronics and inverters, and hydrogen tanks.

Table 28: PEMFC Critical Components[124]

Application	Critical Component	Supply Chain Sector
PEMFC	Supported catalyst	Specialized materials
	Membrane	Sub-component
	Membrane electrode assemblies	Sub-component
	Gas diffusion layer	Sub-component
	PEMFC stack	Sub-system
	PEMFC system	System
	Vehicle integration	Application
	Coated plate materials	Specialized materials
	Membrane support	Specialized materials
	Ionomer	Specialized materials
	Bipolar plates	Sub-component
	Air handling/recirculation	Sub-component
	H_2 sensor	Sub-component
	Power electronics/inverters	Sub-system
	Hydrogen tanks	Sub-system

The following figure outlines the PEMFC supply chain for cars, vans, heavy goods vehicles, buses, and forklifts.

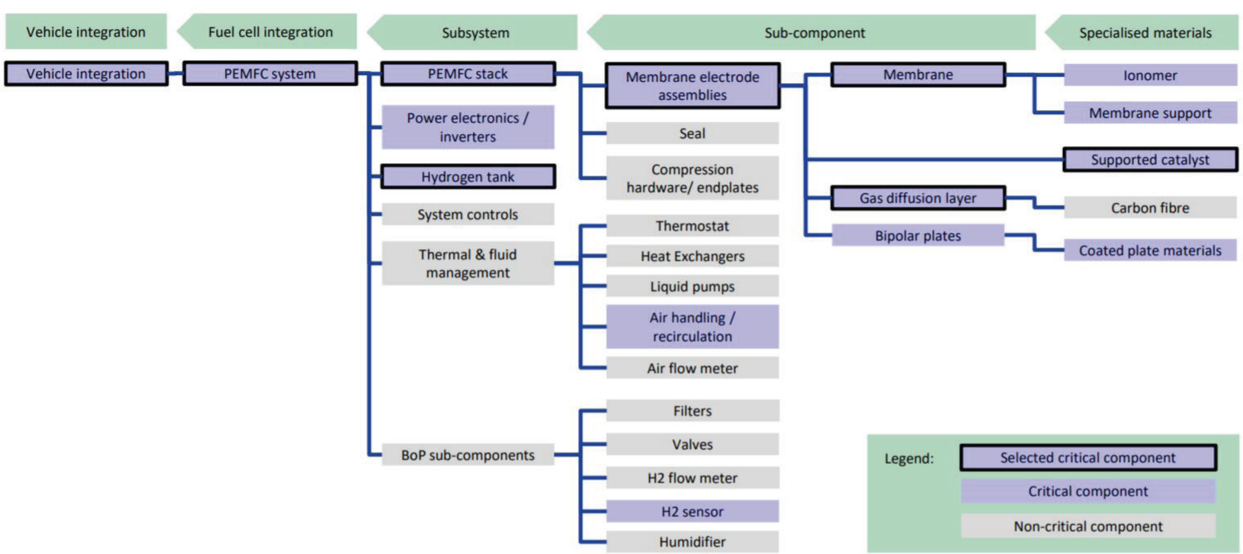


Figure 6: Supply Chain for PEM Fuel Cells in Transport Applications[125]

The Hydrogen Fuel Cell Nexus (HFCnexus) is a comprehensive database of hydrogen and fuel cell suppliers in the United States. The database features over 350 suppliers, covering the entire hydrogen fuel cell supply chain. This source may play an important role in terms of identifying key players at various levels of the supply chain.

7.2 CATALYST

There are different components that come together to form the membrane electrode assembly (MEA). One key component of the MEA is the catalyst. A catalyst is "a chemical substance that increases the rate of a reaction without being consumed."[126] Within a fuel cell, the catalyst facilitates the reactions of oxygen and hydrogen.[127] Fuel cell catalyst suppliers located in the United States include:

- BASF Catalysts (Iselin, NJ)
- Ceramatec (Salt Lake City, UT)
- Clariant (Charlotte, NC) – Sud-Chemie was purchased by Clariant
- Entegris (Decatur, TX)
- Fuel Cell Materials (Lewis Center, OH)
- Giner (GES) (Newton, MA)
- Independent Energy Partners (Parker, CO)
- InnovaTek (Kennewick, WA)
- MetaMateria Partners (Columbus, OH)
- Pajarito Powder (Albuquerque, NM)
- pH Matter (Columbus, OH)
- Powder Processing and Technology (Valparaiso, IN)
- Pred Materials International (New York, NY)
- Reaction Design (Canonsburg, PA)
- Umicore (Auburn Hills, MI)
- ZTEK Corporation (Woburn, MA)[128]

7.3 PLATES

Plates are also a key component within the MEA. Metal, carbon, or composite plates support the fuel cell catalyst layer and gas diffusion layer (GDL) in platinum-based fuel cells. These plates also help to conduct gases and liquids through the MEA through channels on the surface of the plate. Finally, they aid in the conduction of electricity.[129] Plate suppliers located in the United States include:

- 3M Fuel Cell Components (Oakdale, MN)
- American Fuel Cell (Rochester, NY)
- Asbury Carbons (Asbury, NJ)
- ATI Specialty Alloys and Components (Pittsburgh, PA)
- Bodycote Thermal Processing (Berlin, CT)
- Branson Ultrasonics Corp (Danbury, CT)
- Bulk Molding Compounds (West Chicago, IL)[130]

7.4 GAS DIFFUSION LAYERS

Gas diffusion layers (GDLs) are a main component of platinum-based membrane electrode assemblies. Gas diffusion layers are often thin carbon paper or woven carbon materials placed in between the catalyst layer and bipolar plates. They help to manage reactant and cooling flows while simultaneously collecting current.[131] Suppliers of gas diffusion layers in the United States include:

- 3M Fuel Cell Components (Oakdale, MN)
- American Fuel Cell (Rochester, NY)
- AvCarb Material Solutions (Woburn, MA)
- Chemours (Wilmington, DE)
- ElectroChem (Woburn, MA)
- FuelCell Propulsion Institute (Golden, CO)
- Gerard Daniel Worldwide (Hanover, PA)
- GKD USA (Cambridge, MD)
- GrafTech International (Advanced Energy Technology) (Independence, OH)

