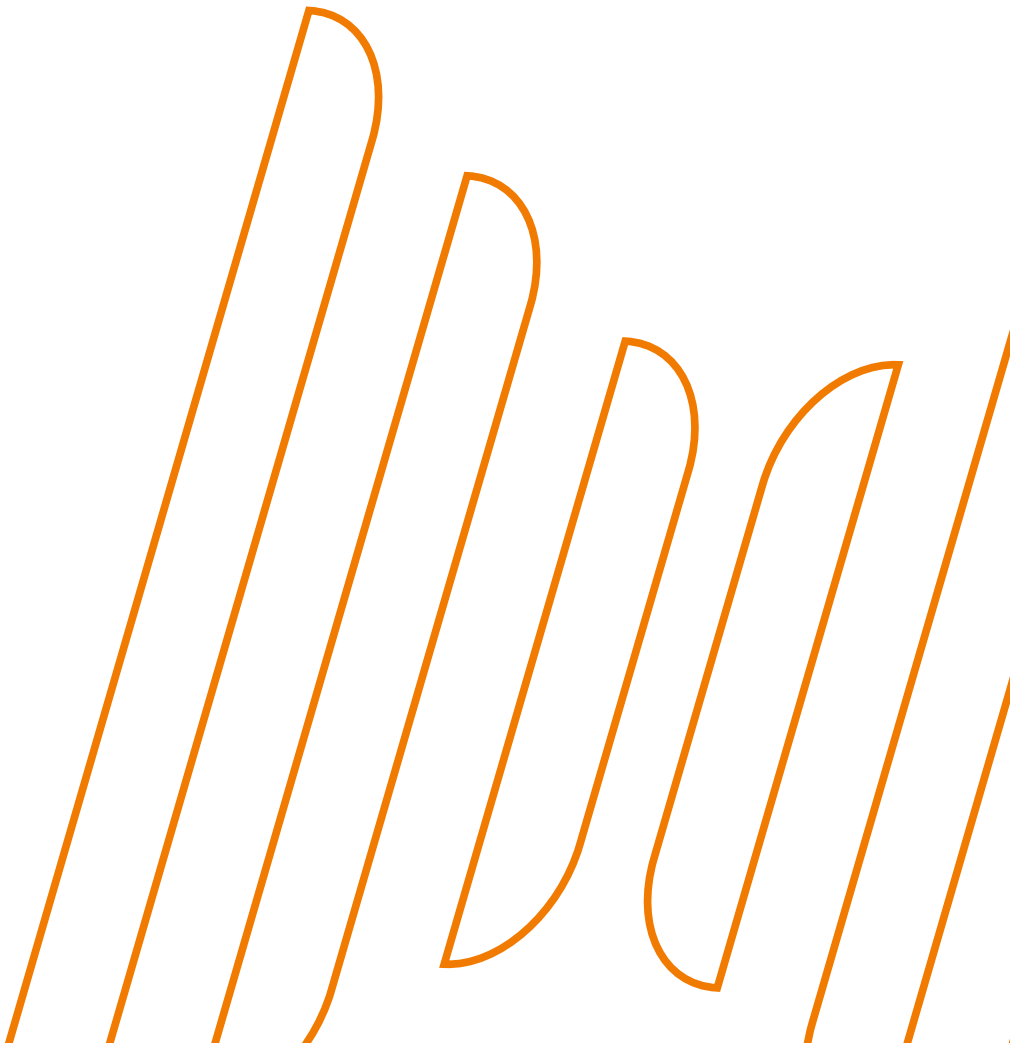
VDMA

FLUID POWER

Digitalization of Fluid Power



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Short summary

This document describes why and how the fluid power sector — long recognized as a strong and innovative industry — must undergo a transformation. Despite its success and reputation for delivering highly reliable, flexible, and powerful solutions for a broad range of industries, fluid power faces new demands for greater efficiency, adaptability, and data exchange. These necessities are driving the industry to embrace digital transformation.

Central to this transformation is the adoption of digital technologies that enable smarter, connected, and more efficient fluid power systems. By integrating digital solutions, companies unlock benefits such as predictive maintenance and advanced forms of human-machine collaboration, while also reducing operating costs and supporting development of new service-based business models.

A key enabler for this digital future is the Asset Administration Shell (AAS), which acts as the fluid power industry's digital twin. The AAS provides a standardized, comprehensive digital representation of products and systems, capturing all relevant information and data across the entire product lifecycle. This foundational element supports both the digitalization of products and the evolution of business models, ensuring fluid power remains competitive and continues to drive innovation in the era of Industry 4.0 and beyond.

