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Alliance for Batteries Technology, Training and Skills

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Skills and Job Roles in Battery Applications Supporting the Modern Society

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D4.7 - Desk research and data analysis for sub-sector ISIBA-Release 3

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Executive Summary

The **Data Centres** chapter discusses using batteries and UPS systems as backup power sources for these critically essential installations that support the information society. The annual emissions are estimated to equal the level of the global aviation industry. There is a growing trend among data centre operators towards applying renewable energy. The shift from diesel generators to batteries is in progress. Battery-equipped data centres storing energy from VRE sources could become important components in carbon-free energy systems.

We describe the anatomy of a data centre and cover the technology of battery backup systems and UPS. We learn these two technologies, often considered the same, have differences. The battery backups are less advanced than UPS systems, with higher protection rates. We also discuss the safety and conclude that while Li-ion batteries provide fire risks, there are methods and tactics to address them.

We studied a number of data centre job advertisements that promoted positions that involved working with batteries. Many were engineer and technician positions working in areas ranging from developing and constructing data centres to maintaining, supporting, and servicing them.

We discovered that the most desired skills/knowledge included critical infrastructure expertise, battery backup operation and design, battery installation and configuration, BMS, battery maintenance and battery test processes. An interview with a data centre engineer provided us with more detailed insight into what needs to be understood, for example, when replacing batteries, and the importance of understanding certain specific areas, such as thermal scan patterns and battery data in maintenance.

In the **Renewable Power Farms** chapter, we discuss the application of Battery Energy Storage (BESS) in the context of variable renewable energy. With this topic, it is impossible to ignore the war in Ukraine when considering the various drivers of change. In March 2022, the European Commission published the REPowerEU plan that outlined a reduction of dependency on Russian gas imports and reaching independence from Russian fossil fuels well before the decade's end. That could boost the process of complying with the Green Deal to make Europe a net zero emissions continent by 2050. Europe needs to diversify energy sources with such methods as energy efficiency and applying renewable energy.

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The chapter covers wind power, hydroelectric power, and solar plants. We visit the history, explain the involved technology, and discuss Energy Storage systems' power plant optimisation. The power plant types harnessing geothermal, biomass and wave/tidal energy are also introduced.

Just for wind, hydroelectric, and solar power plants, we went through tens of job advertisements that combine renewable energy with battery storage. We discovered that most job advertisements specially mentioned wind, solar, or both. That potentially reflects the increase in the ongoing or planned construction of sites involving either of those VRE sources.

Staff are needed for various functions from project planning and development, operation and maintenance to different supporting positions. Many job ads were about various engineer positions, such as managing/developing/operating projects, integration, supplier quality, electric systems, logistics, maintenance and related planning. There were also technician positions (maintenance/installation) and other roles such as consultants, asset managers, business developers, etc. Naturally, knowledge/skills regarding BESS and related technologies and naturally electrical proficiency are required basically in all of them. We also identified skills/knowledge needs for contracts, feasibility studies, data analysis, cost estimates, pricing mechanisms, risk management, software, programming, testing, standards, business models, legal support, safety, etc. Even physical fitness was mentioned.

With the **Heavy Work Machines** chapter, Work Package 4 enters the area at or behind the border zone between stationary and mobile applications of batteries, but too important to be left unstudied. They are contributors to significant CO_2 emissions. For example, just the mining industry contributes 2-3 % of the global CO2 emissions. We study the current or near future use of batteries in the currently most promising areas from the electrification point of view involving off-road, heavy machinery: mining equipment, forest machines, cargo handling and heavy construction equipment.

Electrification of heavy work machines is in progress, and especially the mining industry, with its special conditions, is already moving strongly to replace diesel-powered machines with electrified equivalents. Forestry is taking its first steps with the introduction of hybrid machines and the first prototypes of fully electric machines. At the same time, construction equipment manufacturers are already a bit more advanced with the electrification process.

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Cargo handling equipment already includes not only a variety of electric but also autonomous machines. Factors affecting the electrification processes are discussed further in the concerned chapter.

Most job ads involving batteries covered engineer positions with heavy work machines. The roles that especially emphasized batteries included/involved, for example, battery technology specialists, system design, thermal management, battery modelling & analysis, battery module performance, battery regulations, BMS, battery software architecture, and supply chain management with adequate skills and knowledge.

In the **BESS in Residential Applications** chapter, we learn how the increasing amount of production shifting to renewable energy sources has also boosted demand for BESS (Battery Energy Storage). The reason is the growing need for self-sufficiency and to decrease electricity costs. Countries like Germany have implemented policies and incentives to stimulate the process further. We also discuss other drivers affecting the development that favour the introduction of the BESS and renewable energy source combinations. In the chapter, we also discuss the market situation and development, identify the biggest stakeholders in the business, and briefly introduce the technologies themselves.

The main skill/knowledge areas are similar to what has been identified earlier. They include, for example, power conversion, high voltage systems, system design, BMS, Current and Voltage Sensing, Risk and Safety, and New Battery Materials and Technologies.

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Introduction and methodology

The first desk research (2020) introduced and studied the entire battery value chain. The second one (2021) provided information about the anatomy of a gigafactory. In this third ALBATTS desk research of Work Package 4, we ventured into the areas of battery applications uncovered by the previous research.

For this desk research, we studied the stationary battery applications in

- data centres,
- renewable power farms and
- residential applications.

We also stepped into the border zone between stationary and mobile applications or even beyond. We studied the battery applications in the off-road type of heavy machinery used in such applications as

- mining equipment,
- forest machines,
- cargo handling and
- heavy construction equipment.

Once again, similar to the previous desk research, we collected intelligence from various sources available on the Internet to understand the needed job roles, skills, and competencies and the related operating environments, including technologies and drivers of change. We used information sources such as corporate and technology news, companies' career pages, websites, recruitment services providers, research papers, and more.

Additionally, to gain first-hand information about skill needs, we conducted a closed interview with a data centre engineer working for one of the top companies in the world by market value and for which data centres are a critical element of its operations.

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List of Abbreviations

C	…	Celsius
8D	…	Eight Disciplines Problem Solving Process
AC	…	Alternating Current
ACC	…	Automotive Cells Company
AD	…	Anno Domini
AD	…	Active Directory
AGV	…	Automated Guided Vehicle
AIA	…	Automotive Industry Association of the Czech Republic
APQP	…	Advanced Product Quality Planning
AQP	…	Advanced Quality Process
ARPA-E	…	Advanced Research Projects Agency-Energy
bcm	…	Billion Cubic Meters
BESS	…	Battery Energy Storage System
BEV	…	Battery Electric Vehicle
BMA	…	Bayesian Model Averaging
BMS	…	Battery Management System
BOM	…	Bills of Material
BOP	…	Balance Of Plants
B-RTG	…	Battery RTG
CAES	…	Compressed air energy storage systems
CAGR	…	Compound annual growth rate
CAPA	…	Corrective Action and Preventive Action
CAPEX	…	CAPital EXPansion
CE	…	Conformitè Europëenne (French)
CEAP	…	Circular Economy Action Plan
CEDEFOB	…	The European Centre for the Development of Vocational Training
CHE	…	Cargo handling equipment
CO2	…	Carbon dioxide
COPQ	…	Cost of Poor Quality
CP	…	Cyber-Physical
CPD	…	Continuing Professional Development
Cpk	…	Process Capability Index
CPO	…	Chief Product Officer
CTO	…	Chief Technology Officer
DC	…	Direct Current
DFMEA	…	Design Failure Mode and Effect analysis
DMAIC	…	Define, Measure, Analyze, Improve and Control
DoC	…	Drivers of Change
DoE	…	Design of Experiments
DP	…	Deep sea port
DPAR	…	Design Process Assembly Review
E&E	…	Electrical and electronic
EBA	…	European Battery Alliance
EERE	…	Energy Efficiency and Renewable Energy
EESC	…	European Economic and Social Committee

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EMS	…	Energy Management System
EPC	…	Engineering, Procurement, and Construction
EPRS	…	European Research Service
EQF	…	European Qualifications Framework
ERP	…	Enterprise Resource Planning
ESG	…	Environmental, Social and Governance
ESS	…	Energy Storage Systems
EU	…	European Union
EV	…	Electric Vehicle
FAT	…	Factory Acceptance Testing
GHG	…	Green House Gases
GW	…	Giga Watt
GWh	…	Giga Watt hour
HV	…	High Voltage
HVAC	…	Heating, Ventilation and Air Conditioning
HW	…	Hardware
ICE	…	Internal Combustion Engine
ICT	…	Information and Communication Technologies
IEA	…	International Energy Agency
IoT	…	Internet of things
IPCC	…	Intergovernmental Panel on Climate Change
IPCEI	…	Important Projects of Common European Interest
ISO14001	…	Environmental management system
ISO9001	…	Quality management system
JHA	…	Job Hazard Analysis
KPI	…	Key Performance Indicator
kWh	…	Kilowatt-hour
LEED	…	Leadership in Energy and Environmental Design
LHD	…	Load-Haul-Dump loader
LOTO	…	Lockout Tagout
LV	…	Low Voltage
MBA	…	Master of Business Administration
MEI2	…	Maryland Energy Innovation Institute
MLOC	…	Machine Life Operating Costs (MLOC)
MOOC	…	Massive Open Online Courses
MRB	…	Non-Conformance Tracking
MSA	…	Measurement System Analysis
MSc	…	Master of Science
MV	…	Medium Voltage
MW	…	Mega Watt
MWh	…	Mega Watt hour 10^6
NASA	…	National Aeronautics and Space Administration
NMP	…	N-Methyl-2-pyrrolidone
NOx	…	Nitrogen Oxide
NPD	…	New Product Development
NTNU	…	Norwegian University of Science and Technology.
NZE	…	Net-Zero Emissions by 2050 Scenario

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O&M	…	Operation and Maintenance
OEM	…	Original Equipment Manufacturer
P2G	…	Power to gas
PC	…	Personal Computer
PDSA	…	Plan, Do, Study Act
PFMEA	…	Process Failure Mode Effects Analysis
PhD	…	doctor of philosophy (Philosophiae Doctor)
PHEV	…	Plug-in Hybrid Electric Vehicle
PHS	…	Pumped hydropower storage
PLM	…	Product Lifecycle Management
PPAP	…	Production Part Approval Process
PSA	…	Peugeot S.A
PV	…	Photovoltaic
QC	…	Quality Control (of the final product)
QMS	…	Quality Management Process
QR	…	Quick Response code
R&D	…	Research and Development
RA	…	Risk Assessment
RES	…	Renewable Energy Sources
RFI	…	Requests for Information
RFP	…	Review Requests for Proposals
RISE	…	Research Institutes of Sweden
RoRo	…	Shipping vessel
RTAC	…	Real-Time Automation Controller
RTG	…	Rubber-Tired Gantry Cranes
SAT	…	Site Acceptance Testing
SCADA	…	Supervisory Control and Data Acquisition
SCAR	…	Supplier Corrective Actions
SLD	…	Single line diagram
SOx	…	Sulfur Oxide
SPC	…	Statistical Process Control
SQC	…	Supplier Quality Scorecard
SW	…	Software
T	…	Temperature
TLD	…	Three Line Diagrams
TQM	…	Total Quality Management
TWh	…	Tera Watt-hour 10^{12}
UK	…	United Kingdom
UPS	…	Uninterruptible Power Supply
US	…	United States
USA	…	United States of America
USD	…	United States Dollar
UVV	…	Accident Prevention Regulation
VRE	…	Variable Renewable Energy
VW	…	Volkswagen