- Hamilton Precision Metals (Lancaster, PA)
- Hitachi Metals America (Arlington Heights, IL)
- Hosokawa Nano Particle Technology (Summit, NJ)
- i-2-m (spinoff of MANN+HUMMEL) (Raleigh, NC)
- Inorganic Specialists (Miamisburg, OH)
- MEGTEC Systems (De Pere, WI)
- Mott Corporation (Farmington, CT)
- National Coating Corporation (Rockland, MA)
- Refrac Systems (Chandler, AZ)
- Siemens Power Generation (Pittsburg, PA)
- Toray Carbon Fibers America (Flower Mount, TX)
- Trenergi Corporation (Franklin, MA)
- ZTEK Corporation (Woburn, MA)[132]

7.5 MEMBRANES

A membrane is a separating layer in a fuel cell. It acts as an electrolyte (ion exchanger) and a barrier film separating the gases in the anode and cathode compartments of the fuel cell.[133] Suppliers of fuel cell membranes in the United States include:

- 3M Fuel Cell Components (Oakdale, MN)
- Advance Systems (Green Bay, WI)
- Alfa Laval (Warminister, PA)
- American Fuel Cell (Rochester, NY)
- Amsen Technologies (Tucson, AZ)
- Ceramatec (Salt Lake City, UT)
- Chemours (Wilmington, DE)
- Dow (Philadelphia, PA)
- ElectroChem (Woburn, MA)
- Energy Related Devices (Los Alamos, NM)

- FuelCell Propulsion Institute (Golden, CO)
- Gerard Daniel Worldwide (Hanover, PA)
- Gore Fuel Cell Technologies (Elkton, MD)
- Hitachi Metals America (Arlington Heights, IL)
- Hosokawa Nano Particle Technology (Summit, NJ)
- i-2-m (Raleigh, NC)
- Inorganic Specialists (Miamisburg, OH)
- It4ip (Pittsburgh, PA)
- Mott Corporation (Farmington, CT)
- Siemens Power Generation (Pittsburgh, PA)
- Toray Carbon Fibers America (Flower Mound, TX)
- Trenergi Corporation (Franklin, MA)
- ZTEK Corporation (Woburn, MA)[134]

7.6 DISPERSIONS

Within a fuel cell, dispersions refer to the distribution of active material—notably catalysts or polymers—in or on a solid or liquid.[135] Providers of dispersions located in the United States include:

- 3M Fuel Cell Components (Oakdale, MN)
- American Fuel Cell (Rochester, NY)
- Chemours (Wilmington, DE)
- ElectroChem (Woburn, MA)
- FuelCell Propulsion Institute (Golden, CO)
- Nosokawa Nano Particle Technology (Summit, NJ)
- Siemens Power Generation (Pittsburgh, PA)
- Toray Carbon Fibers America (Flower Mound, TX)
- Trenergi Corporation (Franklin, MA)
- ZTEK Corporation (Woburn, MA)[136]

7.7 GASKETS USED IN MEMBRANE ELECTRODE ASSEMBLIES

A gasket is a shaped piece or ring of rubber or another material that seals the junction between two surfaces in an engine or another device.[137] There are gaskets used in membrane electrode assemblies. Companies providing gaskets for MEAs in the United States include:

- 3M Fuel Cell Components (Oakdale, MN)
- American Fuel Cell (Rochester, NY)
- Branson Ultrasonics Corp (Danbury, CT)
- Chemours (Wilmington, DE)
- Circle Seal Control Division – Circor International (Corona, CA)
- COGEBI (Dover, NH)
- ElectroChem (Woburn, MA)
- Energy Related Devices (Los Alamos, NM)
- Freeman Schwabe Machinery (Cincinnati, OH)
- Freudenberg Group (Plymouth, MI)
- FuelCell Propulsion Institute (Golden, CO)
- FXI (Media, PA)
- Hosokawa Nano Particle Technology (Summit, NJ)
- Mott Corporation (Farmington, CT)
- Rel-Tek Corporation (Monroeville, PA)
- Siemens Power Generation (Pittsburgh, PA)
- Toray Carbon Fibers America (Flower Mound, TX)
- Trenergi Corporation (Franklin, MA)
- ZTEK Corporation (Woburn, MA)[138]

7.8 MEMBRANE ELECTRODE ASSEMBLIES

The membrane electrode assembly, or MEA, in a PEM fuel cell includes a polymer membrane, catalyst layers (anode and cathode), and gas diffusion. MEA suppliers in the United States include the following companies. Ballard Power Systems is in Burnaby, British Columbia, but the company is serving the U.S. market.

- 3M Fuel Cell Components (Oakdale, MN)
- Advance Systems (Green Bay, WI)
- Advent Technologies (East Hartford, CT)
- Alfa Laval (Warminister, PA)
- American Fuel Cell (Rochester, NY)
- Amsen Technologies (Tucson, AZ)
- Asbury Carbons (Asbury, NJ)
- ATI Specialty Alloys and Components (Pittsburgh, PA)
- AvCarb Material Solutions (Woburn, MA)
- Ballard Power Systems (Burnaby, British Columbia)
- Blasch Precision Ceramics (Albany, NY)
- Bodycote Thermal Processing (Berlin, CT)
- Branson Ultrasonics Corp (Danbury, CT)
- Bulk Molding Compounds (West Chicago, IL)
- Burkert Fluid Control Systems (Huntersville, NC)
- Caran Precision (Fullerton, CA)
- Ceramatec (Salt Lake City, UT)
- Chemours (Wilmington, DE)
- Circle Seal Control Division – Circor International (Corona, CA)
- COGEBI (Dover, NH)
- Columbia Chemical (Brunswick, OH)
- CoorsTek (Golden, CO)
- Corning (Corning, NY)
- Dana Corporation (Auburn Hills, MI)
- Dexmet Corporation (Wallingford, CT)
- Die-Matic Corporation (Brooklyn Heights, OH)
- Dow (Philadelphia, PA)
- ElectroChem (Woburn, MA)
- Energy Related Devices (Los Alamos, NM)