1 Status Quo in Fluid Power

Fluid power industry, which includes the subfields of hydraulics and pneumatics, generates an annual revenue of approximately €9.6 billion in Germany, with an export rate of around 60%. Fluid power products are known for their high flexibility, dynamic performance, reliability, robustness, long lifespan, and high-power density while being relatively lightweight. Because of these qualities, fluid power products are essential components in both stationery and mobile systems across nearly all sectors of mechanical engineering.

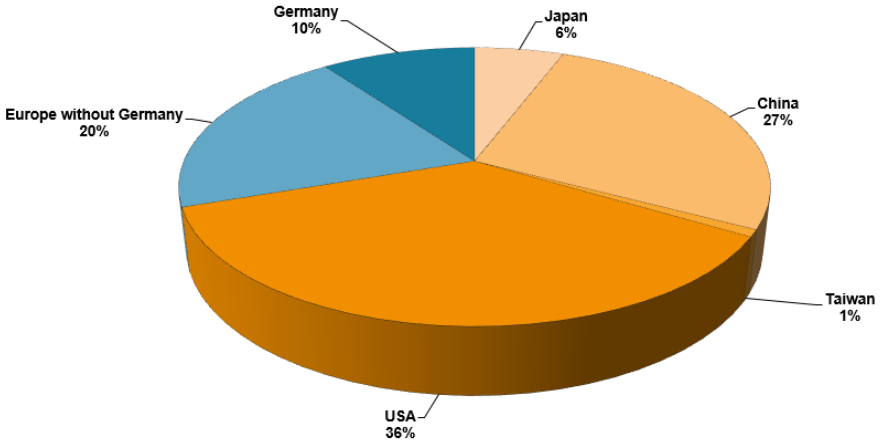

Figure 1.1. Global national home sales 2023 © ISC Statistics.

1.1 Key Industries and Market Leadership

Key customer industries for hydraulics include mobile machinery, such as construction and building material machines with €14.9 billion in revenue in 2022, and agricultural machinery with €16.8 billion in revenue in 2022. Other important sectors are machine tools, which generated €20.8 billion in revenue in 2022, and conveying technology with €19.4 billion in revenue in 2022. For pneumatics, the main customer sectors are food and packaging machinery, which generated €6.0 billion in revenue in 2022, as well as automotive manufacturing and electrical engineering. Germany is the global market leader in fluid power, ahead of the USA and China. These two countries, along with the EU, are also the largest importers of German fluid power products.

1.2 Added Value Through Digitalization

Fluid power products are known for their low acquisition cost, high reliability and great power density. With the help of more innovative digital solutions, operating costs can be reduced and precision as well as energy efficiency increased. In addition, digitized, connected and intelligently controlled fluid power products make it possible for new products and services to be developed in user industries. These include for example predictive maintenance or new forms of collaboration between man and machine. New business models based on product service systems and on data analysis will play an even more important role in company portfolios in the long run.

2 Why We Must Digitalize Fluid Power

The digital transformation of fluid power is not just a technological evolution - it is a strategic necessity. Driven by regulatory demands, sustainability goals, and the need for greater efficiency and flexibility, digitalization opens new opportunities for innovation, differentiation, and value creation across the entire fluid power ecosystem.

2.1 Handling Data as a Success Factor

Intelligent data handling is a key success factor in fluid power. Advanced analytics enable real-time monitoring and optimization of processes, improving product quality, energy efficiency, and system flexibility.

To prevent data overload, edge computing complements cloud solutions by processing data at its source. This allows manufacturers to apply domain expertise and share only relevant information, enhancing collaboration and performance.

A central enabler is the industrial dataspace – a secure, interoperable environment for data exchange. Supported by initiatives like the International Data Spaces Association, it ensures data sovereignty and standardized collaboration across the ecosystem.

Digitalization also supports sustainability goals. By capturing and analyzing climate-relevant data such as carbon footprints, companies can identify optimization potential and contribute to EU climate targets. These efforts align with Industry 4.0 and IoT principles and are supported by initiatives like Platform Industrie 4.0. A practical example is the Fluid 4.0 project, which will be addressed later. Together, these initiatives ensure that fluid power remains a future-ready technology, capable of delivering both economic and ecological value.