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Glossary

Leadership in Energy and Environmental Design (LEED)	…	LEED is the most widely used green building rating system in the world. Available for virtually all building types, LEED provides a framework for healthy, efficient, and cost-saving green buildings. LEED certification is a globally recognized symbol of sustainability achievement and leadership.
REPowerEU	…	REPowerEU: affordable, secure and sustainable energy for Europe
PVSyst	…	PVSyst is the standard for large and utility-scale solar installations.
Solometric shading analysis	…	The Solmetric Certified™ Shade Analysis course is an online, interactive course that trains students on best practices in using the Solmetric SunEye™ and accurately performing Shade Analysis Measurements.
Single Line Diagram	…	Single line diagrams are electrical drawings that provide a basic visual guide to an electrical system detailing various nodes and interconnections. These often serve as a base reference for further systems analysis.
Three Line Diagram	…	A three-line diagram is, however, a more detailed presentation of an electric system with actual cabling information involving positive, negative, and ground cables for DC, L1, L2, L3, Neutral and Ground cables on an AC system.
RoRo	…	Roll On, Roll Off. It's a shipping vessel designed to handle freight that is too large to fit into shipping containers—initially developed in the 19th century to transport trains across waterways.

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1 Data Centres

1.1 Drivers of Change

In our previous desk research deliverables, D4.1[1] and D4.4[2] , we identified and analysed the Drivers of Change macro areas and their subcategories that affect the battery value chain.

Data centres are affected, for example, by the following drivers of change identified earlier:

- Reducing CO2 emissions
- Electrification and green energy
- New technologies such as smart grids
- *It can be assumed that population and economic growth (identified in chapter 4.1.) will also affect data centres and, consequently, related battery applications*

Reducing CO2 emissions as well as electrification and green energy

It is estimated that data centres consume 1 % of the electricity used on the planet (around 205 TWh in 2018). There are also concerns about CO_2 emissions, but it appears that accurately estimating the volumes of those emissions is not possible so far. Some claims place the emissions at the same level as the global aviation industry, which is approximately 900 billion kg of CO_2 annually. There thus appears to be a growing trend among the biggest data centre operators towards applying renewable energy. [3]

The aim is to reduce CO_2 emissions by introducing cleaner technology by replacing diesel generators. For example, Google is considering the application of backup batteries, when not needed to provide backup power, to supply energy to the local grid. Suppose this proves to be a successful mechanism. In that case, battery-equipped data centres that store energy generated by variable renewable energy sources could become important components in energy systems that are carbon-free.[4]

[1] D4.1 - Desk research and data analysis for subsector ISIBA - Release 1, https://www.project-albatts.eu/Media/Publications/5/Publications_5_20201106_123821.pdf
[2] D4.4 - Desk Research and Data Analysis for sub-sector ISIBA – Release 2, https://www.project-albatts.eu/Media/Publications/23/Publications_23_20210920_83914.pdf
[3] https://energyinnovation.org/2020/03/17/how-much-energy-do-data-centers-really-use/, last accessed on 23.8.2022
[4] https://techwireasia.com/2021/04/the-data-centers-of-the-future-will-run-on-batteries/, last accessed on 23.8.2022

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Widespread support for renewable energy and carbon reduction drives battery storage technology adoption. The crucial role that batteries can play in countering the intermittent nature of renewables and decreasing curtailment is well understood. Still, the enthusiasm for clean energy among electrical users is expanding. That is particularly noticeable in the business and public sectors. That heralds the long-term growth of renewable energy, which may be used for battery energy storage to aid in integrating increasingly dispersed power.

Data centre UPS and smart grid

Battery storage deployment is being accelerated by digitalization and commercial innovation. Many wealthy nations are launching grid modernization initiatives to increase resilience in extreme weather events, minimize system outages caused by aged equipment, and enhance overall system performance. These schemes frequently entail integrating dispersed energy resources and deploying innovative technology into existing electrical grids. That enables two-way communication and enhanced digital control systems (i.e., renewables, fuel cells, diesel or natural gas generators, storage assets, and microgrids).[5]

The power grid can be reimaged as similar to the Internet, which enables a mechanism to share power. In the context of data centres, the unused energy from the UPS batteries could be shared locally. For example, the UPS batteries required to power a 15 MW data centre for approximately 6 minutes could be harnessed to power about 15000 houses for the same duration. A smart grid could support data centres with more uninterruptible power while also supporting the neighbours. The data centres testing this concept are not numerous yet, but the situation may change in the future.[6]

1.2 Introduction to Data Centres

Data centres were chosen to be studied in this desk research due to their utmost importance to the world as we know it today, and they have not been covered in earlier desk research of Work Package 4. Data centres are crucial, for example, to how modern business functions. [7]

[5] https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Energy-and-Resources/gx-er-challenges-opportunities-global-battery-storage-markets.pdf, last accessed on 24.8.2022
[6] https://www.colocationamerica.com/blog/smart-grid-data-centers, last accessed on 24.8.2022
[7] https://www.colocationamerica.com/blog/explaining-data-center-batteries, last accessed on 1.8.2022

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We are a data-hungry society, and while the hardware is continually becoming smaller, quicker, and more powerful, the need for processing power, storage space, and information is always rising and posing a danger to organisations' ability to meet it. Data centres are necessary for any organisation that produces or uses data, including governmental organisations, educational institutions, telecommunications firms, financial institutions, retailers of all sizes, and providers of social networking and online information services like Google and Facebook. The inability to deliver essential services and a failure in customer satisfaction and income can result from a lack of quick and reliable access to data.

Organizations utilise data centres to gather, analyse, store, and distribute massive quantities of data. A data centre is a building comprised of networked computers, storage systems, and processing equipment. A location where an organisation may house its infrastructure and resources for data processing, storage, and communications; its applications, services, and data that are housed in a data centre are often significantly relied upon by businesses, making it an essential asset for daily operations.

We'll be hearing the phrase "data centre" a lot as the biggest digital and social media companies in the world are in transition to cloud computing. Some methods have to be used to store all of this media. And more and more items these days are going into the cloud, which means that instead of using or keeping them on our personal computers at home or the office, we are accessing them through the host servers of cloud providers.

Nearly all contemporary businesses and government agencies now either need their data centre or can choose to rent one. If they have the resources, large enterprises and governmental organisations may decide to create and operate them internally. However, some people decide to lease servers from "colos," or colocation centres. Additionally, some business owners might choose to employ publicly accessible cloud-based services. Businesses that deal with social networking services, education, banking, communications, and other industries generate enormous amounts of data daily. Data centres are essential to the operations of these enterprises that create and use data.

Data centres host websites, handle emails and operate instant messaging applications. Both e-commerce transactions and cloud storage applications are supported. Additionally, data centres are necessary for managing internet activity for even online gaming groups.

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To reduce the expense of maintaining their centralised computer networks and servers, companies like Google, Meta (Facebook), Microsoft, IBM, and maybe every top-tier tech firm also need data centres and migrate their professional applications to cloud services. It is reasonable to argue that in the context of contemporary technology, a tech company couldn't operate without data centres. Without these centres, they will suffer from a lack of quick and safe access to data. The inability to provide services will result in loss of customers and profits. Data centre facilities offer data computation, collection, storage, sharing, accessing, and processing data across the organisation; physical infrastructure for supporting data processing and data communications; and utilities such as electricity, network security access, and uninterruptible power supplies (UPS) including racks, cabinets, cables, and batteries, as well as backup generators for data backup and recovery in the event of a power outage. They also include cooling systems to avoid overheating since they can store billions of megawatts of data. Moreover, one of the important benefits of a data centre is that its services are constantly accessible and failover-free, thanks to system backups.

1.3 Stakeholders

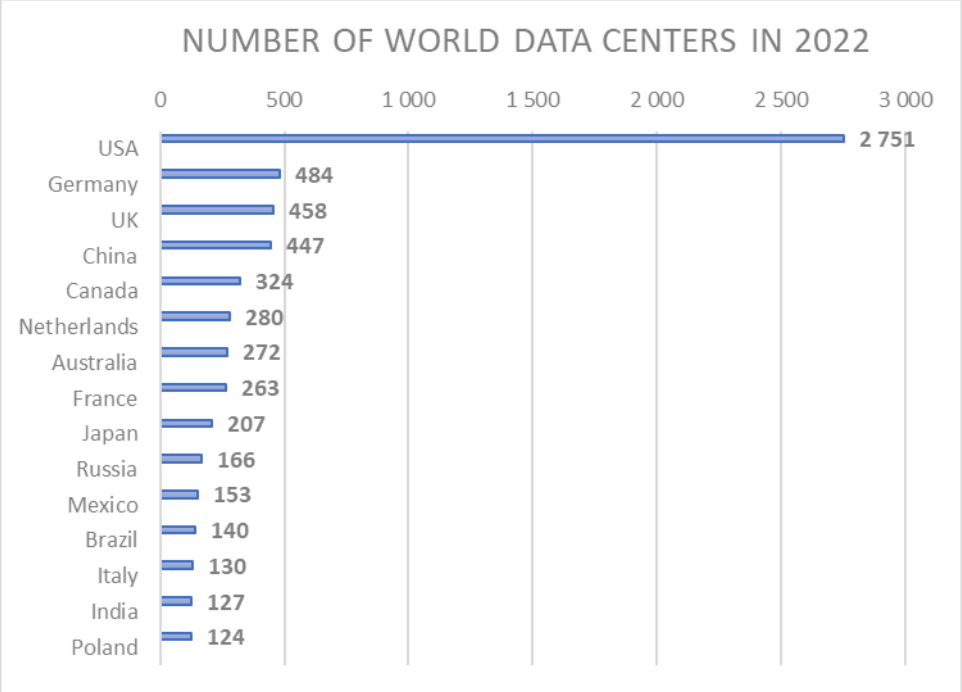

Figure 1. The data centres per country in 2022.[8]

[8] https://www.statista.com/statistics/1228433/data-centers-worldwide-by-country/, Last accessed in June 2022

The demand for data centre services has increased due to the growth among Internet users worldwide. From 2010 until 2018, the volume of data transferred over the Internet increased 10-fold. At the same time, the worldwide data centre capacity in terms of storage increased by a factor of 25. Additionally, parallelly, the number of compute instances that run on the servers worldwide increased more than 6-fold. [9]

Top Data Centre Organisations In 2022

According to BlueWeave Consulting, the data centre industry was pegged at $206.2 billion in 2021 and is expected to reach $404.9 billion by 2028.