- ENrG (Buffalo, NY)
- Entegris (Decatur, TX)
- ESL Electro-Science (King of Prussia, PA)
- FEV Engine Technology (Auburn Hills, MI)
- Fotofab (Chicago, IL)
- Freeman Schwabe Machinery (Cincinnati, OH)
- Freudenberg Group (Plymouth, MI)
- FuelCell Propulsion Institute (Golden, CO)
- FXI (Media, PA)
- Gerard Daniel Worldwide (Hanover, PA)
- GKD USA (Cambridge, MD)
- Gore Fuel Cell Technologies (Elkton, MD)
- GrafTech International (Advanced Energy Technology) (Independence, OH)
- Haiku Tech (Miami, FL)
- Hamilton Precision metals (Lancaster, PA)
- Hitachi Metals America (Arlington Heights, IL)
- Hosokawa Nano Particle Technology (Summit, NJ)
- i-2-m (Raleigh, NC)
- Inorganic Specialists (Miamisburg, OH)
- Ion Power (New Castle, DE)
- It4ip (Pittsburgh, PA)
- Materion Corporation (Lincoln, RI)
- MEGTEC Systems (De Pere, WI)
- Metro Mold & Design (Rogers, MN)
- Minco Tool and Mold (Dayton, OH)
- Mott Corporation (Farmington, CT)
- National Coating Corporation (Rockland, MA)
- Nissan Technical Center North America (Farmington Hills, MI)
- Porvair Fuel Cell Technology (Hendersonville, NC)

- Precix (New Bedford, MA)
- Premix (Conneaut, OH)
- Quintus Technologies (Lewis Center, OH)
- Ragan Technologies (Winchendon, MA)
- Refrac Systems (Chandler, AZ)
- Rel-Tek Corporation (Monroeville, PA)
- Showa Denko Carbon (Ridgeville, SC)
- Siemens Power Generation (Pittsburgh, PA)
- SKRL Tool & Die – Polarcell Division (Eastlake, OH)
- Tech-Etch (Plymouth, MA)
- Techneglas (Perrysburg, OH)
- The Lanly Company (Cleveland, OH)
- Toray Carbon Fibers America (Flower Mound, TX)
- TreadStone Technologies (Princeton, NJ)
- Trenergi Corporation (Franklin, MA)
- VDM Metals (Florham Park, NJ)
- Waukesha Metal Products (Sussex, WI)
- World Class Plastics (Russells Point, OH)
- ZTEK Corporation (Woburn, MA)[139]

7.9 SENSORS

There are a number of different sensors used in the hydrogen fuel cell supply chain—including sensors to support flow management, pressure control, leak detection, and safety and alarm systems. These sensors are used for fuel cells and hydrogen production, storage, distribution, and at fueling stations.[140] Companies providing sensors for hydrogen fuel cells in the United States include:

- Agilent Technologies (Santa Clara, CA)
- Alicat Scientific (Tucson, AZ)
- Azbil North America (Phoenix, AZ)
- Burkert Fluid Control Systems (Huntersville, NC)

- Element One (Boulder, CO)
- Figaro USA (Arlington Heights, IL)
- H2scan Corporation (Valencia, CA)
- Habco (Glastonbury, CT)
- Hughes Peters (Huber Heights, OH)
- Makel Engineering (Chico, CA)
- Midsun Specialty Products (Berlin, CT)
- MKS Instruments (Andover, MA)
- MSA/General Monitors (Lake Forest, CA)
- NTM Sensors (Lewis Center, OH)
- Pfeiffer Vacuum (Nashua, CT)
- Power+Energy (Ivyland, PA)
- Sensor Electronics Corporation (Savage, MN)
- Setaram (Hillsborough, NJ)
- Sustainable Innovations (East Hartford, CT)
- Teledyne Hastings Instruments (Hampton, VA)
- Unison Industries (Dayton, OH)
- Vaisala (Woburn, MA)
- Watlow (Mason, OH)
- ZTEK Corporation (Woburn, MA)[141]

7.10 THERMAL MANAGEMENT

There are companies operating in the U.S. that provide strategies, devices, and systems to ensure that fuel cells operate correctly and within a specific temperature range.[142] Companies providing thermal management devices and systems include:

- AFC (Advanced Fuel Components) (Marshall, MI)
- Alfa Laval (Warminister, PA)
- ATI Specialty Alloys and Components (Pittsburgh, PA)
- Chart Industries (New Prague, MN)

- Eastman Chemical Company (St. Louis, MO)
- ENrG (Buffalo, NY)
- Exergy (Garden City, NY)
- Exothermics (Amherst, NH)
- Haynes International (Kokomo, IN)
- Heat Exchange Applied Technology (Orrville, OH)
- Johnson Matthey Process Technology (Ravenna, OH)
- Meggitt Control Systems (Indianapolis, IN)
- MKS Instruments (Andover, MA)
- Modine Manufacturing Company (Racine, WI)
- Morgan Thermal Ceramics (Augusta, GA)
- Mott Corporation (Farmington, CT)
- Quintus Technologies (Lewis Center, OH)
- Rath Performance Fibers (Wilmington, DE)
- Refractory Specialties (Sebring, OH)
- Senior Flexonics (Bartlett, IL)
- Setaram (Hillsborough, NJ)
- Sono-Tek Corporation (Milton, NY)
- The Lanly Company (Cleveland, OH)
- Thermal Dynamics (Ontario, CA)
- Thermogym US (Plantation, FL)
- Vaisala (Woburn, MA)
- Wisconsin Thermoset Molding (Milwaukee, WI)
- ZIRCAR Refractory Composites (Florida, NY)
- ZTEK Corporation (Woburn, MA)[143]

7.11 POWER ELECTRONICS

Power electronics are a critical sub-system component within the hydrogen fuel cell supply chain. Power electronics refers to “solid state systems that control and convert one form of energy to another, including inverters, converters, motor drives, and other devices."[144] Companies in the United States providing power electronics for hydrogen fuel cells include:

