ELECTRIFICATION IN FLUID POWER

INTRODUCTION

Electrification is a buzzword throughout most industries now and is a common topic being discussed at conferences, events, and board rooms. While many businesses and industries have already embraced electrification, others are still working to understand the impacts, opportunities, and decision points to make. To add further confusion, electrification means many different things and is a broad term encompassing all types of ideas, products, movements, efforts, and industries. This confusion hinders the ability of an industry or company to digest and fully understand what is going on and how to react within the context of their business strategy.

As part of its mission to strengthen the fluid power industry, and as a key initiative within its objective of providing effective fluid power forums where its members, OEMs, and related technology partners can connect and advance their collective interests, the National Fluid Power Association (NFPA) launched an Electrification in Fluid Power Task Force in September 2022 with the following objectives:

1. Explore myths, trends, and buzzwords that have arisen in the space and that have caused confusion.
2. Define electrification within the fluid power industry.
3. Outline the electrification architectures that are commonly applied in the mobile and industrial markets served by fluid power.
4. Define and compare important metrics related to the use of electro-mechanical and electro-hydraulic actuation solutions in these architectures in order to provide guidance on potential applications and technology break points.
5. Describe potential changes in market size among mobile and industrial markets served by fluid power as a result of the likely pace of electrified system adoption.
6. Describe the product categories within fluid power that are most likely to be affected by those market changes.
7. Explore strategies for effectively marketing fluid power solutions in this evolving space.

The Task Force met multiple times to discuss these objectives, share information and resources, and develop a set of responses and recommendations. This is the report of the Task Force's final consensus, published in March 2023.

PART 1
Defining Electrification within the Fluid Power Industry

Current State

A clear and common definition of electrification within the fluid power industry is needed to help frame the scope, discussion summaries, and recommendations contained in this report.

In the past, electrification of fluid power systems has sometimes referred to the integration of fluid power technologies with sensors and electronic controls. At the time of this report, however, electrification is a term that most often refers to the machine or vehicle on which a fluid power system performs some function, not necessarily to the fluid power system itself. In this understanding, electrification results in an “electrified machine,” i.e., one in which the prime mover of the machine system that controls propulsion and/or actuated functions is an electric power source, either batteries, direct AC, an engine-generator, or a combination of these technologies.

This “electrified machine” architecture is already state-of-the-art in most industrial applications of fluid power. Although continued advancements in the use of sensors, computing power, data, control, or other electrical components in these systems are helping to improve their productivity, reliability, and maintenance, these electrified industrial fluid power systems are not the primary focus of this report.

However, the use of different “electrified machine” architectures are newly proliferating in many mobile applications of fluid power, where the prime mover has traditionally been an internal combustion engine (ICE). Many different power architectures are manifesting in the marketplace, with some still reliant on the traditional ICE, some hybridizing the ICE with electric power sources, and some switching fully to electric power. This is creating disruptive change in this market segment, and the impact of this change on the on-board fluid power systems, on general fluid power technology, and on the fluid power market itself will be the primary focus of this report.

“Electrified Machine” Architectures

A review of the common and emerging “electrified machine” architectures, and the relationship each describes between their prime movers and their on-board fluid power systems, may also be helpful in framing the scope, discussion summaries, and recommendations contained in this report.

1. **Diesel Powered, or ICE.** This is the traditional architecture. It consists of two general types:

    A. **Fully Hydraulic.** This system consists of a diesel engine as the prime mover and only hydraulic pumps attached to the output of the engine. Typically ground/traction drive is hydrostatic. Common configuration is a hydrostatic variable volume piston pump for the motive power with a tandem secondary variable or fixed displacement pump for work functions. Sometimes a third or fourth auxiliary gear pump is added for auxiliary hydraulic work. This can be tandem mounted to the main pump stack or belt/gearbox mounted on the engine.

B. **Direct Driveshaft.** This system consists of a diesel engine with a transmission and driveshaft output powering the propulsion work function. Hydraulic pumps to power other work functions are typically gearbox, PTO, or belt driven off the engine.

2. **Hybrid Electric, or HEV.** This is an emerging architecture and can come in many configurations. Generally speaking, this type of system consists of an internal combustion engine as the prime mover that uses diesel, gas, LNG, or other types of fuel. This engine can then be utilized in many architectural variations with an electric generator coupled to either hydraulic, battery, or fuel cell energy storage and/or energy recovery. The primary function of this hybrid system is to reduce energy consumption during duty cycle periods that do not require the full use of the ICE power output.