Comparison Of The Best Data Center Service Providers

Company	Headquarters	Founded In	# of Data Centers	Markets Served	Services
Equinix	Redwood City, CA, US	1998	202 (12 more to come)	24 countries	5
Digital Realty	San Francisco, CA, US	2004	214	14 countries	3
China Telecom	Beijing, China	2002	456	>10 countries	6
NTT Communications	Tokyo, Japan	1999	48	17 countries	9
Telehouse/KDDI	London, UK /Tokyo, Japan	1988/1953	40	12 countries	4

Figure 2. Comparison of the Best Data Centre Service Providers, Source: SoftwareTestingHelp

The top known data centre companies in the world are [10]:

1. Equinix EQUINIX

   In 1998, Equinix was established. Its corporate offices are in Redwood City, California, in the USA. As of 2017, the business employed 7273 people and provided services to 24 nations, including the USA and the UK. It now has 202 data centres worldwide, with 12 more added.

2. Digital Realty DIGITAL REALTY

[9] https://energyinnovation.org/2020/03/17/how-much-energy-do-data-centers-really-use/, last accessed on 23.8.2022

[10] https://www.softwaretestinghelp.com/data-center-companies/#Top_11_Data_Center_Companies_In_The_World, Last accessed in June, 2022

San Francisco, California, in the US, is the home of Digital Realty, established in 2004. The business operates in 14 countries, with 214 data centres and approximately 1530 workers.

3. China Telecom

One of the biggest global suppliers of data centre services is China Telecom. With its primary offices in Beijing, it was established in 2002. Even though the corporation only offers its services in ten countries, it supports mainland China with more than 456 data centres. 287,076 people work for the firm.

4. NTT Communications

In 1999, NTT Communications was established, with its headquarters in Tokyo, Japan. The business operates in 17 countries and has 48 data centres. Nearly 310,000 people work for it globally.

5. Telehouse/KDDI

Telehouse/KDDI is a merger of two businesses. While Telehouse was created in 1988, KDDI was established in 1953. In Tokyo for the former and London for the latter. They operate in 12 countries and have a total of 40 data centres. They employ 35,000 people worldwide in total.

6. Coresite

Coresite was established in 2001 and is based in Denver, Colorado, in the United States. Nearly 454 people work there. Currently, it has roughly 22 data centre locations spread across eight nations.

7. Verizon

Basking Ridge, New Jersey, in the US, is home to Verizon, established there in 1983. The business employs close to 139,400 people. It has almost 40 data centres and offers services in around 150 countries.

8. Cyxtera Technologies

Cyxtera was established in 2017 and is based in Coral Gables, Florida, in the United States. It operates in 9 countries and has around 1150 workers. There are 60 data centres for it worldwide.

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9. China Unicom

The Beijing-based China Unicom was established in 1994. It has 550 data centres overall and around 246,299 employees. The firm provides services to Hong Kong and mainland China, two significant markets.

10. Amazon Web Services

In 2006, Amazon Web Services was established as a subsidiary. Its headquarters are in Seattle, Washington, and it employs nearly 25,000 people nationwide. It operates 116 data centres globally.

11. 365 Data Centres

The headquarters of 365 Data Centres are in Connecticut, USA, and it was established in 2002. The firm employs approximately 81 people and has 11 data centres around the country.

Top Key players of UPS Battery Market for Data Centre

The forecast 2022-2026 top UPS battery companies in the industry market are [11]:

• Chaowei Power Holdings Ltd. • Delta Electronics Inc. • EaglePicher Technologies LLC • East Penn Manufacturing Co. Inc. • Eaton Corp. Plc • EnerSys • ETERNITY TECHNOLOGIES FZ LLC • EverExceed Industrial Co. Ltd. • Exide Industries Ltd. • FIAMM Energy Technology Spa • First National Battery • Fullriver Battery • GS Yuasa Corp.	• HBL Power Systems Ltd. • Kokam Co. Ltd. • LG Corp. • Lithium Werks • Saft Groupe SAS • Schneider Electric SE • Vertiv Holdings Co. • Accumulatorenwerke HOPPECKE Carl Zoellner and Sohn GmbH • Amara Raja Batteries Ltd. • C and D Technologies Inc. • Leoch International Technology Ltd. • MIDAC SpA

[11] https://www.prnewswire.com/news-releases/ups-battery-market-for-data-center-industry-market-segmented-by-product-and-geography-region-size-outlook-share-and-forecast-2022-2026--technavio-301526000.html, last accessed in June 2022

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The rising use of modular UPS systems is one of the key reasons propelling the UPS battery market expansion in the data centre sector. The surge in data centre construction is another trend for the industry that is fuelling market expansion.

Data Centre Examples

UPS At Telia's Helsinki Data Centre, Finland

Telia's 34,000 sqm (366,000 sq ft) 24MW Helsinki data centre, which was opened in 2018, is one of the largest in Finland, Figure 3, and received LEED Gold certification in 2019. The facility will be linked to a local district heating program this year.

Nordic telecommunications company Telia has linked its Helsinki data centre to the power grid, allowing its UPS systems to assist balance changes in energy supply and demand. The UPS systems will participate in (Fortum Spring), a "virtual battery" plan run by local utility Fortum, which will be able to rely on them as needed to compensate for future energy shortages. That will allow renewables to play a more significant role in Finland's electrical mix. It helps in displacing the country's fossil-fuel producing capacity - and Fortum promises other possible participants that the UPSs will always be available for their primary function, keeping the data centre operational.

Figure 3. Telia's Helsinki Data Centre, Helsinki, Finland; By Google Earth[12]

“The UPS batteries are still available to cover against any power outage or other exceptional situation. At this point, they are designed to keep the data centre running for minutes before the UPS diesel generators can switch on. If a major disruption occurs in balancing the grid,

[12] https://earth.google.com/web/search/Telia%27s+Helsinki+data+center,+Helsinki,+Finland/

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Telia's UPS equipment will respond within a few hundred milliseconds and help recover from the disruption." Telia's development manager Harri Vilonen said.[13]

UPS At Google Data Centre, Mons, Belgium

The Google hyper-scale data centre team at St. Ghislain, **Figure 4**, will deploy lithium-ion batteries as backup power for 3MW of live production computing load — a first for Google. At its Belgium data centre, a large-scale battery facility will supply backup power and assist in balancing the grid. In the case of a power outage, the technology will assist in keeping users' searches, e-mails, and movies moving—without the emissions associated with diesel burning.

Figure 4 Google data centre, Mons, Belgium; By Google Earth [14]

The data centre battery plant in Belgium will offer grid services by working with ELIA, the local transmission system operator in Belgium, to make the project a paradigm for how data centres may become anchors for carbon-free electric grids.[15,16]

Microsoft Data Centre to support grid in Ireland[17]

The wind power farms collectively generate over 25 % of the electricity in Ireland. The intermittent nature of wind power causes variation in power production. Lithium batteries applied in Microsoft's data centre in Dublin will partially be a solution to this problem. These

[13] https://www.datacenterdynamics.com/en/news/upss-at-telias-helsinki-data-center-to-put-power-into-the-grid/, last accessed on 22.8.2022
[14] https://earth.google.com/web/search/Google+data+center,+Mons,+Belgium/
[15] https://blog.google/inside-google/infrastructure/cleaner-data-centers-batteries-included/, last accessed on 24.8.2022
[16] https://www.datacenterknowledge.com/google-alphabet/google-thinks-data-centers-armed-batteries-should-anchor-carbon-free-grid, last accessed on 24.8.2022
[17] https://news.microsoft.com/innovation-stories/ireland-wind-farm-datacenter-ups/, last accessed on 24.8.2022

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backup power-enabling batteries will be connected to the grid to support grid operators in providing uninterrupted service. That will occur when the supply generated in the grid by variable renewable systems or other sources is exceeded by the demand.

The grid operators normally rely on power plants running on fossil fuels to maintain spinning reserve (excess capacity) to respond to that exceeded demand. If grid-interactive UPS batteries like the ones in the data centre can replace these plants, significant CO_2 emissions could be avoided. Microsoft is exploring whether it could provide such grid-stabilization services with its data centres worldwide to boost the progress of grids' decarbonisation.

1.4 Technologies

UPS For Data Centres

Uninterruptible power supply (UPS) and battery backup are frequently confused, but they are actually very different concepts. The term UPS refers to a more sophisticated form of battery backup, or, to put it another way, all uninterruptible power supplies are battery backups with improved protection levels. Below, we'll get into some of the variations.

Battery Backup[18]

For plugged-in equipment like computers, battery backup reduces the negative consequences of power-related problems. The battery backup will immediately start working to temporarily power the device in the event of a surge or power outage. If a computer is being utilised, the battery backup will be used to save files safely and guarantee the computer is shut down appropriately. Your investments in computers and other gadgets are protected by battery backups. The size of the battery will affect how long your devices can operate.

Uninterruptible Power Supply UPS

In case of an interruption with the main power supply, data centre operations require the most cutting-edge batteries and battery technology for their backup system. Compared to conventional battery backup, UPS features more modern technologies. Devices connected to the UPS are directly powered by the battery through an uninterruptible power supply. In standby mode, the electricity charges the battery, which supplies power to the devices when

[18] https://www.hcienergy.com/blog/what-is-the-difference-between-ups-and-battery-backup, last accessed on 26.8.2022

needed. A UPS always provides power from a supply of clean energy instead of waiting and giving it when required. The UPS, which has additional features, can guard against power surges, voltage dips, brownouts, blackouts, and other power supply problems. Depending on the size of the battery and how much power the device needs, an uninterruptible power supply will keep your gadgets operating like previous battery backups.

Difference Between UPS and Battery Backups[19]

Both UPS and battery backups can protect devices that experience power issues like surges and power sags. Both methods offer protection against internal component damage, operating system corruption, and corrupting unsaved data.

Between UPS and battery backups, there are significant differences.

- The power filtering procedure

Not all brownouts, fluctuating electricity, and power surges cause a battery backup to activate. However, a UPS will filter that electricity and provide a steady power supply to critical equipment that must continue operating and processing.

- Batteries store and charge at DC, but UPS functions on AC power

Batteries discharge as DC as well; however, the UPS converts AC to DC for charging, whereas appliances require AC. The UPS will still convert DC to AC even if the power goes off.