2.2 Laws and Regulations: Enabling Digital Transformation

The digitalization of fluid power is not only driven by technological innovation but also by a rapidly evolving regulatory landscape:

- Digital Product Passport (DPP): From 2024, most products in the EU must include a digital record of lifecycle data—origin, material composition, carbon footprint, repairability, and recycling. This is part of the Ecodesign for Sustainable Products Regulation (ESPR), which sets requirements for durability, circularity, and resource efficiency.
- EU Data Act (effective Sept 2025): Requires manufacturers of connected products to enable user access to usage data and ensure interoperability. Data sharing is mandatory, with strict conditions for protecting trade secrets.

These regulations aim to enhance transparency, support circular economy, and enable data-driven business models. For fluid power, this means integrating lifecycle data into digital twins and using standardized formats like the Asset Administration Shell (AAS).

2.3 Intrinsic Motivation – Use Cases, Business Models & Added Value

To stay competitive, fluid power companies must evolve beyond mechanical excellence. Digitalization enables this shift by **embedding intelligence into systems** that deliver real customer value. Solutions like smart/soft sensors, condition monitoring, and predictive maintenance boost productivity, reduce downtime, and optimize energy use. They also support compliance through transparent reporting and lifecycle tracking.

Digitalization also opens the door to innovative business models. Instead of selling components alone, manufacturers can offer integrated product-service systems that combine hardware with digital services.

A key enabler of this transformation is the emergence of digital ecosystems - interconnected platforms where data, services, and products interact seamlessly. These ecosystems allow fluid power companies to collaborate across supply chains, integrate with smart factory environments, and offer scalable, plug-and-play solutions. Standards such as OPC UA, AutomationML, and Asset Administration Shell (AAS) ensure interoperability and compatibility across vendors and technologies, making it possible to participate in broader industrial networks. Tools like virtual prototyping, simulation, and digital twins accelerate development and improve responsiveness to customer needs. Ultimately, differentiation lies in delivering intelligent, connected, and adaptive solutions that create value beyond traditional mechanics.

3 Concept –Approach to Digitalizing Fluid Power

3.1 The Asset Administration Shell (AAS)

The Asset Administration Shell (AAS) is the cornerstone of digital transformation in fluid power. It acts as a digital twin of a physical asset, enabling structured, standardized, and machine-readable data exchange across systems and companies.

The AAS encapsulates all relevant data about assets such as CAD models, simulation data, digital nameplates, handover documentation, and technical specifications—in a format that is IEC-compliant, XML-based, and interoperable. This ensures that information is unambiguous, manufacturer-independent, and accessible throughout the asset's lifecycle.

By assigning an AAS to a physical object, a bridge to the digital world is created. This allows the asset to be digitally represented, monitored, and managed in Industry 4.0 environments. The AAS supports standards like AutomationML and OPC UA, making it compatible with existing digitization strategies and enabling seamless integration.

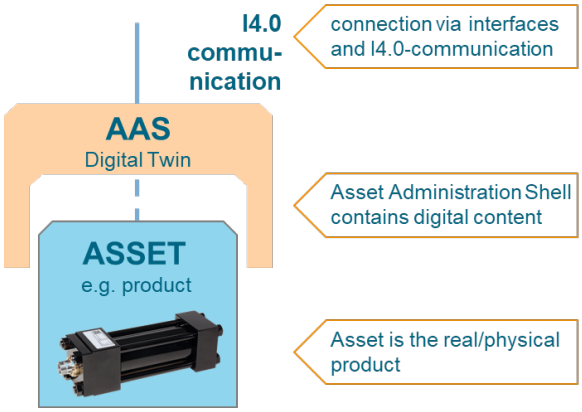

Figure 3.1 the Asset administration shell implements the digital twin

3.2 The Central Role of Standardization

Standardization is the backbone of digitalization. It ensures that data is consistent, interoperable, and usable across different systems and manufacturers. For years, the VDMA Fluid Power Association, in cooperation with DIN, has been actively shaping these standards. The focus lies on ISO (International Organization for Standardization) standards, which define everything from dimensions and safety requirements to the structure of technical documentation and digital attributes.

In the context of the AAS, properties must be uniquely identifiable. This is achieved through IRDIs (International Registration Data Identifiers), which are standardized via ISO and ECLASS. These identifiers ensure that each data point is clearly defined, machine-readable, and semantically consistent.