   Hydraulic pumps or power units that drive work functions in these systems can also be traditionally configured, i.e., connected directly to the prime mover through gearboxes, PTOs, or belt drives, or they can be individually electrified, i.e., driven by an electric motor or powered directly off the electric AC or DC bus.

3. **Fully Electric, or EV.** This is an emerging architecture. Generally speaking, this type of system replaces the ICE with electrical energy as the prime mover. Most common fully electric systems consist of a battery bank to store/discharge electrical energy to electrically powered work functions. These systems also typically include an inverter (less so in low voltage applications). Fuel cell systems can also provide electric energy either with or without battery storage.

   Hydraulic pumps in these systems must be electrified (i.e., the pump is driven by an electric motor) but there are many types of configurations. Single or multiple electric motors can drive a single or multiple hydraulic pump system.

General Trends and Myths

The on-going move towards electrified machines in the configurations described above is both a response to and a driver of several multi-faceted trends occurring in the larger marketplace. These trends include:

- The need for productivity enhancements (including due to operator, labor, and skill shortages)
- Advancements in connectivity, connected machines, IOT, and sensors (allowing for autonomous functions and advanced machine control strategies)
- Corporate sustainability initiatives
- Cybersecurity concerns

- Big data capabilities
- The creation of new business models
- Regulatory requirements, including those mandating lower emissions, higher efficiency, and/or more compact/lighter machines

In response, the fluid power industry is responding to and driving its own multi-faceted trends, especially with regard to the performance and operation of its technologies. These trends include:

- Power-on-demand, flow rate control, and/or dedicated or distributed pumps
- Noise reduction
- Novel energy storage strategies, including through the use of batteries, hydrogen fuel cells, and accumulators
- Environmentally friendly hydraulic oils and lubricants
- Thermal management
- Increases in system and component efficiency
- Load balancing

Despite the advancements described by these trends, a number of perceptions about the impact of electrification on the use of fluid power technology and on the fluid power industry persist, some of which appear based on inconsistent or inaccurate understandings of the marketplace. Among the most persistent of these “myths” are:

- Electrification is just a passing trend
- Electrification will not affect most businesses for many years to come
- There is no business case for electrifying machines
- Electrified machines will be all autonomous in the future
- Battery-powered machines are not cost effective
- Batteries are not yet up to the task for heavy equipment
- On electrified machines, hydraulics will be entirely replaced with electro-mechanical actuation
- On electrified machines, it is either electro-mechanical or hydraulic actuation, one or the other
- Electro-mechanical actuation will keep increasing in power and power density
- Hydraulics has to be noisy

PART 2
Describing the Impact of Electrification on Fluid Power

Competing Actuation Technologies

In the competitive landscape of actuation technologies, different machines, applications, and duty cycles can each maximally benefit from either an electro-mechanical, an electro-hydraulic, or a hybridized solution of the two. As mobile machines electrify their power sources, the different architectures have the potential to alter the benefit profiles of these actuation technologies.

As such, it will be important for stakeholders across the fluid power supply chain to monitor and compare a variety of metrics in order to determine changes in break points between these technologies and to make better decisions regarding their advantages and disadvantages. What follows is a list of some metrics that may be appropriate in this regard, and some current assumptions about the relative strengths and weaknesses of each technology.

Electric > Hydraulic
Metrics or performance characteristics in which, generally speaking, electric-driven electric actuation currently has an advantage over electric- or ICE-driven hydraulic actuation:

- Energy efficiency
- Ease of integration and use of data
- Maintenance
- Fluid leakage
- Audible noise
- Actuator stiffness (no fluid bulk-modulus impact)

Hydraulic > Electric
Metrics or performance characteristics in which, generally-speaking, electric- or ICE-driven hydraulic actuation currently has an advantage over electric-driven electric actuation:

- Power density at the location of work
- Fuel energy density
- Ability to survive shock load, fatigue, acceleration, etc.
- Robustness (including environmental factors like ingress protection)
- Component range and scalability
- Electrical field interference

It is important to note that the technology advantage for some of these metrics or performance characteristics can change based on the specific application or duty cycle. For example, the advantages for hydraulics increase when one looks at linear vs. rotary actuation. Use of energy efficient, eco-friendly, or other high-performance fluids can also increase the advantages for hydraulic technology.