- Advanced Power Associates Corp. (New Milford, NJ)
- AeroVironment (Monrovia, CA)
- AMETEK Rotron Technical and Industrial Products (Woodstock, NY)
- Ardica Technologies (San Francisco, CA)
- BAE Systems (Endicott, NY)
- Bloom Energy Corporation (Sunnyvale, CA)
- Burkert Fluid Control Systems (Huntersville, NC)
- Eco Energy International (Mansfield, OH)
- Energy Technologies (Mansfield, OH)
- Exeltech (Fort Worth, TX)
- Fuses Unlimited (Strongsville, OH)
- Hughes Peters (Huber Heights, OH)
- Ladd Industries (Kettering, OH)
- Lynntech (College Station, TX)
- Maxwell Technologies (San Diego, CA)
- MTU Onsite Energy (Mankato, MN)
- Neah Power systems (Bothell, WA)
- Nextek Power Systems (Detroit, MI)
- Nissan Technical Center North America (Farmington Hills, MI)
- Omni Power (Arnoldsville, GA)
- Rockwell Automation (Mayfield Heights, OH)
- Schaefer (Hopkinton, MA)
- Schrader-Bridgeport International (Rochester Hills, MI)
- Staubli Electrical Connectors (Windsor, CA)
- Sustainable Power Systems (Boulder, CO)
- Tecknowledgey (Peekskill, NY)
- Tekmos (Austin, TX)

- TransPower (Escondido, CA)
- UQM Technologies (Longmont, CO)
- Valtronic USA (Solon, OH)
- ZTEK Corporation (Woburn, MA)[145]

7.12 VESSELS

There are companies that manufacture pressure vessels for fuel cell and reformer systems. Vessel manufacturers in the United States include:

- Advanced Structural Technologies (Oxnard, CA)
- Agility Fuel Solutions (Costa Mesa, CA)
- AT&F (Cleveland, OH)
- Branson Ultrasonics Corp. (Danbury, CT)
- COGEBI (Dover, NH)
- Coldwater Machine Co. (Coldwater, OH)
- Corning (Corning, NY)
- CP Industries Holdings (McKeesport, PA)
- Die-Matic Corporation (Brooklyn Heights, OH)
- Edison Welding Institute (EWI) (Columbus, OH)
- FIBA Technologies (Millbury, MA)
- Harrop Industries (Columbus, OH)
- Hexagon Lincoln Composites (Lincoln, NE)
- Luxfer Gas Cylinders (Riverside, CA)
- Maysteel (Menomonee Falls, WI)
- Oasis Engineering (Griffin, GA)
- Optimum Composite Technologies (Brigham City, UT)
- Preco (Somerset, WI)
- Premix (Conneaut, OH)
- Safe Hydrogen (Lexington, MA)
- Steelhead Composites (Golden, CO)

- Superior Energy Systems (Columbia Station, OH)
- Toray Carbon Fibers America (Flower Mound, TX)
- WireTough Cylinders (Bristol, VA)
- Worthington Industries (Columbus, OH)
- Xperion Energy & Environment (Heath, OH)
- ZTEK Corporation (Woburn, MA)[146]

7.13 PEM FUEL CELL STACKS AND SYSTEMS

Key players in the global market for PEM fuel cells include:

- Ballard Power Systems (Canada)
- Plug Power (U.S.)
- Hydrogenics (Canada)
- Nuvera Fuel Cells (U.S.)
- Horizon Fuel Cell Technologies (China)
- Nedstack Fuel Cell Technology (Netherlands)
- ITM Power (U.K.)
- AVL (Austria)
- ElringKlinger (Germany)
- Intelligent Energy (U.K.)
- W.L. Gore & Associates (U.S.)
- Pragma Industries (France)
- Umicore (Belgium)
- Shanghai Shenli Technology Co. (China)
- Johnson Matthey (U.K.)[147]

In the Hydrogen Fuel Cell Nexus, notable fuel cell developers, integrators, and manufacturers include:

- Ballard Power Systems (Burnaby, British Columbia)
- Horizon Fuel Cell Americas (Chicago, IL)
- Hydrogenics USA (San Diego, CA)
- ITM Power (Anaheim, CA)
- Nuvera Fuel Cells (Billerica, MA)
- Plug Power (Latham, NY)
- Siemens Power Generation (Pittsburgh, PA)
- US Fuel Cell Corporation (South Windsor, CT)[148, 149]

7.14 TRACTOR MANUFACTURERS

While the use of hydrogen fuel cells in tractors and farm equipment is a nascent application for fuel cells, tractor manufacturers would become part of the supply chain (similar to vehicle manufacturers with fuel cell-powered vehicles). Top tractor manufacturers include companies like John Deere, CNH (including Case IH and New Holland), Kubota, AGCO, Yanmar, CLAAS, and Mahindra.[150, 151]

8.0 Primary Market Research

8.0 PRIMARY MARKET RESEARCH

As part of this project, Dawnbreaker reached out to several points of contact in multiple stakeholder groups—including farmers, those affiliated with farm associations or agriculture-related associations, associations focusing on farm equipment, farm equipment dealers, and associations for farm equipment dealers—to gauge interest in hydrogen fuel cell tractors and zero-emission tractors, more generally. In total, 124 people were involved in this outreach effort. There is overlap among their roles, as a strategy for finding appropriate points of contact was to explore the various farm associations, including leadership and those on the board of directors. Many of the people who are on a board of directors for an agriculture-related association are also farmers, placing them in both the farmer category and the association category. Those who hold positions with agriculture associations may be farmers themselves, former farmers, or have close family members who are farmers. Many of those who have involvement in equipment dealer associations are also equipment dealers themselves. Due to the considerable overlap, we have grouped the points of contact accordingly:

- Farmers and those affiliated with farming associations
- Those affiliated with farm equipment manufacturing associations
- Farm equipment dealers and those affiliated with farm equipment dealer associations

The following table summarizes our primary research, in terms of the number of people contacted in each group, the number of responses received (interviews conducted), and the response rate.