Choose Between a Battery Backup And a UPS.[19]

Battery backups are often advised for PCs and other low-cost machines in homes and small offices. That is due to the typically lower cost of battery backups. For more important equipment, a UPS is advised. Like a server for a business. For a company or data centre, a UPS system might be essential. A high-quality UPS system will offer far greater protection, even if it is more expensive than a battery backup.

UPS function

Figure 5 shows an Uninterruptible Power Supply (UPS) system. Due to the ageing electrical infrastructure, increased power consumption, harsh weather, defective wiring, and disrupting

[19] https://www.hcienergy.com/blog/what-is-the-difference-between-ups-and-battery-backup, last accessed on 26.8.2022

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devices connected to an AC line, power issues constantly threaten electronic equipment. In the case of a catastrophic shutdown, any data in memory but not saved to a non-volatile storage device, such as hard drives, will be lost forever; this can mean losing the work of thousands of users logged into the system. Moreover, the power delivered from the utility grid is not always steady and pure. Many times, it is from a brief loss of power (power outage) or even with momentary transient power fluctuations, waveform irregularities in line power and abnormal voltages like Sag/dip, Swell, Surge/Spike (short-term temporary voltage increases), Blackout (also known as a power outage or power failure), Brownout (also known as an Undervoltage), Line Noise, Frequency Variations, Harmonic Distortion[2021] (**Figure 6**).

An Uninterruptible Power Supply (UPS) system delivers conditioned utility power to its outputs and maintains its internal batteries charged as long as the power is turned on. With the help of storage batteries, the UPS system provides constant backup power to applications and infrastructure with a continuous critical power need. That allows a sufficient amount of time, usually less than 30 minutes, to be used in conjunction with a facility generator to ensure that the infrastructure continues running even in extended power outages.

Whenever there is a loss in utility power, UPS helps to correctly power down working equipment and supplies clean and safe energy to IT devices or server rooms. The quantity of power delivered is determined by the kind of UPS and batteries used. Security alarms, defence systems, and industrial infrastructures are a few of these uses. Various UPS systems are available, and their functions may vary depending on the requirements. Still, their primary goal is to provide battery backup power to the data centre or server room in the case of a brownout, surge or drop in the input power supply. Choosing the proper UPS, connecting it with network monitoring software, and implementing emergency plans for automatic backup power out of its battery bank in the event of such an occurrence are all critical.

[20] https://www.aspsys.com/solutions/infrastructure/power/data-center-uninterruptible-power-supplies-ups/, last accessed in June 2022
[21] https://www.tripplite.com/products/ups-buying-guide, last accessed in June 2022

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Figure 5. Uninterruptible Power Supply (UPS) System

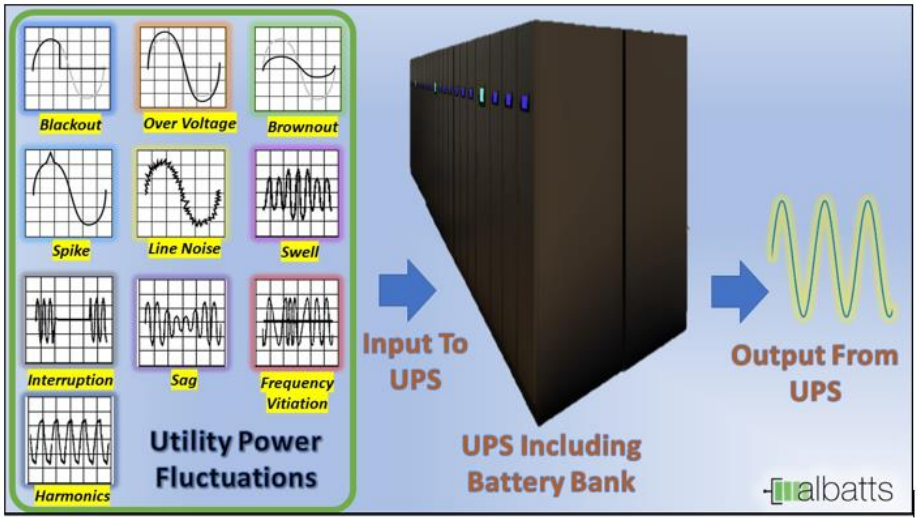

Figure 6. UPS is necessary to ensure that there is no power interruption and face all types of transient power fluctuations that occur

UPS System Topologies

There are three main types of UPS designs (known as UPS system topologies) that accomplish this in different ways, such as “standby” and “line-interactive” systems, which do not offer the kind of protection that double-conversion (online) UPSs do.

Standby UPS systems[22]

Standby UPS Systems; are simple UPS systems that provide the most basic functionality. The majority of workstation UPSs use this technique. The output socket of the UPS (into which the

[22] https://www.aspsys.com/solutions/infrastructure/power/data-center-uninterruptible-power-supplies-ups/, last accessed in June 2022

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equipment is inserted) is physically linked to the same line that charges the battery. When there are a power outage or abnormal line voltages, the line switches mechanically to battery power. That protects the equipment, but only for as long as the battery backup duration of the UPS system lasts. Frequent switching to the battery and accompanying recharging cycles might further limit the battery's lifespan in places with frequent voltage difficulties, whether from inadequate utility supply or harsh circumstances at the installation site. These are typically non-configurable boxes with minimal features that cannot be expanded.

Line-interactive UPS systems[22]

Line-Interactive UPS Systems, which contain a function known as automatic voltage regulation (AVR), are far more sophisticated than a standard standby UPS and can manage much more than simply power failures (blackouts). Line-interactive UPSs include an autotransformer that may change the number of powered wire coils to adjust aberrant voltages without turning to the battery. When the input voltage is either low or too high, the UPS system automatically boosts or decreases it by a certain proportion before delivering it to connected equipment. Typically, line-interactive UPS systems adjust output to 10-15% of the nominal voltage.

On-line UPS systems[22]

Online UPS Systems; The Online double-conversion UPS offers high power protection for essential applications against aberrant input voltage and the most precise output voltage control. As a result, they are the ideal choice for mission-critical equipment, places with demanding power circumstances, and devices that are highly sensitive to power quality, and they are commonly used in data centres. In contrast to standby and line-interactive designs, an online, double-conversion UPS continuously regenerates new, clean AC power through its continuous duty inverter and effortlessly transitions, even matching the phase of the mains line, so the equipment can't detect the difference. A control room manages all operations. A datacentre's control room diagram is depicted in Figure 7.

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Figure 7. Layout for the control of a data centre

How might datacentres help to secure carbon-free power grids? Wind and solar power flourish worldwide, but bright days and windy hours don't necessarily coincide with a community's energy needs. Large-scale batteries in data centres can address this issue by storing renewable energy when it is plentiful and discharging it when required. Batteries can also assist power networks in balancing other types of fluctuation, allowing for further cost-effective and efficient operations.

Line-interactive UPS systems offer outstanding, cost-effective protection for most kinds of technology. Online UPS systems are a better alternative for data centres with crucial equipment critical to production, devices sensitive to power quality, and regions with severe power circumstances. They offer total isolation from most power issues, the highest protection against costly downtime, and the best compatibility with sensitive equipment. Figure 8 depicts the overall layout of the data centre building.

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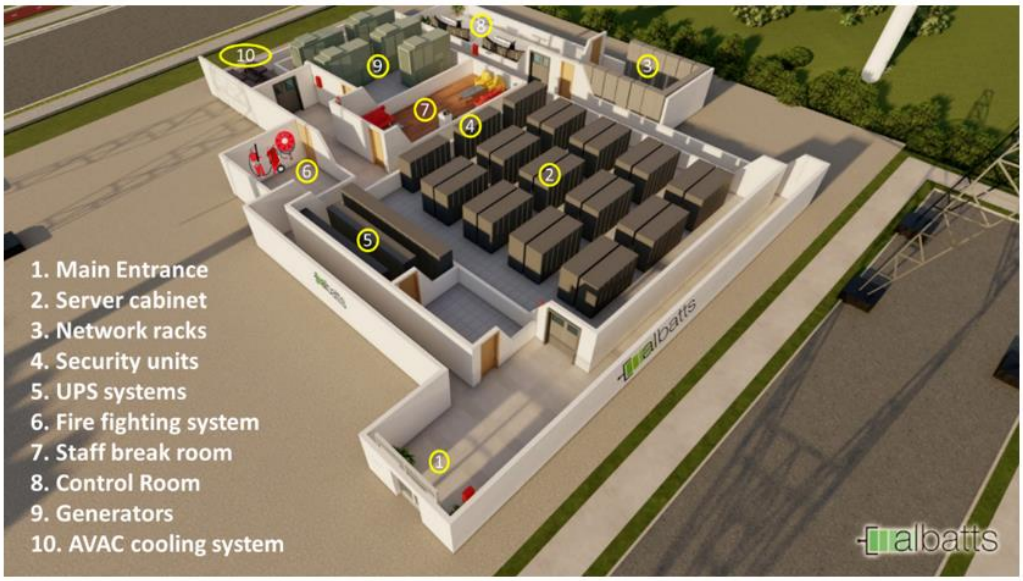

Figure 8. Layout for designed Datacentre

UPS Battery Backup for Data Centres

Standby generators previously represented the backup power supply market for data centres, but tales of carbon monoxide poisoning have prompted many to look at other options. Battery backups have evolved as a more environmentally friendly and perhaps safer alternative to traditional generators. Today's battery backup systems, such as Tesla Powerwall [23] or the LG Chem RESU [24], store energy that may be used during a power loss. Battery backups can also be powered with renewables such as solar plants, wind power, hydropower, or the electrical grid. As a result, they have the potential to be far more environmentally friendly than fuel-powered generators. They are also less expensive than generator backup power.

"I think we're gonna see an increase in battery ride-through time to enable some data centres to run a little bit longer, without having to employ an on-site power production system, which typically is engine generators," says Chris Brown, CTO of the Uptime Institute [25].

[23] https://www.tesla.com/en_eu/powerwall, last accessed in June 2022
[24] https://www.solartopstore.com/collections/lg-chem-resu-battery, last accessed in June 2022
[25] https://www.datacenterdynamics.com/en/analysis/batteries-of-the-future/, last accessed in June 2022

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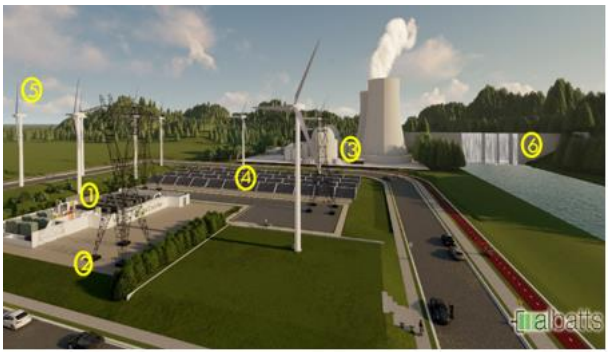

Figure 9. Imaginary layout for illustration purposes of various green power sources used in the context of a data centre: 1-Datacentre, 2-Electrical grid, 3-Nuclear power station, 4-Solar panels system, 5-wind turbines energy system, and 6-Hydro-power system.