Varying parameters such as engine size and voltage level can also provide different advantages or disadvantages for both electric and hydraulic technologies.

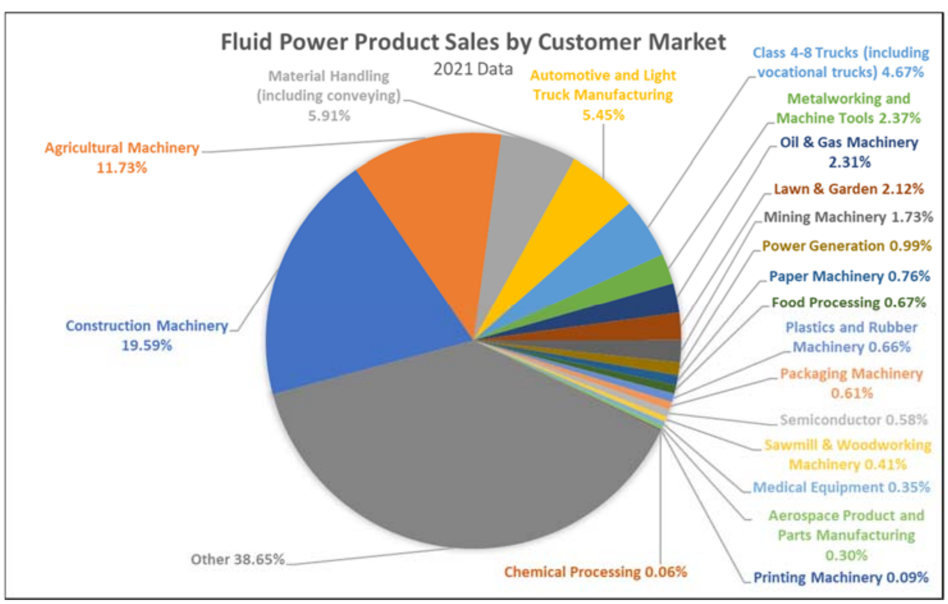
Other Metrics
Several other metrics or performance characteristics exist for which the specific technology advantage remains uncertain or too dependent on specific applications or duty cycles to make any general statements. These metrics include:

- Total cost of ownership
- Cost - Force per dollar
- Cost - Dollar per kilowatt, per volt
- Force - Distance moved per volume
- Weight
- Physical size
- Reliability and continuous operation

Again, it will be important for stakeholders across the fluid power supply chain to monitor and compare a variety of these metrics in order to determine changes in break points between these technologies and to make better decisions regarding their advantages and disadvantages. To the degree they are able, fluid power stakeholders should focus on increasing their advantage over competing technologies in these performance characteristics, as they will likely be the factors that matter in choosing which actuation technologies to embrace. A detailed analysis of specific case studies may be helpful in determining improvement opportunities for specific applications and duty cycles.

Predicted Changes in Market Sizes

According to the latest data collected by the National Fluid Power Association (NFPA), the twenty largest end markets for fluid power product sales are shown on this chart.



In December 2022, NFPA surveyed a wide audience of fluid power suppliers, manufacturers, distributors, and OEMs with knowledge of these markets, and asked the following two questions for each market.

1. Many markets are experiencing an electrification trend, that is, an increase in the use of electric power sources that serve as the prime mover in either the propulsion circuit, work circuit, or both. Is this a trend in the XXX market?
   A. Yes
   B. No (if no, skip to next section)

2. Please estimate the percent of products in the XXX market that employ an electric power source (either alone or in hybridization with an internal combustion engine) as the prime mover in either the propulsion circuit, work circuit, or both.
   A. In 2022:
   B. In 2030:

The survey generated responses from 74 people across the fluid power supply chain, and provided the following picture of the state and future trend for electrified machines in each of these markets.

Is There an Electrification Trend?

Many customer markets are experiencing an electrification trend, that is, an increase in the use of electric power sources that serve as the prime mover in either the propulsion circuit, work circuit, or both. When asked if this was a trend in the markets they were familiar with, a high amount of consensus clustered around many of the largest markets for fluid power.