Table 28: Primary Market Research

Group	Contacted	Received Feedback	Response Rate
Farmers and Farm Associations	104	20	19%
Farm Equipment Manufacturing Associations	5	2 (3 people, but 2 interviews)	40%
Farm Equipment Dealers and Related Associations	15	4	27%
Total	**124**	**26**	**21%**

The following sections summarize the feedback that was received from individuals in each of the three groups.

8.1 FEEDBACK FROM FARMERS AND FARM ASSOCIATIONS

When reaching out to farmers and leaders/directors of farm associations, our questions focused mainly on farmer attitudes toward zero-emission tractors and equipment, as well as existing on-farm fueling infrastructure. The questions that were asked include the following:

1. Considering the group of farmers that you work with or represent—or even your own personal experience in farming—are you seeing increasing interest in energy-efficient or zero-emission tractors (this could include electric, hybrid, methane, and/or fuel cell powered tractors, most notably)? Why do you think that is?
2. Do you think that zero-emission equipment would be of value to farmers? Why or why not?
3. We are also trying to better understand the extent to which farms have fueling infrastructure onsite or nearby. Can you speak to this at all?

We received feedback from 20 people in this category. The first two questions were closely related and there was some overlap in the responses. From a high-level perspective, the people we spoke with noted that, while they are open to innovation, farmers are not necessarily known for being early adopters. The technology will need to be proven and reliable before farmers gave it serious consideration. Not surprisingly, the concept of a hydrogen fuel cell tractor—or a zero-emission tractor—was more attractive to those focusing on organic farming, regenerative farming, and sustainable farming. This group of farmers tends to be environmentally conscious to begin with—and their customer base also tends to be in favor of more eco-friendly practices (getting away from fossil fuels can help to attract positive media attention and increase sales for some farmers). These types of farmers tend to use smaller tractors and more agile and specialized equipment, which better lends itself to more alternative sources of power (like electric). Organic farms have explored the use of electric tractors and fuel cell forklifts—both technologies have gone over fairly well in this segment, mainly because they are environmentally friendly, less noisy, and they expose the driver to less (or no) pollution. Because the technology is more advanced at this time, electric tractors are likely to see initial adoption before something like a hydrogen fuel cell tractor. Companies such as John Deere have developed higher HP electric tractors and other OEMs are exploring this technology, as well. The lack of hydrogen infrastructure is also a consideration, and part of the reason why most felt that electric tractors would be more viable in the near-term.

If a zero-emission tractor, such as a hydrogen fuel cell tractor, were to be competitive in the commercial market, it would have to offer comparable performance (HP, runtime, efficiency) to conventional tractors, be cost-competitive with current diesel-powered tractors, proven to be a reliable technology, infrastructure would have to be put in place to support this equipment, and the equipment would need to be easy to maintain and repair, as farmers often prefer to repair their own equipment onsite.

Everyone confirmed that diesel tractors are primarily used today. The technology behind these tractors is proven, reliable, they have the fueling infrastructure in place to support the use of this equipment, and farmers understand how to repair diesel-powered equipment. The ability to repair equipment is important—and it was mentioned by multiple people in this category. Since many farmers are in rural areas, they may be located far from mechanics and other service providers. Many farmers have the skills required to repair their own equipment and this appears to be something that is done quite frequently. Farmers are also often at the mercy of a short growing season, and they have a narrow window for planting and harvesting—they need their tractor to work right when they need it. In many cases, it is more economical for farmers to troubleshoot or fix their own equipment, but in other cases farmers like the autonomy. Some tractor OEMs now have proprietary software for repairing and fine tuning their own equipment, which requires farmers to return back to the dealers to get things fixed. This can certainly be inconvenient for some, and it has led many farmers to hang on to—or even to acquire—older equipment that is easier to repair onsite. If zero-emission tractors, or hydrogen fuel cell tractors more specifically, become mainstream in the market, farmers would need to feel confident that they are not going to breakdown or malfunction—and if they do, they also need to understand how to troubleshoot issues and repair the tractors. If a zero-emission tractor were to become competitive in the market, it would have to be affordable (cost-competitive with current diesel-powered tractors), reliable, and easy to maintain.

Hydrogen fuel cell powered tractors and zero-emission tractors were generally more attractive to those focusing on organic farming, regenerative farming, and sustainable farming. These farmers tend to be environmentally conscious themselves, and their customers are also in favor of more environmentally friendly practices. These farmers tend to use smaller tractors and more agile and specialized equipment, which are better suited to leveraging alternative sources of power.

In speaking with traditional growers, farmers of large farms, and those representing these farmers, some common themes emerged. While pretty much everyone perceives energy-efficiency as a good thing, and everyone wants to generate fewer greenhouse gas emissions, it is hard to get past economics. To see widespread adoption of a zero-emission tractor or hydrogen fuel cell tractor in the broader agricultural industry, the technology will have to be energy-efficient, cost-effective (again, at least cost-competitive with diesel-powered tractors), reliable, it will have to offer horsepower comparable to conventional tractors, and there should be a clear value-add. Profitability is the bottom line for most farmers. If a piece of equipment can

Profitability is the bottom line for most farmers. If a piece of equipment can increase profits, cut costs, or increase productivity, farmers will be interested in exploring this further. Even if the tractor is cost-competitive, there still has to be a clearly positioned value-add. It's not a matter of "if you build it, they will come," but rather "if you build it, they will chat.

make a farmer more profitable—or if it can help to cut costs or increase productivity, then that will be something that they will explore further. In most cases, however, you will not see many farmers investing in a zero-emission tractor for altruistic reasons (helping the environment, protecting the air on their own farms, etc.), alone. According to one person that we spoke with: "Even if it can be cost-competitive, there still has to be a value add. It's not a matter of 'if you build it, they will come,' but rather 'if you build it, they will chat.'" The product has to address a need and the economics have to make sense.