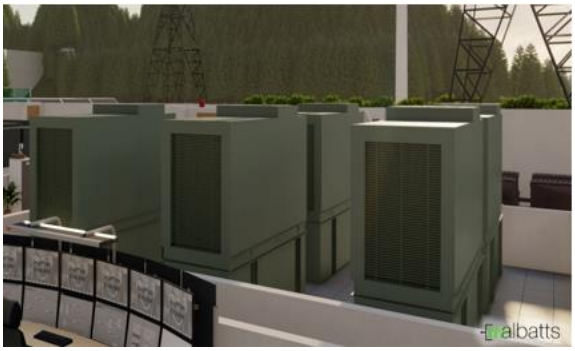

Figure 10. Layout for data centre generators, side view

A layout of the whole grid, including the data centre building and renewable energy resources to feed the electrical grid, such as nuclear power system, solar panels system, wind turbines energy system, and hydro-power system, can be seen in Figure 9.

As long as the power is turned on, the UPS system supplies utility power to the devices attached to its outlets, charges its internal battery, and protects equipment against power outages. During a power outage, the UPS system keeps connected devices running by drawing power from its internal battery. The UPS's battery backup runtime estimates how long its battery will keep support-related equipment running during an outage without the ability to recharge its batteries. The runtime of a UPS battery varies based on its size and the watts needed by the devices connected to the UPS system's outlets, as well as parameters such as efficiency, ambient temperature, and battery age. The shorter the runtime, the greater the power.

In the case of a prolonged blackout that exceeds the backup duration of the UPS, a battery backup allows you to power down equipment and avoid data loss correctly. Many networks and mission-critical UPS systems will enable you to boost the battery capacity to increase runtime from minutes to hours. Because network and mission-critical applications frequently contain standby generators as part of the facility's backup system, UPS systems may only need enough runtime to maintain the equipment load until the generators start up, stabilize, and take over. Figure 10 illustrates the layout side view of a generator unit in a data centre. UPS systems continue to adapt electricity before reaching connected equipment even while generators run.

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Battery technologies

Batteries are the most critical component in an evolving UPS and data centre. The development of battery technology offers greater reliability, longer service life, lower maintenance, and ultimately a reduced total cost of ownership.

Lead-acid UPS battery backup systems

Lead-acid UPS battery backup systems for data centres, power supplies, cooling technologies, and equipment room space are changing due to data centre technologies and market demands. Valve Regulated Lead-Acid (VRLA) batteries are employed primarily in data centres to meet power supply needs. Lead-acid batteries have been the usual solution for many years. It is ideal for storing items for 15 minutes. However, if we proceed to four hours, we need to double it by a factor of 16 - which results in a massive installation. Lead acid has difficulty with compactness. Lead acid also has environmental problems; even though it is entirely recycled, there is some leakage in the recycling system, which has a significant environmental impact. Furthermore, because of their weight and size, they necessitate strengthened bearing structures in data centres. The performance characteristics of VRLA batteries are likewise temperature dependent, increasing the demand for air conditioning systems. VRLA batteries are not long-lasting and must be replaced regularly, resulting in higher running expenses.
The high-power technology has extremely dynamic charge and discharges capabilities and significant performance and lifetime features over VRLA lead-acid batteries. Due to the failure of UPS and challenges with VRLA batteries, distributors presented lithium-ion UPS solutions and Nickel Zinc and Prussian Blue Sodium-ion batteries. Most data centres operating in Europe are establishing N+N redundant infrastructure. “N” is a definition of the full UPS capacity required to handle the total load. Most data centres are constructing facilities with areas for updating up to 2N+2 redundant UPS systems to deal with the facility's diverse feed designs effectively.

Lithium-ion UPS battery backup systems

Lithium-ion battery (LIB) is expected to witness significant growth in the industrial battery market over the forecast period due to its favourable capacity-to-weight ratio. Other elements driving LIB usage are its improved performance, higher energy density, and lower price. The

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Western European data centre industry saw investments of USD 35.06 billion in 2021, with an estimated growth of $8+ billion in countries like Belgium, Portugal, Spain, Switzerland, and Italy on acquiring UPS Systems in data centres between 2022 and 2027.[26] Colocation, cloud, telecommunications, and internet service providers work on various initiatives. [27]

Due to their limited area and need for better effective performance, data centres have recently sought to boost their power density. One of the essential jobs for data centre operators is to use existing space better. Compact lithium-ion batteries lower the size of an uninterrupted power supply system by 50-80%[28]. Such batteries need less time to charge and have a higher self-discharge rate, which is essential in frequent power outages. A lithium-ion battery loses roughly 1-2 per cent of its charge every month when left inactive. The most significant benefit is its long service life. Lead-acid batteries have a relatively limited life cycle, ranging from 3 to 6 years. Lithium-ion batteries are also expected to endure for roughly ten years. Based on chemistry, technology, and temperature, they can have a charging efficiency of approximately 5,000 life cycles and are maintenance-free.

In contrast, lead-acid batteries have an average charging efficiency of just 700 life cycles. In comparison to many of its counterparts, the lithium-ion UPS battery backup solution for data centres is three times smaller, six times lighter, and has a cycle life that is ten times longer. This sophisticated lithium-ion UPS battery backup technology for data centres decreases power usage with a surprisingly high (97 per cent) roundtrip efficiency while providing a low ownership cost and industry-leading power and energy density.[29]

Many data centre operators adopt lithium-ion-based UPS systems. For instance, NTT Global Data Centres adopted lithium-ion batteries with five minutes run time at full load in its data centre in Chicago. That boosts the data centres' UPS services market. Growing demand for Li-ion UPS battery backup solutions in data centres has led companies to develop a new, fully modular system. It is designed for AC & DC UPS, ancillary power backup, and switchgear applications in data centres, telecom, oil & gas, and utility markets.

[26] https://www.businesswire.com/news/home/20220202005480/en/Western-Europe-Data-Center-Market-Outlook-Forecasts-2022-2027-Increase-in-Investment-in-Italy-Spain-Portugal-Belgium-and-Switzerland---ResearchAndMarkets.com, last accessed in June 2022

[27] https://www.prnewswire.com/news-releases/western-europe-data-center-market-outlook--forecasts-2022-2027-multiple-projects-are-being-carried-out-by-colocation-cloud-telecommunication-and-internet-service-providers-301474845.html, last accessed in June 2022

[28] https://www.delta-emea.com/en-GB/news/30621, last accessed in June 2022

[29] https://www.delta-emea.com/en-GB/news/30621, last accessed in June 2022

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Safety [30]

Installing a reliable Li-ion UPS battery backup system for data centres is essential. That is the case, especially with mission-critical applications and industries in which Li-ion UPS battery solutions must deliver safety and cost-effectiveness, thereby, the growth of the lithium-ion UPS batteries in the data centre market.

While there are risks involved with Li-ion batteries, the risks are not extremely high considering how widely they are already applied (**Figure 11**). Battery fires are difficult to extinguish, and the prospect of re-ignition is extreme. That has generated a need for new methods and tactics for fire and rescue departments. That, again, needs encouraging collaboration between fire and emergency services globally. What is required to improve the situation from the safety perspective includes education, innovation, information, installation, and regulation. Each stakeholder, such as manufacturers, has a role in ensuring safety. Authorities are responsible for the legislation and surveillance. Currently, energy storage systems are not covered well by EU legislation. Some aspects could use improvement from the safety point of view.

Even physical damage may occur if the lithium is exposed to oxygen since it can explode into a fire. For a suppression system to put it out, we're not going to throw water on it because it would have a second negative response.

Another long-term issue with lithium-ion is that many insurance companies will not insure them. In Morris, Illinois, hundreds were evacuated for four days in June while firefighters battled a fire in 80 tons of used EV batteries stored at Superior Battery. Also, the 13-ton shipping container that caught fire at a 300MW Tesla battery storage plant in Australia in August had to be permitted to burn itself out over four days**, Figure 12**.

[30] Robert Zalosh, Pravinray Gandhi, Adam Barowy, Lithium-ion energy storage battery explosion incidents, Journal of Loss Prevention in the Process Industries, Volume 72, 2021, 104560, https://doi.org/10.1016/j.jlp.2021.104560.

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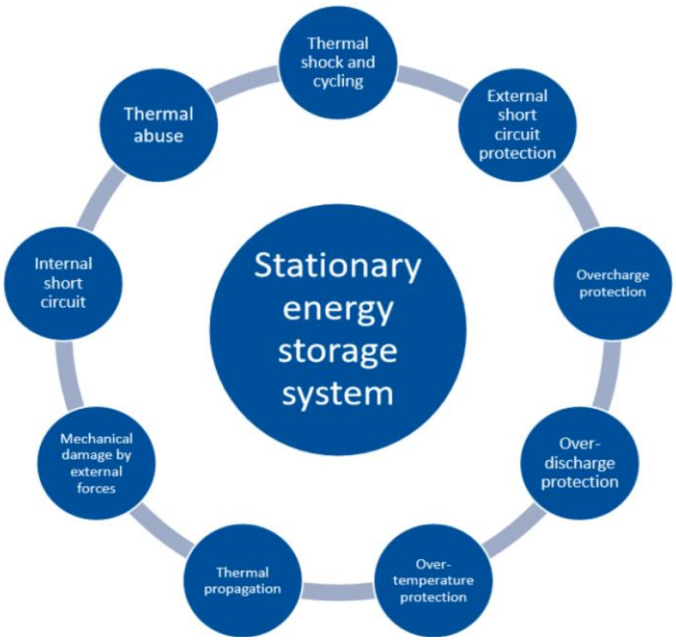

Figure 11. Risks involved with stationary energy storage systems[31]

Figure 12. A fire in a 13-ton shipping container of Li-ion batteries in the Tesla Megapack battery storage facility in Australia[32]

[31] Karoliina Meurman, Tukes, 29.1.2021, https://www.project-albatts.eu/Media/NewsEvents/3/NewsEvents_3_SLIDES_20210210_133035.pdf, last accessed on 17.8.2022
[32] https://www.itpro.co.uk/hardware/360437/tesla-megapack-battery-catches-fire-during-testing-in-australia, last accessed on June 2022