More than 90% of respondents agreed that such a trend was occurring in:

- Automotive and Light Truck Manufacturing
- Chemical Processing Machinery

CUSTOMER MARKETS	N	Is there an electrification trend in this market?
Aerospace Product and Parts Manufacturing	12	75%
Agricultural Machinery	49	71%
Automotive and Light Truck Manufacturing	11	91%
Chemical Processing Machinery	2	100%
Class 4-8 Trucks (including vocational trucks)	8	88%
Construction Machinery	37	89%
Food Processing Equipment	12	100%
Lawn and Garden Equipment	13	100%
Material Handling (including conveying) Equipment	26	92%
Medical Equipment	8	50%
Metalworking Machinery and Machine Tools	15	40%
Mining Machinery	18	78%
Oil and Gas Machinery	9	56%
Packaging Machinery	10	70%
Paper Machinery	6	67%
Plastics and Rubber Machinery	4	75%
Power Generation Equipment	2	50%
Printing Machinery	3	67%
Sawmill and Woodworking Machinery	7	71%
Semiconductor Machinery	6	67%
All Responses	**258**	**78%**

Yes
91-100%
81-90%
71-80%
61-70%
51-60%
0-50%

- Food Processing Equipment
- Lawn and Garden Equipment
- Material Handling (including conveying) Equipment

More than 80% agreed for:

- Class 4-8 Trucks (including vocational trucks)
- Construction Machinery

It was additionally observed that there are other markets not captured in this data set where an electrification trend is also occurring, such as recreational vehicles and marine applications.

Predicted Growth of Electrified Machines

CUSTOMER MARKETS	N	Estimated percent of electrified machines in 2022	Estimated percent of electrified machines in 2030	Increase 2030 vs. 2022
Aerospace Product and Parts Manufacturing	2	53%	55%	3
Agricultural Machinery	24	8%	32%	24
Automotive and Light Truck Manufacturing	8	10%	45%	35
Chemical Processing Machinery	1	20%	60%	40
Class 4-8 Trucks (including vocational trucks)	6	6%	26%	20
Construction Machinery	28	4%	23%	19
Food Processing Equipment	8	58%	79%	21
Lawn and Garden Equipment	11	10%	37%	27
Material Handling (including conveying) Equipment	20	34%	53%	18
Medical Equipment	2	98%	98%	0
Metalworking Machinery and Machine Tools	4	75%	85%	10
Mining Machinery	14	21%	39%	18
Oil and Gas Machinery	4	18%	36%	19
Packaging Machinery	4	65%	84%	19
Paper Machinery	4	70%	81%	11
Plastics and Rubber Machinery	2	45%	53%	8
Power Generation Equipment	1	90%	95%	5
Printing Machinery	2	63%	73%	10
Sawmill and Woodworking Machinery	5	53%	75%	22
Semiconductor Machinery	2	55%	88%	33
All Responses	152	26%	46%	20

% electrified	Increase % points
81-100	31-40
61-80	21-30
41-60	11-20
21-40	1-10
1-20	0
0	

When asked to estimate the percent of machines electrified in each market in 2022 and in 2030, a wide variety of responses were received, which were then averaged.

One way to examine this data is to focus on those markets with a low current percent of electrified machines AND a high predicted increase in electrified machines by 2030. Noteworthy markets here include:

- Agricultural Machinery
- Automotive and Light Truck Manufacturing
- Chemical Processing Machinery
- Class 4-8 Trucks (including vocational trucks)
- Construction Machinery
- Lawn and Garden Equipment
- Oil and Gas Machinery

Since the terminology surrounding electrification in fluid power is new and not universally understood, and since responses likely contain wide variations based on perceptions of application size and duty cycle, it is best to see these responses as largely directionally significant rather than precise in their analysis of specific markets and quantifications of electrified machines. Roughly speaking, these responses indicate that the various markets served by fluid power technology may see 20-percentage-point increase in electrified machines over the next eight years.

Predicted Impacts on Fluid Power Products

It is likely that the increases in electrified machines in the markets described above will have the following general effects on fluid power system strategies and the demand for specific fluid power components.

These predictions assume that one primary strategy for optimizing hydraulic actuation systems with electric power sources will be to decentralize them, that is, to move away from architectures in which a single hydraulic pump drives multiple actuators and towards architectures in which multiple electro-hydraulic pumps each act on individual actuators. Note the distinction drawn here between "distributed" hydraulic systems, in which a traditional single pump and valve bank architecture is maintained with control products distributed closer to and acting on each actuator, and "decentralized" hydraulic systems, in which multiple pump/motors are deployed and moved closer to each point of actuation.