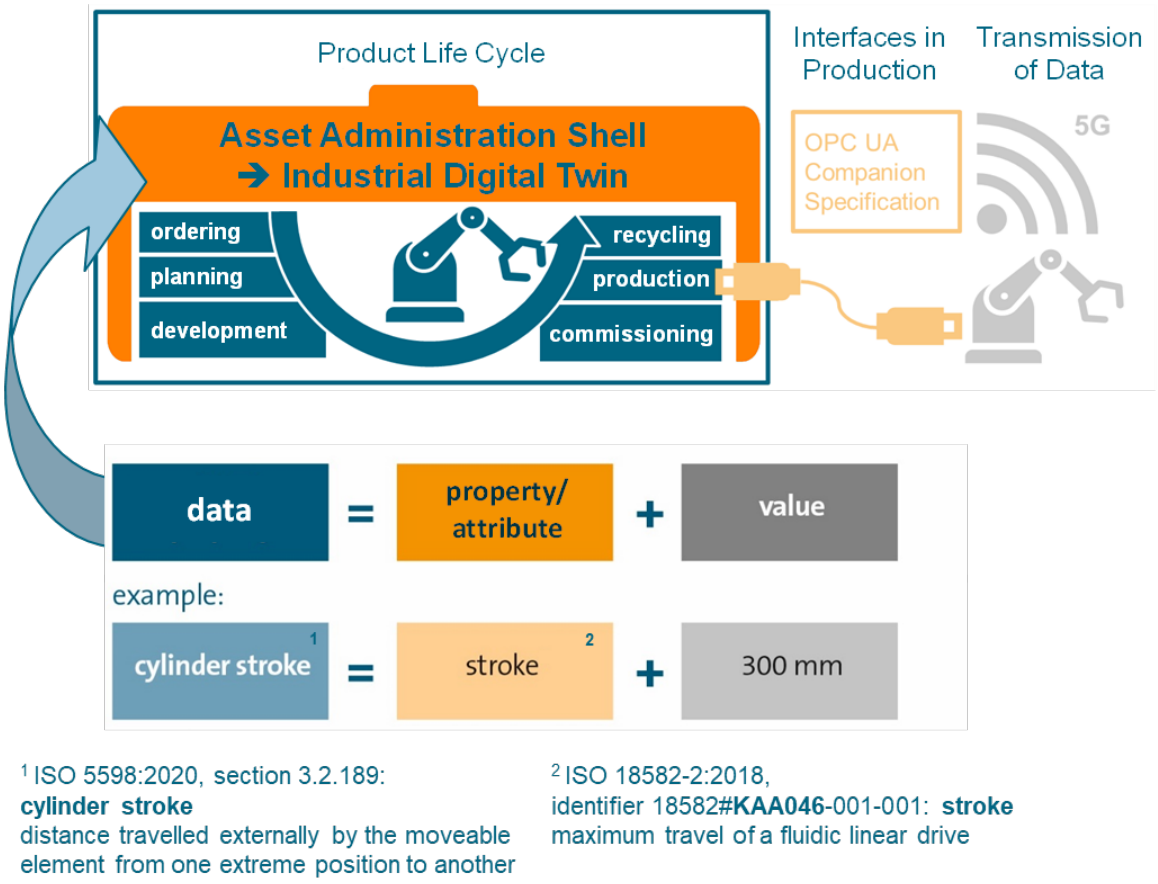

Figure 3.4 Asset Administration Shell in the Product Life Cycle - Example of Standardized Data

3.3 ISO – The Global Framework

The VDMA Fluid Power Association plays a leading role in ISO, particularly in ISO/TC 131, *Fluid Power Systems*. German experts, coordinated by VDMA, chair the key working groups and subcommittees. Among the most important standards for Industry 4.0 are:

- ISO 5598, which defines the vocabulary for fluid power systems and components.
- ISO 18582, a series of standards that specify reference dictionaries for product properties. Part 2 defines pneumatic characteristics, while a hydraulic counterpart is currently in development.

These standards form the semantic foundation for digital twins and ensure that fluid power data is globally compatible and future-proof.

3.4 ECLASS – A Practical Digital Standard

Complementing ISO, ECLASS, a German consortium standard that is available an applicable in several languages, provides a hierarchical classification system for fluid power products. It organizes products into domains, main groups, subgroups, and classification classes. Each class is linked to standardized characteristics, many of which are derived from ISO 18582.

Since 2016, the VDMA and its member companies have actively contributed to ECLASS, ensuring that fluid power has its own structured domain with relevant properties. ECLASS supports multilingual access and digital availability, making it a practical tool for global data exchange. Its use of blocks and aspects mirrors the concept of submodels in the AAS, creating synergies with the Industrial Digital Twin Association (IDTA) and other Industry 4.0 frameworks.