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1.5 Job Roles And Skills

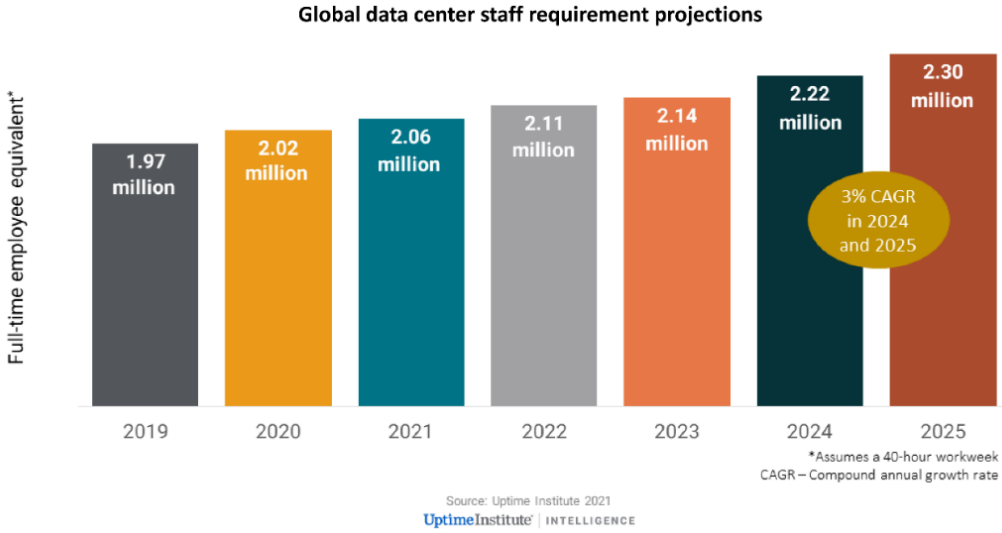

Figure 13. Chart from Uptime Institute, Global Data Center Staffing Forecast 2021-2025. [33]

Analysing job advertisements

The purpose of batteries and UPS systems is to safeguard the functionality of data centres in outage situations. Therefore, UPS systems belong to the critical infrastructure of data centres. Consequently, many job roles in data centres emphasize essential infrastructure expertise that includes UPS/batteries (along with other supporting systems).

We went through a number of job advertisements for data centre-related positions. Jobs are offered for engineers in various roles requiring UPS/batteries skills and knowledge. They include, for example:

- **Data centre engineers**
- **Facility controls engineers**
- **Electrical engineers**
- **Power engineer**
- **Service engineers**
- **Electrical subject matter experts**

We encountered positions that were related to developing and constructing data centres. For example, in these positions, battery/UPS skills are important:

[33] https://datacenter.uptimeinstitute.com/2021-staffing-report.html, last accessed on 17.8.2022

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- **Data Center Solution Architects**
- **Data Center Construction Managers**

Maintaining, supporting, and servicing data centres and their infrastructure/systems naturally involve the batteries/UPS:

- **Electrical engineers (critical environment)**
- **UPS Battery Maintenance Engineers**
- **Critical Facility Technician and Critical Engineering Technicians**
- **Data Center Support Technicians**
- **Computer Support Coordinators**
- **Service Sales Specialists**

Various managerial positions are needed to lead processes that involve UPS/batteries:

- **Critical environment program managers**
- **Data Center Facility Managers**
- **Critical Facilities Managers**
- **Project Managers**

Such skills/knowledge can be seen repeating in the above positions as:

- **critical infrastructure expertise (mentioned repeatedly)**
- **battery backup operation and design**
- **battery installation and configuration**
- **applicable electrical codes & standards**
- **BMS, operational experience**
- **battery maintenance, including preventive maintenance (especially servicing related jobs)**
- **battery test practices, processes and tools (especially servicing-related jobs)**

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Data centre engineer interview[34]

To gain deeper insight, we conducted interviews about the skills and competencies required for **Electrical Subject Matter Expert**'s position in a data centre. Working with UPS batteries is a significant part of that job role. The primary responsibilities include, for example:

- supporting the team and shift personnel
- addressing operational questions, internal procedures, troubleshooting, root causes
- when building a data centre, taking part in the design process and feasibility studies
- providing feedback from the operational perspective

The experience and education preparing for the role include in this example case:

- working as a service engineer for a provider of UPS systems with battery packs
- engineer studies: low voltage circuitry, electronics and electricity in general, programming (C++, logical gates etc.) etc.,
- Example of experience and training gained at work
    - installation methods, low and medium voltage systems, certification in using a thermal scanner
- multiskilled applicants are preferred with not only battery skills but also experience in electric cooling, switchgear, other critical infrastructure, circuit-breakers etc.

Skills and knowledge that are relevant in the position of an electrical subject matter expert:

- battery installation and replacing process with lead-acid and Li-ion batteries
    - lead-acid: more specific conditions, air ventilation, ambient temperature etc.
    - safety for the operators, protecting poles, the installation methods on the containment, understanding cables and their ratings
    - breaker settings (critically important due to a risk of electrocution)
    - Lockout/Tagout procedure[35][36]
- how to identify weak/faulty batteries

[34]Interviews with Mr. Johan Rautila, data centre electrical subject matter expert, May/June 2022
[35] The safety procedures to ensure equipment is shut down and inoperable until maintenance or repair work is completed.
[36] https://www.osha.gov/sites/default/files/publications/factsheet-lockout-tagout.pdf, last accessed on 29.8.2022

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- thermal scanner skills (certified) are especially needed with lead-acid batteries but also with Li-ion batteries to verify the condition of batteries
    - understanding scanned thermal patterns vs applied battery technology
- performance deviation and discharge tests

- Monitoring and maintenance
    - understanding the data provided and collected from batteries
    - understanding the reasons for battery issues and consequent measures
    - planning the maintenance intervals to maximize battery lifespan
    - understand what needs to be checked and with which procedure
    - understand and evaluate the thresholds
    - understand the alarm mechanism and what they indicate
- Safety in a data centre
    - awareness of potential hazards and how to react in different scenarios
    - use of the safety gear and staff training on safety
- When planning a battery backup system, one has to understand
    - the battery setups and arrangements (energy saver modes, double conversion, parallel systems, internal redundancy, monitoring systems etc.)
    - the pros and cons and specialities of different battery types and brands

When commissioning a new data centre installation, the following procedures need to be undertaken or ensured:

- contractor reviewing and analysis
- skill level assessment of staff
- guidance, follow up and checks of quality/methods
- supervising test procedures

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2 Renewable Power Farms

2.1 DRIVERS OF CHANGE

Europe imports about 40% of its gas needs from Russia, and in 2021 26% of these supplies passed through Ukraine, a privileged gas pipeline from Siberia to the EU. Italy is, among the European countries, the one that makes the most use of natural gas as an energy source (43%), followed by Germany (26%) and France (17%).

The European Commission published its REPowerEU plan on March 8, 2022. The plan outlined measures to drastically reduce Russian gas imports from the 2021 level of 155 bcm before the end of this year. It also aimed to complete independence from Russian fossil fuels before the decade's end[37]. It is possible to outline a strategy for diversifying supplies into the plan. That could be done by importing LNG and producing biomethane from agricultural and industrial waste.

Additionally, renewable hydrogen could be produced. Industrial and domestic use of fossil fuels could be reduced with energy efficiency and renewable energies. After the missed opportunity of the pandemic, this could be the right push to comply with the Green Deal, to make Europe a net zero emissions continent by 2050.

According to our previous desk research[38], "CO_2 reduction" and "access to raw materials" were among the top 3 in the ranking list shown in **Figure 14**. The Russia-Ukraine crisis has demonstrated these trends. Russia and Ukraine lead the global production of metals like nickel, copper, and iron. They are also largely involved in exporting and manufacturing other essential raw materials like neon, palladium and platinum (which are critical for microchip production)[39].

[37] EUR-Lex, Document 52022DC0108, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A108%3AFIN, last accessed in May 2022
[38] ALBATTS Project, „D4.4 Desk Research and Data Analysis for sub-sector ISIBA – Release 2", https://www.project-albatts.eu/Media/Publications/23/Publications_23_20210920_83914.pdf
[39] The Conversation, https://theconversation.com/five-essential-commodities-that-will-be-hit-by-war-in-ukraine-177845, last accessed in May 2022

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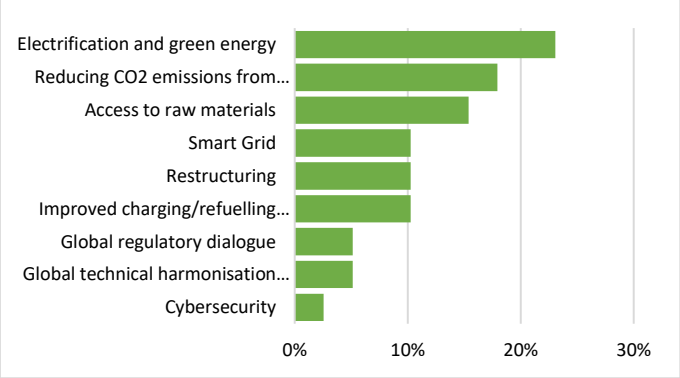

Figure 14. Occurrence of DoC, 2021 ALBATTS project desk research

As mentioned in the previous ALBATTS activities:

- **Reducing CO_2 emissions from battery manufacturing**[40] [41,42]
  Since the production of batteries requires significant amounts of energy, an increase in the share of renewable energies and energy efficiency in the battery value chain would be a major step toward decreasing CO_2 emissions from battery production. Also, moving from a linear to a circular value chain can improve both the environmental and economic footprint of batteries by getting more out of batteries in use and harvesting end-of-life value from batteries. Carbon footprint criteria could be useful to increase transparency and provide relevant information about the battery's environmental impacts. It should be based on the location of the production of batteries and their key components, like cathodes. It should also be based on CO_2 per kWh.
- **Access to raw materials** [43,44,45,46,47]

In a disruptive scenario (a rapid increase of EVs, a regulatory push across different European countries, complementing renewable energy generation), activities linked to raw materials

[40] UN report highlights urgent need to tackle impact of EV battery production boom, https://www.greencarcongress.com/2020/07/20200704-un.html?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+greencarcongress%2FTrBK+%28Green+Car+Congress%29, last accessed on 15.6.2022
[41] Batteries and hydrogen technology: keys for a clean energy future, IEA, https://www.iea.org/articles/batteries-and-hydrogen-technology-keys-for-a-clean-energy-future, last accessed on 15.6.2022
[42] A Vision for a Sustainable Battery Value Chain in 2030 (McKinsey World Economic Forum, 2019)
[43] UN report highlights urgent need to tackle impact of EV battery production boom, https://www.greencarcongress.com/2020/07/20200704-un.html?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+greencarcongress%2FTrBK+%28Green+Car+Congress%29, last accessed on 15.6.2022
[44] Transformation-in-energy-utilities-and-resources (PricewaterhouseCoopers, 2019)
[45] Three surprising resource implications from the rise of electric vehicles (McKinsey, 2018)
[46] Policy Recommendations German EU Presidency (EUROBAT 2020)
[47] Lithium and cobalt: A tale of two commodities (McKinsey, 2018)

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become critical. That is especially the case if some resources (limited in quantity or geographical presence) are necessary to produce key components. From this perspective, the battery sector needs to innovate new battery chemistries (e. g., lithium-sulphur[48]). It also needs to develop sourcing strategies to ensure a stable supply of critical raw materials (e.g., lithium, cobalt) and recycling to prevent shortages and potential price spikes.