Farmers provided some insight into challenges that zero-emission tractors would have to overcome before becoming part of the mainstream market. One factor to consider is that even some very large farms—major farms in the United States—are still using tractors that are decades old. One major U.S. farm has a fleet of tractors, and most are from the 1960s-1980s, with their "newest" 100+ HP tractor being 11 years old. Many pieces of equipment are specialized for a certain job and a lot of farms only use equipment in the summer months. To make an investment in newer technology that might only get used 100 hours per year may not be viewed as a wise investment. Another farmer we spoke with actually purchased two low-emission tractors a few years ago, but they were having technical issues with it and now they will not buy a tractor with a pollution device on it until the technology advances to a point where the equipment runs reliably. A number of people discussed issues with Tier 4 engines. There is some hesitation with low-emission or no-emission equipment.

Some farmers today are apprehensive when it comes to the newer tractor technologies available in the current market. Reliability and technical issues tied to Tier 4 engines and pollution devices were reported. Farmers are also using tractors that are decades old—and in same cases, going out of their way to acquire older tractors—because they are easier to maintain and repair.

There are a few factors that may ultimately encourage adoption of zero-emission tractors. The tractor OEMs will play a key role here. Some automakers have stated that, at some point in the near future, they are going to stop producing internal combustion engines. What if some of the tractor companies decided they were going to do that? There would be some initial resistance from farmers to be sure, but cost share programs, grants, and other incentives would encourage adoption and improve acceptance. Ford is releasing an electric F-150 (pickup truck). This could spark a trend and encourage farmers to more seriously consider electronic or zero-emission vehicles. Factors such as technology development and capability (horsepower, runtime, efficiency, etc.), costs (cost of the tractor, cost of the fuel, and cost per job/hour/acre), availability of both tractors and fuel (infrastructure), and safety will play a role, but adoption will likely happen slowly (farmers are generally slow to change). One of the farmers we interviewed does not think there will be a successful entry for a zero-emission tractor until something like this is mandated. The exception might be if a major manufacturer (John Deere, for example) got into the space and heavily promoted it. Until then, the major tractor manufacturers may focus on any perceived disadvantages of the new technology, making it more challenging for anyone who tries to enter the market.

> Based on the feedback that was received, it appears that smaller, more specialized equipment, forklifts, UTVs for on-farm transportation, light hauling trucks, and small-scale utility equipment for homeowners and hobby farmers may be good candidates for zero-emission technology, including hydrogen fuel cells.

Based on the feedback that was received, it appears that smaller, more specialized equipment, forklifts, UTVs for on-farm transportation, light hauling trucks, and small-scale utility equipment for homeowners and hobby farmers may represent good candidates for zero-emission equipment. Forklifts are an interesting example in the context of the agricultural industry—having a zero-emission forklift would make sense because they are often used inside of a structure (such as a freezer or in refrigeration), where one would not want to diminish the air quality. One major U.S. vegetable grower noted that they use some electric UTVs for on-farm transportation. Zero-emission light hauling trucks are being promoted and may have some promise, people are excited about these entering the market. Smaller tractors could be good candidates for zero-emission technology, but larger tractors would be more challenging. Horsepower requirements are high for deep tillage and hauling and the units would need to be capable of pulling the existing implements that they have to use in order to do their work.

Most of the people interviewed acknowledged some merits of the technology and saw value, at least to an extent, in zero-emission equipment. With that said, it is generally believed that mandates, policies, regulations, and incentives may need to play a role if the industry is going to see widespread adoption. Incentives are well received, mandates—not so much. If the new technology being proposed is unproven, farmers will figure out a way to keep older models running. A few individuals mentioned carbon credits and/or carbon sequestration—if farmers can gain some financial reward for being emission-free or more energy-efficient, then this will be a value-add for them. There would likely need to be some incentives in place to support the purchase of the new technology and also to support fueling infrastructure and fuel availability.

> Mandates, policies, regulations, and incentives may play a role in the ultimate adoption of zero-emission tractors and equipment. Incentives would certainly be preferable to mandates—if farmers can gain some financial reward for being emission free or more energy-efficient, then this will be perceived as a value-add for them.

Many people focused on the economics of all of this. You will not see many farmers taking a stand and being an early adopter of new technology because the margins in agriculture are already thin and they often do not have the money to do something like that. A publicly-traded company could invest in a new technology, produce an annual report for shareholders, and show that they are being sustainable and adopting renewable energy technology—farmers are not in that position, and it is hard to position this in such a way where they could use it to gain contracts or increase revenue. One could say that something is locally grown, organically grown, grown with increased safety, etc.—this is already a lot of messaging to be putting out there. Would adding energy-efficiency to this messaging justify a premium price?

A number of people also spoke to fueling infrastructure and what that looks like on many U.S. farms. Nearly everyone we spoke with confirmed that it is common to see fueling infrastructure on farms. A large operation could go through tens of thousands of gallons of diesel fuel per month. Often mid-size to large-size farms will have fuel pump with a tank for fuel storage onsite, and this is often centrally located on the farm. Farms that are very small—10 acres, used to produce food for a road-side farm stand or small market, etc.—likely would not have this fueling infrastructure onsite. The same is true of many small urban farms (they typically lack onsite fueling infrastructure). However, location often plays a more significant role than farm size—those that are in very rural areas, far from any fueling stations, are likely to have onsite fueling, regardless of size. Many farms also use large fuel tanks on the bed of a pickup truck or on a diesel trailer—they can fill up the large fuel tank at the centrally located fuel pump and then drive out to the field and fuel up the equipment wherever the equipment is at that point in time. Farms can get away with not having gasoline onsite, but diesel is considered to be pretty essential. We spoke with a number of farmers who shared some insights with us, regarding onsite fuel infrastructure:

- According to one farmer in Colorado, they have a very dispersed and distributed farm that includes different plots of land throughout an area—the plots of land could be many miles apart. They purchase approximately 500,000 gallons of diesel fuel each winter and have a large fuel tank at the farm headquarters. They fill up trucks and diesel trailers at the headquarters and then drive out into the field to refuel equipment, as needed. The ability to transport fuel to where it is needed is an important capability for them. Would a hydrogen fuel cell tractor be able to be refueled in such a way?

- Another farmer who has a 120-acre farm noted that they have one onsite central fueling spot with a 500-gallon diesel tank and a 500-gallon gasoline tank. They also had a secondary site at one point, which also had these tanks. He noted that it is very common to have fuel infrastructure onsite.