3.5 Submodels – Structuring the Digital Twin

Within the AAS, submodels organize related data into logical groups such as digital nameplate, handover documentation or technical specifications. This modular structure makes the AAS scalable, adapting to different lifecycle stages and use cases.

Submodels mirror the structure of ECLASS blocks and aspects, enabling fluid power companies to create digital twins that are both standardized and application-specific. Their development is led by the Industrial Digital Twin Association (IDTA), with over 77 submodel specifications already published, including widely used ones like Digital Nameplate or Handover Documentation.

To ensure interoperability, all submodels must conform to the Metamodel Industrie 4.0 (currently version 3), which defines the structural rules for submodel design. However, version changes are not backward compatible, requiring updates to maintain compliance.

While submodels provide essential structure, many still lack semantic depth, limiting intelligent data interaction. Addressing this is key to unlocking the full potential of Fluid Power 4.0.

3.6 Practical Application of Submodels in Fluid Power

Submodels become truly valuable when applied to real-world use cases across the asset lifecycle. AAS instances can be stored in the cloud, on servers, or directly on components, enabling seamless integration into digital workflows. Even passive components can be digitally represented via QR codes or RFID, linking to their AAS and ensuring accessible, up-to-date information.

To address specific industry needs, the VDMA Fluid Power Association identified practical use cases involving manufacturers, OEMs, and service providers. This led to the development of targeted submodels such as Change Notification, Parameter Information or Technical Handover Information. These submodels are documented in VDMA whitepapers and are being prepared for standardization through the Industrial Digital Twin Association (IDTA), ensuring relevance and interoperability across industrial applications.

4 Proof of Concept: Demonstrators and Fluid 4.0

4.1 Preparatory Work and Early Demonstrators

The foundation for Fluid Power 4.0 was laid through early demonstrators at Hannover Messe 2022 and 2023, where Asset Administration Shells (AAS) were presented in action. Visitors could scan components and access their digital representations, showcasing the feasibility and maturity of the approach. A highlight was the VDMA digitalization demonstrator (2023), featuring a stack light, weighing system, and pneumatic actuator. While the stack light and scale system used OPC UA, the actuator's data was displayed live via its AAS.

More information, including explanatory videos, articles, and examples of AAS implementations, can be found on the dedicated website: www.fluidtechnik40.de.

Figure 4.1 Digitalization Demonstrator at Hannover Fair Trade 2023

4.2 The Fluid 4.0 Project - Vision and Strategic Relevance

The digitalization pace and the activities increased when the Fluid 4.0 project started.

Fluid 4.0 is a cross-industry initiative aimed at advancing the digitalization of fluid power products and systems. It builds upon the groundwork of Fluid Power 4.0, extending its principles into system-level applications and industrial use cases. The project was initiated by the VDMA Fluid Power Association, Bosch Rexroth, and TU Dresden, and is supported by a consortium of 15 project partners and 16 associated partners from across the fluid power sector as well from customer branches.

The initiative focuses on the development and implementation of Asset Administration Shells (AAS) for fluid power products and systems. These technologies enable machine-readable, interoperable data exchange across manufacturers and users, forming the basis for intelligent system management. The project addresses four key industrial use cases: machine control development, energy monitoring, cross-industry CO_2 calculation, and circular economy.

By leveraging existing standards such as OPC UA, ECLASS, and concepts from Catena-X, Fluid 4.0 aims to use secure, role-based data spaces that facilitate collaboration and innovation across the product life cycle. Demonstrators are being developed to showcase the practical benefits of these technologies and to support knowledge transfer within the industry.

Fluid 4.0 is also part of the broader Manufacturing-X ecosystem and is funded by the European Union (NextGenerationEU) and the German Federal Ministry for Economic Affairs and Energy (BMWE).

4.3 Goals and Use Cases

Fluid 4.0 addresses key industry needs through four practical use cases:

1. **Machine Control**: Digital twins of systems (built out of components' AAS) enable real-time simulation, virtual commissioning, and adaptive control, improving system performance and flexibility.
2. **Energy Monitoring**: Data-driven insights help to optimize pressure, cycle times, and energy use—supporting cost reduction and sustainability.
3. **Carbon Footprint Calculation**: The AAS aggregates emissions data across the lifecycle, enabling automated CO_2 tracking and optimization.
4. **Circular Economy**: Lifecycle data exchange supports R-strategies and contributes to the Digital Product Passport with circular economy information.