The purpose of this chapter that covers renewable power plants is to explore the use of renewable energy to substitute fossil fuels and decrease dependence on other nations. We also study the importance of energy storage for the future of renewable energy since its role is to store electricity and make it available when needed. It thus balances supply and demand and helps to stabilize the network.

2.2 INTRODUCTION TO RENEWABLE POWER FARMS

Energy manifests itself in very different forms: heat is thermal energy, light is radiant energy, movement is kinetic energy, and all these energies can be obtained from the various sources available in nature, in some cases from a single source and others from several different sources. Therefore, all substances and phenomena capable of supplying energy are defined as "sources".

Electricity generation is the process of generating electric power from primary energy sources. For utilities in the electric power industry, it is the stage before its delivery (transmission, distribution, etc.) to end users or its storage.

Generally, the sources whose energy content is used directly are defined as "primary", while the sources obtained by transforming primary sources are defined as "secondary". For example, the source of energy (primary energy) that supplies a power plant can vary oil, methane, coal, uranium, wind, water or the sun. However, the energy produced at the end of the production process (secondary energy) is always electricity. The passage from primary to secondary sources always causes losses; therefore, reducing the phenomenon as much as possible is necessary. Electricity, however, is such a convenient secondary source that it continues to be produced despite the considerable transformation losses (which reach up to 2/3 of the primary energy used to produce it)[49].

[48] Example of a project: https://www.vutbr.cz/en/rad/projects/detail/2643, last accessed on 15.6.2022
[49] EEA, https://www.eea.europa.eu/data-and-maps/indicators/energy-efficiency-in-transformation/are-energy-losses-in-transformation, last accessed in March 2022

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Fossil fuels are still the most widely used source of energy today. Most (about 80%) of the energy consumed by man is produced through the combustion of oil, coal and methane[50]. However, these primary sources have the defect of not being eternal because their deposits will run out sooner or later: they are non-renewable sources. Nuclear energy is also a non-renewable source because the uranium used to produce it is also found in underground deposits that will run out.

Renewable sources of energy are those that are continuously produced by the natural cycles of the Earth and therefore do not risk exhaustion.

Renewable sources of energy are: solar energy, wind energy, which was once used to spin the blades of mills and today used to rotate the blades of wind turbines; water energy, that is, the kinetic energy of moving turbines connected to electricity generators; geothermal energy, that is, the heat of the earth's depths; biomass, such as wood or plant residues (or special crops) that can be distilled to obtain fuel.

The energies from renewable sources are more advantageous because they will never run out and pollute little or nothing, perfectly integrated into natural cycles.

2.3 WIND POWER PLANTS

2.3.1 Stakeholders

Market, figures and players

China and US are the world's largest onshore wind markets, accounting for more than 60% of new capacity in 2019. Offshore wind is increasingly important in driving global wind installations, with the sector installing a record 6.1 GW in 2019, accounting for 10% of new installations[51]. The top 10 Wind Turbine Manufacturers in the World are in Table 1, where Europe is in 2nd and 8th position.

Table 1: Top 10 Wind Turbine Manufacturers in the World 2020 (Global Wind Energy Council)

Rank	Company	Headquarters	Total Capacity (GW)
1	Vestas	Aarhus, Denmark	9.60
2	Siemens Gamesa	Biscay, Spain	8.79
3	Goldwind	Beijing, China	8.25

[50] EESI, https://www.eesi.org/topics/fossil-fuels/description#:~:text=Fossil%20fuels%E2%80%94including%20coal%2C%20oil,were%20compressed%20and%20heated%20underground., , last accessed in May 2022

[51] „Global Wind Report 2019", Global Wind Energy Council, 2020

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Rank	Company	Headquarters	Total Capacity (GW)
4	GE	Boston, U.S.	7.37
5	Envision	Shanghai, China	5.78
6	MingYang	Zhongshan, China	4.50
7	Windey	Zhejiang, China	2.06
8	Nordex	Hamburg, Germany	1.96
9	Shanghai Electric	Shanghai, China	1.71
10	CSIC	Chongqin, China	1.46

Europe in 2021 has 236 GW of wind capacity, and into the next period, 2022-2026, the expectation is to install 116 GW of new wind farms, having a total of over 350 GW available.

In 2021 Europe installed 17.4 GW[52] of new wind power capacity, with a +18% compared to 2020 and onshore wind made up 81% of the new installations.

According to Wind Europe, the 2021 wind energy generation will cover about 15% of Europe's electricity demand, and the TOP 5 producers in EU27 are Germany (64 GW), Spain (28 GW), France (19 GW), Sweden (12 GW) and Italy (11 GW). [53]

2.3.2 Technology

History

Wind energy has been used for thousands of years to move boats (sailing ships). Still, it was exploited as early as antiquity (1st century AD) with the wind wheel invented by the Greek mathematician and engineer Heron of Alexandria. Between the 7th and 9th centuries AD, the first windmills appeared in the Middle East and Central Asia. In Sicily, windmills were used from the 10th century onwards to pump seawater and extract salt, an extremely valuable commodity for preserving foodstuffs and subject to duty and tax (the gabella) from the 14th century onwards. In 1881, Kelvin used the energy force of the wind as an alternative to the depletion of coal: a few years later, a Scot invented the first wind turbine, patented in 1891. It was not until the 1970s that NASA developed a technology that is still used in today's wind turbines.

[52] 11 GW (of 17.4 GW) of the new installations were in the EU-27
[53] Wind energy in Europe, 2021 Statistics and the outlook for 2022-2026, Wind Europe, February 2022

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How it works

A wind turbine is a machine that converts the kinetic energy of the wind (i.e. a moving mass of air) into mechanical energy. The wind turns the blades, which turn the generator that transforms mechanical energy into electricity thanks to a dynamo. Two types of wind farms are differentiated by their installation on land or sea. The first is called onshore and is mainly designed and installed on open ground, hills and mountains. The second, called offshore, is placed on the sea near coastal areas or offshore, and in this case, the plant is built with wind turbines mounted on a floating platform.

Pros and cons

After the wind turbines are built, operational costs involved in maintaining wind power plants are low and generally considered relatively cost-effective. Offshore wind is more stable, provides more energy and has a lower visual impact; however, the construction and maintenance costs are significantly higher than the onshore.

Wind farms can also be constructed on agricultural lands without causing any interruption to cultivation activities. Even if wind turbines' maintenance may vary, some need to be frequently checked, and wind power projects typically require huge capital expenditure.

Commercially available wind turbines range between 5 kW for small residential turbines and 5 MW for large-scale utilities. Wind turbines are 20% to 40% efficient at converting wind into energy. The typical life span of a wind turbine is 20 years, with routine maintenance required every six months. Wind turbine power output is variable due to the fluctuation in wind speed; however, when coupled with an energy storage device, wind power can provide a steady power output[54].

2.3.3 Job roles and skills

New Global Wind Energy Council analysis shows that 3.3 million new wind power jobs can be created globally over the next five years, including direct jobs onshore/offshore.

What is common with the positions[55] listed below is that **knowledge of and/or skills in BESS technology, its design and related technologies** are required basically in all of them. Many of the positions appear such that while they existed in wind-related job advertisements, it can

[54] "Renewable Energy Fact Sheet: Wind Turbines", United States Environmental Protection Agency, August 2013
[55] Indeed, www.indeed.com, job advertisements accessed in June, July and August 2022

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be presumed that the positions involving batteries/BESS are very similar to comparable positions in other renewable energy sites. In the advertisements, wind and solar were occasionally referred to along with batteries/BESS.

Project planning and development

- **Managers, Project Development**
  - develop wind and energy storage projects
- **Project Engineers – Wind**
  - understanding/experience with BESS technology
  - coordinate engineering activities: contracts, schedules, and budgets
  - conduct wind farm due diligence analysis, feasibility studies
- **Engineering & Logistics Managers – BESS**
  - R&D management, product development and design
- **Estimators, Energy storage**
  - Estimate EPC & BOP costs for energy storage system construction projects
  - comprehensive knowledge of energy storage technologies
- **Renewable Development Specialists**
  - assess renewable site studies, conceptual designs, optimization, risk managing
- **SCADA Engineers**
  - SCADA skills: design, development, implementation, commissioning phases
  - BESS and EMS, Inductive Automation Ignition software
  - communication protocols, automation control systems programming
  - SAT and FAT testing and related documentation
  - knowledge of Utility Meters, RTAC, Protection Relays
  - Managed switches, Power Plant Networking, Security and Firewalls

Operation and Maintenance (O&M)

- **Managers, Operations and Maintenance**
  - ensuring optimal BESS availability and state of health (degradation)
  - maintenance & monitoring of the energy storage fleet (managing warranties, BESS components, spare parts, 3rd party service providers/contracts)

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- Review Requests for Proposals (RFPs), Requests for Information (RFI), Engineering Procurement Construction (EPC) contracts

- **Site Operations Managers**
  - develop & lead O&M of wind farm sites incl. Battery Energy Storage Systems
  - Procurement of services & materials and working with services contracts
- **Senior Integration Engineers**
  - BESS planning & design: transformer & inverter sizing, power SLD, cable dimensioning, communications & network, component selection, safety
  - network technology, SCADA systems, relay protection, HVAC, fire suppression
  - commissioning energy storage systems and/or inverter-based technology
  - Familiarity with design software and simulation tools
- **BESS Technicians**
  - Testing, maintaining, troubleshooting, and replacing battery energy storage power plant-related electrical equipment
  - maintaining battery modules and battery support systems
- **Supplier Quality Engineers**
  - Audits, analyze quality and qualify or disqualify suppliers
  - Supplier Corrective Actions (SCAR) for root cause analysis and corrective action
  - Closed-Loop Quality Management System: Non-Conformance Tracking (MRB), Supplier Corrective Action Requests (SCAR), Corrective Action and Preventive Action (CAPA), Supplier Quality Scorecard (SQC), Cost of Poor Quality (COPQ)
  - Statistical Process Control (SPC) and Advanced Quality Process (AQP) to identify/help implement improvements within Supply Chain Department

Supporting/other occupations:

- **Battery Technicians (service providing to wind and energy storage assets)**
  - renewable energy experience, electrical proficiency
  - Physical fitness for climbing and lifting operations
  - supervise field work on-site, focusing on Safety, Quality, and Efficiency
  - perform LOTO (Lockout Tagout) of equipment
  - conducting pre-task planning, Job Hazard Analysis (JHA), Risk Assessment (RA)
- **Renewable Energy Consultants (consulting)**

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- undertake Technical Due Diligence projects (Wind and Solar Farms, BESS)
- Risk Review of potential buy-side/sell-side assets
- experience: renewable energy projects (development, construction, operation)
- interpersonal skills, demeanour: ability to interact with high-level executives

- **Product Manager Energy Storage Systems (business development)**
  - support sales process to better understand customer requirements
  - Review/understand BESS project requirements (Request for Proposals etc.)
  - Understand requirements incl. BESS use cases and applications, power and energy sizing, reactive power capability, and system operational performance
  - knowledge of BESS subcomponent equipment: Batteries, Power Conditioning System (PCS), Energy Management Systems, Power Plant Controller, SCADA

2.4 HYDROELECTRIC POWER PLANTS

2.4.1 Stakeholders

Market, figures and players

At 1,295GW, hydropower accounted for approximately 55% of the global installed renewable energy capacity in 2018. China, Canada, Brazil, Russia, and France host some of the world's biggest hydropower producers[56]. The top 5 world's biggest hydroelectric power plants are in Table 2.