In this environment, observers should see:

System strategies

MORE DEMAND FOR:

- Controls
- Hydraulic heating
- Thermal management
- Integrated devices (EHAs, etc.)
- Decentralized systems
- Noise reduction

- Higher connectivity to sensors and data, likely driven by demand from customers for higher value (predictive maintenance, optimized and efficient control, etc.)
- Variable speed electric motors driving smaller fixed displacement pumps

LESS DEMAND FOR:

- Hydraulic cooling

Components

MORE DEMAND FOR:

- Thermal valves
- Smaller, higher-pressure pumps (able to handle higher input speeds from electric motors)
- Use of new thermally-capable, variable viscosity fluids
- Accumulators
- Sensors, controllers, IoT products

LESS DEMAND FOR:

- Valves (in general)
- Variable volume pumps
- Use of traditional hydraulic oil
- Small actuators/cylinders
- Small and medium duty motors (especially traction and fan motors)
- Hoses and fittings

NO DRAMATIC CHANGE IN DEMAND FOR:

- Actuators/Cylinders (in general)

PART 3
Strategies for Effectively Marketing Fluid Power Solutions

There are many studies and reports, including this one, that show the trend towards electrified machines is both real and likely to accelerate over the next decade or more. Right now, it is primarily the smaller machines with the shorter duty cycle that are electrifying, but as market demand increases and as technological barriers are removed, it is believed that larger machines with longer duty cycles will also begin to be electrified.

In this environment, hydraulics currently is and will likely remain a primary option for the actuation of work functions on these machines, and it is expected that many transitions and experiments will be conducted over the next several years as the industry adapts to providing hydraulic components and systems better optimized for operating in these electrified architectures.

What follows are some suggestions for successfully marketing and designing fluid power solutions during these transitionary times.

1. **Core Strengths.** Focus on the robustness and superior power density of fluid power -- this is a core strength that will continue to shine in many applications and duty cycles.

2. **Energy Efficiency.** Recognize that hydraulics, when optimized for the electrified environment, can be more energy efficient, and therefore contribute less to emission production, than more traditional hydraulic systems and applications. Look for opportunities to simplify system designs so that, for example, electric motors spin hydraulic pumps only as fast or slow or when needed to provide flow for actuation, or so that engines can run continuously or for longer periods of time at their most efficient level. Optimized, efficient systems may also require less total volume of fluid, thereby reducing environmental risks.

3. **Energy Recovery.** Recognize that hydraulics provides a significant advantage in applications that require or could benefit from energy recovery, storage, and redeployment strategies. Accomplishing these tasks with hydraulic accumulators provide excellent and efficient energy transfer capabilities.

4. **Operational Advantages.** Recognize that hydraulic systems are made of components with distinct operational advantages over systems made of electric and electro-mechanical components, especially in the power characteristics that would be necessary for larger machines with longer duty cycles. These advantages include:
   a. **Availability of parts.** Basic hydraulic components are widely available, more so than the sophisticated electrics that would be needed.
   b. **Component qualification.** Hydraulic components don't need to be qualified for electro-magnetic interference, sensitivity to the environment, and other factors.

c. **Safety.** Hydraulic lines are generally safer than high voltage electric systems.
d. **Serviceability.** Technicians able to service hydraulic systems are typically in greater abundance.
e. **Thermal management.** Hydraulics have an advantage here, as fluids can both transfer energy and carry heat away.

Technology Frontiers

Successfully adapting fluid power systems for electrified mobile equipment will require some technology growth and development -- a task that many in the fluid power industry are already working on and finding success with. As the electrification trend progresses to larger machines with longer duty cycles, several strategies will be key.

1. **Hybridized Devices.** Systems are already hybridizing across the hydraulic and electrical spectrum, but watch for opportunities to hybridize the needed components themselves. For example, a hydraulic pump with its own electric windings could function as a hybridized electric motor/hydraulic pump, and would bring added advantages to compact and efficient designs.

2. **Energy Balance.** A systems approach is needed in order to best optimize the hydraulics in these applications, and one helpful tool in this arsenal is a system-wide analysis of the energy balance -- where the power generates, where it goes, what tasks it performs, and where the losses occur. Simulation tools can help in performing these analyses, and will be pivotal in determining the applications and situations in which hydraulics will be used.