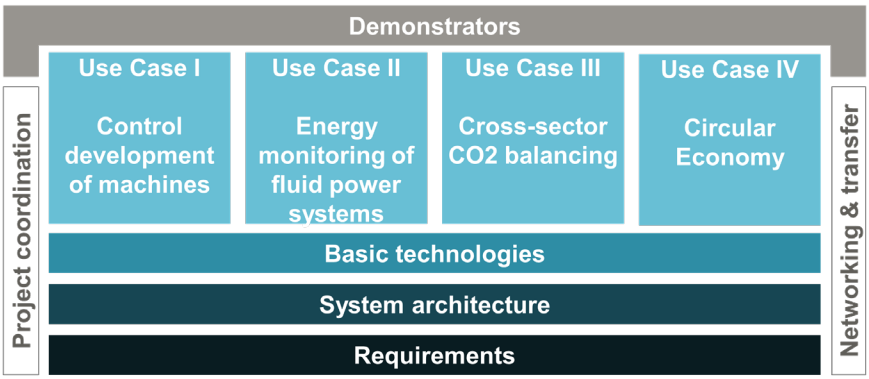

Figure 4.4 Fluid 4.0 Working Packages and Use Cases

4.4 Demonstrators and Transfer Activities

To support knowledge transfer, Fluid 4.0 demonstrators were presented at major industry events. At Hannover Messe 2024, 13 companies showcased interoperable AAS structures, confirming the technical and industrial readiness of the concept.

At Hannover Messe 2025, together the DMAG and the Fluid 4.0 Project consortium organized the highly successful Fluid Power 4.0 special show "Fluid Power 4.0 - Digital Sustainability". 16 exhibitors showcased practical use cases at 20 booths, all centered around the Asset Administration Shell (AAS).

The exhibition demonstrated the benefits of digitalization through its two main eye catchers:

- The Connected Hydraulics Demonstrator, fully controllable via AAS and OPC UA, illustrated plug-and-produce functionality and transparent energy monitoring. These are key features for efficient system integration and operational flexibility.
- The Pneumatic Ballpoint Pen Assembly Machine calculated the carbon footprint of each pen in real time using the current electricity mix, assigning the data via QR code. This makes lifecycle transparency and sustainability measurable and accessible.

Beyond these eye catchers, the exhibition featured a wide range of innovations that showed how digitalization creates added value for customers and end users through digitalization that drives innovation, sustainability, and usability.

The special show was well attended throughout the entire week by interested visitors, including both manufacturers and users. It was complemented by a stage featuring a daily program segment focused on the digitalization of fluid power. A particular highlight was the high-level talk: a distinguished panel discussion with top representatives from industry and politics.

5 Outlook

5.1 Summary of digitalization benefits

The digitalization of Fluid Power offers tangible benefits:

- **For manufacturers**: streamlined documentation, new service models, and enhanced product visibility.
- **For customers**: improved integration, transparency, and lifecycle support.
- **For users**: better usability and efficiency, condition monitoring, and sustainability insights.

Fluid Power has reached a point where digitalization is no longer a vision, it's a competitive advantage. Technology, standards, and use cases are in place. Now, the focus is on scaling and integrating them into everyday industrial practice.

5.2 How to engage in digitalization

To support companies on this journey, training programs will be developed to build up the necessary skills and know-how.

The path begins with the **basics**: understanding the Asset Administration Shell (AAS), submodels, and how to create the first digital twin. Building own AAS and exporting product data from ERP systems like SAP is often the first practical step.

Next comes **data exchange**. Servers and interfaces (REST APIs) enable secure and efficient communication between systems and partners.

Finally, it's about **using the data**. Structured product data opens the door to optimization, predictive maintenance, and new digital services, creating real business value and new revenue opportunities

5.3 Cooperation and build-up of digital ecosystems is key

Companies that embrace digital transformation are not just improving their products but also enabling new forms of collaboration, accelerating innovation cycles, and meeting rising demands for regulatory compliance and environmental responsibility. Intelligent systems, transparent data, and connected services enable new levels of efficiency, flexibility, and customer orientation. This opens the door to innovative business models.

In a global market shaped by rapid change and rising expectations, differentiation is key. The ability to offer smart, responsive, and sustainable solutions is becoming the decisive factor. Fluid power companies that invest in digitalization today will be the ones setting tomorrow's standards.

However, these benefits can only be realized if the entire industry moves together. Standardization, interoperability, and shared platforms require collective commitment.

Let us shape the future of fluid power together — digitally, collaboratively, and with purpose.

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