- Another farmer mentioned that they have multiple large fuel tanks on site—one for each type of fuel (gasoline, on-road diesel, and off-road diesel).

- Another farmer stated that most farms in his area (Iowa) have a gravity-fed above ground tank that can hold a couple hundred gallons of fuel (might be 10 feet off the ground, with a 500-gallon capacity). Many farms have their own gas tank, as well. There is a truck that comes on a regular basis and refills the tank—most farms use that type of system. The local farmers co-op plays an important role in rural areas, selling and distributing that fuel.

- Another farmer reported that they have three sets of tanks onsite for fuel. Smaller farms probably do this less often, depending on how far they are from the gas stations. Most farmers do have onsite fueling. As stated by others, one of the services of the co-op is filling up fuel tanks. The co-ops play a role in delivering fuel (notably gasoline and diesel) to the farms.

As far as fueling infrastructure is concerned, almost everybody has diesel tanks. They use off-road diesel, so no one really goes to the gas stations. Anyone who is commercial, regardless of scale, has a very good chance of having a diesel tank onsite. There are some pros and cons to onsite fueling. On one hand, there is a financial benefit to having this onsite fueling capability—since it is considered off-road diesel, the fuel is not taxed like on-road diesel. One downside is that safety can be a concern. If there is an underground gas leak, for example, this would be an environmental problem and cleanup can be very expensive.

> It is very common for farmers to have diesel fueling infrastructure on their farms, particularly for commercial farms operating in rural areas. Farms that are very small or located in urban areas are less likely to have onsite fueling infrastructure. It is common to have one tank (500-gallon capacity seems to be a popular tank size) and one pump for diesel, centrally located on the farm. Farmers will often fill up portable fuel tanks on trucks or trailers and drive that fuel out to the field to fill up equipment.

On-farm infrastructure for alternative fuels is largely non-existent at this time. However, one exception seems to be methane. Some farms do have methane digesters, which may be helpful for supporting methane-powered tractors. One thing to keep in mind is that farms that already have this onsite fueling convenience would likely want to keep their operations consistent and closely aligned to what they do currently. If they were to invest in a hydrogen fuel cell tractor, they would likely want hydrogen infrastructure onsite, just as they have diesel infrastructure onsite for diesel powered equipment. Hydrogen would have to at least be cost-competitive with diesel and the method of delivery, logistics, etc. would have to be similar to what they are doing for diesel. If the process is more complex, expensive, or inconvenient, that will likely hinder adoption.

8.2 FEEDBACK FROM FARM EQUIPMENT MANUFACTURING ASSOCIATIONS

When reaching out to farm equipment manufacturing associations, our questions focused primarily on tractor buying behavior and the potential advantages (and disadvantages) of hydrogen fuel cell tractors/zero-emission tractors over standard diesel-powered tractors. The following questions were asked:

1. Based on your expertise in the tractor segment, how successful do you think a hydrogen fuel cell tractor—or a zero-emission (electric, hybrid, methane, etc.) tractor—might be in the market?

2. What are your thoughts regarding the advantages/disadvantages of hydrogen fuel cell tractors (or zero-emission/energy-efficient tractors, more broadly)

Those we spoke to in this segment generally felt that a zero-emission tractor would be well received in the market. However, small equipment such as small chore tractors might be more appropriate for this technology than heavy-duty, high HP tractors.

and how they would compare to standard (diesel-powered) tractors?

Based on the feedback received, it seems that a zero-emission tractor would be well received. There are a number of prototypes—including small electric tractors, alternative fuel equipment, and even some methane (some farmers have methane digesters, and they are trying to find a way to use that methane as fuel).

Small equipment where you do not necessarily need the energy density would represent a good candidate for zero-emission technology. This could include small chore tractors, maybe something that one might use for 20 minutes at a time. Heavy duty applications require an incredible amount of power and some of the alternative energy solutions just aren't going to work, in this case. With a 500 HP tractor, it's going to be a challenge to get an alternative energy or zero-emission tractor to meet the necessary HP requirement. Some tractor OEMs have reviewed hydrogen and they do not view it as a viable solution. The infrastructure can also represent a hindering factor. Farmers do not want to fuel up every 30 minutes or so.

Regarding the advantages versus disadvantages of a hydrogen fuel cell tractor (or more broadly, a zero-emission tractor) compared to a diesel tractor, diesel is an old technology. It is reliable, proven, well-known, durable, offers high energy density, you can carry a ton of fuel, and it can operate all day long without stopping to refuel. With some electric and battery-powered equipment, initial testing was done in India and Spain and the equipment was so small, they could not test it with conventional equipment. It also could not survive the test when they actually did the test. The equipment must be reliable, cost-efficient, and powerful. It cannot cost more than the incumbent technology, in terms of cost of ownership (this encompasses the cost of the vehicle itself, fuel, maintenance, and even disposal).

Some tractor OEMs have reviewed hydrogen and they do not view it as a viable solution. The infrastructure can also represent a hindering factor. Farmers do not want to fuel up every 30 minutes or so.

For hydrogen fuel cells, or other low- or zero-emission technologies to become widely accepted on tractors, cost and performance will need to better match the performance of conventionally diesel-powered tractors than they do today. An agricultural tractor is almost always outputting positive power when working, so opportunities for technologies such as regenerative braking are few and far between. Many tractor drivers take pride in their ability to operate a tractor in the field without needing to use the service brakes. Diesel engines also have an enviable torque curve. Power requirements can range widely in the same field with the same operator, tractor and attached implements so the tractor reaction to increased loads is to simply allow the engine to slow down causing output torque to increase. As an example, a tractor may have a rated engine speed of 2100 RPM, but peak torque might occur at 1450 RPM and often this torque is 40% or more than the torque available at rated engine speed. This behavior eliminates the need for shifting gears most of the time, desirable to producers. Another aspect to consider is the energy density of diesel fuel. Diesel fuel has a density of 846 kg/m3 and a heating value of 45.6 MJ/kg. Methane has a density of 0.747 kg/m3 and a heating value of 54 MJ/kg. While methane contains more energy for a given mass, the low density requires far more volume for the same output, even if highly pressurized. Hydrogen, for comparison, has a density of 0.09 kg/m3 and a heating value of 142.2 MJ/ kg. A typical design goal and expectation for a tractor is to provide at least 12 hours of operation before refueling.