3. **Wireless Sensors.** Electrifying machines generally allows for easier integration with electronic sensors and collection of operational system data. On many pieces of construction and agricultural equipment, for example, the movement of the actuated work functions can limit where wired sensors can be placed. Development of wireless sensor technology will likely continue, especially sensor clusters and subsystem modules, so that these systems can be better optimized to actual working conditions.

4. **Thermal Management.** Electrified machines typically require a more complex thermal management system due to the addition of batteries, power electronics, chargers, etc. This opens up the frontiers of new refrigeration valves and controls, coolant valves, pumps, and controls to best optimize thermal considerations on these machines.

5. **Impact of Newer Fluids.** As just mentioned, electrified machines have different thermal management needs, and one strategy beginning to emerge is the use of new hydraulic fluids that can both cool and lubricate these machines. Questions remain about the compatibility of these fluids with traditional hydraulic components, especially seals and if a single, multipurpose fluid would also be compatible to cool electronic components, so development in this area may be important.

GLOSSARY OF TERMS AND BUZZWORDS

In this environment, a common set of terms and definitions remains elusive. For the purposes of discussing and creating this report, the Task Force referred to and recognized the following terms and, where needed, adopted the following definitions.

Vehicle Architectures

- ZEV – Zero Emission Vehicle
- NZEV - Near Zero Emission Vehicle
- EV - Electric Vehicle
- HEV - Hybrid Electric Vehicle
- MHEV - Mild Hybrid Electric Vehicle
- FCEV - Fuel Cell Electric Vehicle
- BEV - Battery Electric Vehicle
- PHEV - Plug-In Hybrid Electric Vehicle
- PEV - Plug-In Electric Vehicle
- ICE - Internal Combustion Engine (includes any fuel type)
- LEV - Low Emission Vehicle
- ULEV - Ultra Low Emission Vehicle

Electric Vehicle Terminology

- REX - Range Anxiety - Fear of not having sufficient battery storage to complete vehicle task
- MPGe - Miles per gallon equivalent
- DC Charging - Direct Current charging
- DC Fast Charging - Providing DC charging direct to vehicle battery
- AC Charging - Providing AC charging to vehicle which then must be rectified to DC to charge battery
- Charge Rate - How much energy can be put into the battery per given time interval
- Level 1 charging - Charging off of 120 volt AC power source
- Level 2 charging - Charging off of 208 to 240 volt AC power source
- Level 3 charging - Charging directly off 400 to 900 volts of direct current DC

Battery Terminology

- Li-ion - Lithium-Ion
- LCO - Lithium Cobalt Oxide ($LiCoO_2$)
- LMO - Lithium Manganese Oxide ($LiMn_2O_4$)
- LFP - Lithium Iron Phospate ($LiFePO_4$)
- NMC - Nickel Manganese Cobalt
- NCA - Lithium Nickel Cobalt Aluminum Oxide
- LTO - Lithium Titanium Oxide

- Swappable - The ability to swap batteries on a vehicle
- End of life - What happens to components, materials, batteries after they are used. (i.e., how are they disposed of and/or recycled)
- Cradle to grave - The journey of any product, component, or material from its source (usually mined or grown) to its end stage (usually disposed of in landfill or recycled)

Power Electronics Terminology
- SiC - Silicon Carbide

Industry 4.0 Terminology
- IOT - Internet of Things
- IIOT - Industrial Internet of Things
- Connectivity - Term used to describe the trend of connecting products, components, and systems together
- Edge Computing - processing / computation / and data storage being performed closer to the source of data (i.e., performing computations onboard of vehicle versus elsewhere)
- The Edge - Shorthand for edge computing
- Big Data - Refers to extremely large data sets that can now reveal patterns, trends, interactions, and other information useful to the machine that the data is being taken from
- Machine Learning - Any program that is able to learn and adapt without using explicitly written code instructions
- AI - Artificial Intelligence
- AN - Neural Net
- ANN - Artificial Neural Net
- Deep Learning - A type of machine learning based on an artificial neural net
- XR - Extended Reality
- AR - Augmented Reality
- VR - Virtual Reality
- Blockchain - A distributed or sharable electronic ledger that is a database that stores data in blocks. It is a type of database that unlike a traditional database that stores its data in a table, a blockchain stores its data in groups known as blocks that are linked together.
- PM - Predictive Maintenance
- XaaS - Everything as a service
- W2W - Well to Wheel
- GHG - GreenHouse Gas

Fuel Cell Types
- SOFC - Solid Oxide Fuel Cell
- PEMFC - Proton-exchange membrane Fuel Cell

Motor Types Used on Electrified Vehicles

- PM - Permanent magnet motor
- PMAC - Permanent magnet AC motor
- BLDC - Brushless DC motor
- IM - Induction Motor

Other Terminology

- TCO - Total cost of ownership

TASK FORCE PARTICIPATION

The following organizations and individuals participated in the production of this report by attending the various meetings held to discuss and draft its content.

		Meeting Dates					
Organization	**Representative**	**9/1/22**	**10/6/22**	**11/3/22**	**12/1/22**	**1/5/23**	**2/2/23**
Afton Chemical Corporation	Brian Rhode	X		X		X	X
B&B Management Labs	Dan Bagley		X		X		
Bosch Rexroth Corporation	Jon Frey	X		X		X	X
Bucher Hydraulics	Christian Eitel	X	X		X	X	
Cascadia Motion	Pete Herder	X	X	X	X	X	X
Cross Company	Jeff Curlee			X			
Crown Equipment	Sharvari Divey-Teall		X	X	X	X	
Danfoss	Jamie LeClair			X			
Danfoss	Mike Betz	X	X	X	X	X	X
Dura-Bar	Jason Parr			X			
Elevat	Adam Livesay		X	X		X	
Fluid Power Journal	Michael Degan	X					
Fluid System Components	Harley Quarnstrom	X	X	X	X	X	
Galland Henning Nopak	Sudarshan Sharma	X	X	X		X	
Galland Henning Nopak	Tom Miklos	X	X	X		X	X
Gates Corporation	Kaare Kurtzke		X	X			
Hallite Seals	Chuck White		X		X		X
HED	Paul Ludwig	X	X	X	X	X	X
Husco	Ben Holter		X	X		X	X
HYDAC	Chris Kolbe	X	X		X	X	
HYDAC	Marty Christianson	X	X				
HYDAC	Olia Mladenova	X				X	X
Hydraforce	Russ Schneidewind	X		X	X		X
Hydraforce	Scott Nagro		X	X	X	X	
Hydra-Power Systems	Tom Patterson	X		X		X	X
Hydrotech	Charles Schreiner			X		X	
Hyster-Yale Group	Narendra Gupta			X	X	X	X
IFP Motion Solutions	Brian Tritle	X		X		X	
IFP Motion Solutions	Reinhold Herrman		X				
J. M. Grimstad	Brian Sternberg	X					
J. M. Grimstad	Geoff Harvey	X	X	X		X	X
J. M. Grimstad	Joe Nelson	X	X	X			
John Deere	Jeff Bauer	X	X	X		X	
John Deere	Paul Marvin	X	X		X	X	X

Komatsu	Gary Dostal		X	X	X	X	
Kraft Fluid Systems Inc.	Patrick Green	X	X	X	X	X	X
Kraft Fluid Systems Inc.	Ryan Walker		X	X	X	X	
Linde Hydraulics	Russell Luzinski	X					
Lubrizol	Gary Garling		X	X	X	X	X
Milwaukee School of Engineering	Lucas Garcia					X	
Milwaukee School of Engineering	Pawan Panwar					X	X
Milwaukee School of Engineering	Sheku Kamara	X					
Monocerus	Michael Terzo	X	X			X	X
Mosey's Production Machinists	Bob Mosey	X					
Motion & Flow Control Products	Jeremy Shubert		X	X		X	
Motion Control Enterprises	Allan Scales					X	
Muncie Power Products, Inc.	Alan Jones		X		X	X	
National Fluid Power Association	Eric Lanke	X	X	X	X	X	X
NORGREN	Kent Sowatzke		X			X	
Nott Company	D.J. O'Konek			X		X	X
Nott Company	Phil Leise		X	X	X	X	X
OPS Controls	Brandon Flick		X		X		
Parker Hannifin	Howard Zhang		X		X	X	X
Parker Hannifin	Kevin Bresnahan	X	X	X		X	X
Parker Hannifin	Kurt Boey				X		
Parker Hannifin	Mike Harman				X	X	
Poclain Hydraulics	Patrick Jalabert	X	X	X			
Sun Hydraulics	Steven Meislahn	X	X	X	X		
Trelleborg Sealing Solutions	John McLaughlin	X		X	X	X	
Trelleborg Sealing Solutions	Trevor Combs	X	X	X	X	X	X