Another consideration is whether or not agricultural tractors will even exist long-term. During the last 120 years or so, the tractor has developed considerably. Prior to WWII, the primary driver was to mechanize agriculture, replacing animal power with tractors. After WWII, we have seen tremendous power growth with the aim of allowing one person to farm more acres. Land productivity has likewise grown by nearly an order of magnitude in terms of bushels harvested per acre over the last century. We now have to face that we need a further 25% improvement in agricultural output by mid-century to feed the world's population and we also have the advent of automation. If there is no operator on the machine, the machines do not have to be as large. It could be that farming changes from treat the field the same way to meeting the individual needs of each plant with small autonomous purpose-built machines that treat a plant from pre-planting through post-harvest. In any case, smaller machines of much lower power are likely in the future and farming by the end of the century will likely be significantly different than it is today.

8.2 FEEDBACK FROM FARM EQUIPMENT DEALERS AND RELATED ASSOCIATIONS

When reaching out to farm equipment dealers and associations representing farm equipment dealers, our questions focused primarily on tractor buying behavior, interest in more energy-efficient tractors, and their thoughts on hydrogen fuel cell tractors. The following questions were asked:

1. Based on your expertise in the tractor segment and your understanding of tractor buying behavior, how successful do you think a hydrogen fuel cell tractor or zero-emission tractor might be in the market?

2. As farmers may be exploring different ways to reduce greenhouse gas emissions, have you noticed any increase in the number of farmers interested in energy-efficient, alternative fuel, and/or zero-emission tractors (i.e., electric, hybrid, fuel cell, and methane powered tractors)? Any thoughts on why that might be?

3. What do you think about the concept of a hydrogen fuel cell tractor? What would you see as the advantages/disadvantages of a zero-emission tractor?

> From a dealer perspective, zero-emission tractor success would be based on factors related to cost, performance, HP ratings, how the machine runs, what type of technology is involved, and the complexity of the unit. Is the level of power appropriate for farming operations and the required scale?

In terms of better understanding tractor buying behavior and gathering thoughts on the potential success of a hydrogen fuel cell tractor (or zero-emission tractor, more broadly), it appears this would depend on a number of factors, in terms of tractor performance: horsepower (HP) ratings, how the machine runs, what technology is involved, the complexity of the unit, and whatever is being added to it. Manufacturers are looking into alternatively powered equipment, but a key consideration is—is it powerful enough? Is it appropriate for farming operations and the scale that is required? Is the horsepower there? When you are in a planting or harvesting situation, you are not able to stop frequently or for a long period of time (such as hours for charging). From a dealer perspective, they would want to understand what sort of advanced education would technicians need to be able to repair and keep the fuel cell running properly?

One person that we spoke with noted that farmers and equipment dealers are not known for being early adopters. That said, farmers are creative and will adopt proven technologies if they are cost-effective, durable, and sustainable. It might be helpful to look at the adoption of CNG powered tractors for some insights. This year (2021) is the first year that a major manufacturer will be offering a CNG tractor for sale to the public (New Holland). The expectation is that we will see both electric (battery powered) and/or semi-autonomous equipment before hydrogen powered units.

As far as interest from farmers is concerned, those that we spoke with in this segment have not witnessed a significant amount of interest in more energy-efficient or zero-emission tractors. Some manufacturers are working on electric tractors and the success of those models will depend on the efficiency of the battery, how it needs to be recharged, and how often it needs to be recharged. It will also depend on how the new technology impacts power and performance. To be successful in the market, the unit will need to be able to do the job that it is designed to do.

Another person that we spoke with noted that farmers can be a conservatively minded group. Many people understand that climate change is a problem and want to move toward more environmentally-friendly practices, alternative fuel use, and they want to ultimately decrease emissions—but they cannot afford to do this simply for the sake of being environmentally conscious. Once again, it comes down to economics. Is the new technology affordable? Does it get the

> While traditional ag producers may not be as concerned with emissions, smaller specialty growers (such as those focusing on vegetables, fruits, and cannabis) have expressed concerns about emissions, climate change, and soil quality. They may be more likely to serve as early adopters of zero-emission equipment, as the interest is there and this segment also tends to use smaller, more specialized equipment.

job done properly and efficiently? If farmers are required to do something, but it is not economical, then some resistance is likely. Everyone wants to do their part to reduce emissions, but this is their livelihood and economics will always play a critical role.

In another interview, it was mentioned that our current political environment (rural vs urban, Republican vs Democrat, etc.) makes it challenging to roll out new technologies, policies, and regulations. It will be important that any rollouts not be perceived as government mandate or sponsorship. While there are traditional production ag producers that are not particularly concerned with greenhouse gas emissions, there are also smaller, specialty growers (such as those focusing on vegetables, fruits, and cannabis) that seem to more often express concern about emissions, climate change, and soil science. These specialty growers may be more likely to be early adopters of zero-emission equipment. They typically use smaller, specialized units, which might represent the best niche for zero-emission tractor technology.

> Current mechanisms in place to make units environmentally friendly have negatively impacted performance and presented maintenance challenges. Potential users will want to understand how the new technology will affect equipment performance, logistics, fueling, fuel infrastructure and storage, and how much downtime would be expected for refueling or recharging.

With respect to the advantages and disadvantages of a hydrogen fuel cell or zero-emission tractor compared to a conventional diesel-powered tractor, there are numerous advantages. They would be better for the environment and hydrogen fuel is probably easier to produce and more readily available. Efficiency does come into play again. The current mechanisms in place to make units environmentally friendly have negatively impacted performance and it has also presented maintenance challenges. How would this new technology affect equipment performance? The industry has experienced issues with Tier 4 engines (and in Europe, there is even a Tier 5 engine). If there is a better technology than that, it has a chance of being more readily accepted.

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