Table 2: World's biggest hydroelectric power plants in 2019 (International Energy Agency)

Rank	Company	Headquarters	Total Capacity (Gigawatts)
1	China Yangtze Power Co. Ltd	China	45,5 GW
2	Centrais Elétricas Brasileiras SA	Brazil	44,2 GW
3	Hydro-Québec	Canada	36,7 GW
4	RusHydro	Russia	27,6 GW
5	Electricite de France (EDF)	France	22,7 GW

[56] NS Energy, https://www.nsenergybusiness.com/features/largest-hydropower-companies/, last accessed in May 2022
Power Technology, https://www.power-technology.com/analysis/worlds-biggest-hydroelectric-power-plants/, last accessed in May 2022

European hydropower plants in a top 10 world ranking are also in Norway[57] with Statkraft AS (15,7 GW) and Agder Energi AS. An estimated 31.5 GW of hydropower capacity was put into operation in 2016, bringing the world's cumulative installed capacity to 1,246 GW[58]. It is one of Europe's main renewable energy sources (EU-28 + Switzerland, Norway and Iceland). Hydropower accounted for 10% of gross electricity generation in 2018 (8 billion EUR) and 36% of all renewable electricity generation in Europe (including Turkey), representing 653 TWh in 2019. In 2019, the TOP 5 European 27 countries' hydropower generation[59] was Norway (125.765 GWh), Sweden (64.826 GWh), France (63.613 GWh), Italy (47.984 GWh) and Austria (42.669 GWh).

In Europe, due to climatic conditions, large differences in hydropower resources and hydropower share of the total electricity mix exist across Europe. Nordic countries contribute 44% of the European hydropower generation, Alpine countries contribute 37%, southern countries provide 12%, and Eastern Countries 6%. The largest capacity is installed in the Alps[60].[61]

2.4.2 Technology

History

Energy from water is one of the oldest sources of renewable energy. With the Nile as their main source of life, trade and commerce, the Egyptians were among the first peoples to use water as a source of energy. They built the first dam and were among the first to exploit the invention of the water wheel, the same one we see in water mills, which, placed in rivers and streams, transforms kinetic energy into mechanical energy. The 19th century was characterised by several scientific advances in the energy field. It was discovered how to store and harness electrical power, and the Italian Alessandro Volta invented the battery, the first electrical generator ever made. Modern hydropower history started in 1832, with the

[57] Technavio blog, https://blog.technavio.org/blog/top-10-hydropower-companies, last accessed in May 2022
[58] China alone accounted for almost one third of global hydropower capacity and added about 11.74 GW of new capacity in 2016.
[59] „Generation of hydropower in Europe in 2019, by country", https://www.statista.com/statistics/690039/hydropower-generation-europe/, last accessed in May 2022
[60] „Strategic Industry Roadmap" Deliverable D4.8, Hydropower Europe Project (Horizon 2020), https://hydropower-europe.eu/, last accessed in May 2022
[61] https://hydropower-europe.eu/, last accessed in May 2022

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invention of the water turbine capable of producing electricity. At the height of the second industrial revolution (late 19th and early 20th centuries), waterpower was used to produce electricity. The hydroelectric plant was built in 1879 and commissioned in 1881 in the United States near Niagara Falls and is considered the first.

How it works

A hydroelectric power station transforms hydraulic energy from a natural or artificial watercourse into electricity. The process takes several steps and starts with transforming the potential energy in the masses of water at higher altitudes than where the power plant's turbines are located.

The functional scheme comprises a dam or cross-river that intercepts the watercourse, creating a reservoir, which can be either a reservoir or a hydropower plant. Through intake works, canals and diversion tunnels, the water is directed towards the hydroelectric turbines through the use of inlet (safety) valves and flow regulating devices (distributors), depending on the energy demand.

The water sets the turbines in motion, generating mechanical energy, and flows out of them into a discharge channel, through which it is returned to the watercourse. Directly connected to the turbine is the rotating electric generator (alternator), which transforms the mechanical energy received from the turbine into electrical power.

Most hydropower plants are small (< 10MW) even if the big share of the electricity generation comes from larger plants. Hydropower plants with more than 10 MW capacity contribute from 60% to over 90% of the total installed capacity in most countries[62].

Pros and cons

Hydroelectric power plants emit fewer greenhouse gases than fossil fuel-powered energy plants. The hydropower plants have a very long asset life, with the oldest facilities operating for more than 100 years. Labour cost is low as facilities are automated and controlled remotely, and a small amount of personnel is required on site. Hydropower is the most

[62] https://hydropower-europe.eu/, last accessed in May 2022

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efficient source of electrical energy by converting over 90% of the available energy into electricity. The best fossil fuel power plants operate at approximately 60% efficiency[63].

The construction of hydroelectric power plants and dams requires huge investment; moreover, according to WWF[64], Europe has the most fragmented river landscape on the planet. At least one million barriers - dams, weirs, ramps, fords and culverts - are clogging up the continent's rivers, affecting their health, the quality and availability of water, and threatening the survival of vulnerable species.

2.4.3 Job roles and skills

Hydropower employed 2.2 million people[65] , and hydropower employment will grow to 3.7 million by 2050. A list of job roles involved in the sector are, for example[6667]:

♦ Hydropower Mechanical Engineer ♦ Site Supervisor – Hydropower ♦ Hydropower Operations Maintenance Worker ♦ Hydropower Plant Efficiency Operator ♦ Hydropower Plant Installation Technician ♦ Operations Supervisor ♦ Hydro-Electric Power Generation Engineer ♦ Supervisory Facilities Specialist ♦ Project Manager ♦ Hydropower Electrical Engineer ♦ Hydropower Structural Engineer ♦ Electrical Engineer	♦ Principal Dam Hydropower engineer ♦ QA Engineer ♦ Hydropower Civil project manager ♦ Senior Plant Leader ♦ Hydropower Structures Project Manager ♦ Hydropower mechanical maintenance ♦ Renewable energy & Power systems Scientist/Engineer ♦ *Engineering & Logistics Manager (BESS)* ♦ *Manager, Operations and Maintenance (BESS)* ♦ *Supplier Quality Engineer (BESS)*

[63] "5 THINGS YOU NEED TO KNOW ABOUT HYDROPOWER", Canadian Hydropower Association, March 2022
[64] "Hydropower is destroying Europe's rivers and biodiversity", WWF, last accessed in May 2022, https://www.wwf.eu/what_we_do/water/hydropower/#:~:text=There%20are%20currently%2021%2C387%20existing,are%20financed%20by%20the%20EU
[65] "Renewable Energy and Jobs, Annual Review 2021", IRENA
[66] European Small Hydropower Association, https://www.greenjobs.co.uk/european-small-hydropower-association.cms.asp, last accessed in May 2022
[67] Indeed, www.indeed.com, job advertisements accessed in June, July and August 2022

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We discovered there were fewer available renewable plus BESS-related job advertisements for hydropower if compared to BESS-related positions in the context of wind and solar power. The potential growth of the wind and solar business may be seen in that fact.

Additionally, it can be assumed that the battery/BESS-related skills needed in the wind and solar power farms (described in the related sections of this deliverable) are similar to those required for battery energy storage in hydropower systems. We found, for example, the following skills and knowledge[68] that are related to batteries/BESS in the context of generic renewable energy projects (not limited to hydro, solar or wind):

- **Engineering-related skills and knowledge**
  - manage R&D
  - project management
  - supporting product development and design
  - coordinating and supporting engineering activities
  - coordinating project management team to project completion
  - Supervise sub-contractors
  - use computer-assisted engineering and design software and equipment
- **Operations and Maintenance related skills and knowledge**
  - responsible for the safe and reliable operations of Battery Energy storage Systems (BESS) projects
  - Ensure optimal BESS availability and state of health (degradation) in relation to the use cases of Battery Storage projects
  - Develop and improve technical standards, maintenance guidelines and procedures, equipment manuals, outage procedures, operational protocols, environmental procedures, and other documents specifically dedicated to the energy storage business.
  - Management of warranties, BESS components, spare parts, 3rd party service providers/contracts and other tasks related to the maintenance and monitoring of the energy storage fleet.

[68] Indeed, www.indeed.com, job advertisements accessed in June, July and August 2022

- Participate in the review of Requests for Proposals (RFPs), Requests for Information (RFI), Engineering Procurement Construction (EPC) contracts for manufacturers, O&M providers and vendors.
- At least 3 years of O&M site-level experience with HV, MV, and LV systems.
- Solid technical background related to the battery storage or energy sector.

- **Supplier quality-related skills and knowledge**
  - performs Audits, analyze quality, and qualify or disqualify suppliers, according to the organization's standards
  - maintains successful relationships with supply, engineering, logistics, battery energy storage, and regulatory departments
  - Initiate Supplier Corrective Actions (SCAR) in partnership with the Engineering, Supply Chain, and BESS departments to ensure complete and effective root cause analysis and corrective action implementation making necessary recommendations and improvements where needed.
  - Helps establish and deploy a Closed-Loop Quality Management System that includes:
    - Non-Conformance Tracking (MRB)
    - Supplier Corrective Action Requests (SCAR)
    - Corrective Action and Preventive Action (CAPA)
    - Supplier Quality Scorecard (SQC)
    - Cost of Poor Quality (COPQ)
  - Performs ISO audits of Supplier Quality Systems to assure continued supplier conformance to the quality system requirements
  - ensuring the supplier and Battery Manufacturer has the capacity to produce what has been ordered and what all other customers have ordered
  - promote the use of Statistical Process Control (SPC) and continuous improvement techniques
  - use Statistical Process Control (SPC), Advanced Quality Process (AQP) tools and metrics to proactively identify and help implement improvements within the Supply Chain Department

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2.5 SOLAR POWER PLANTS

2.5.1 Stakeholders

Market, figures and players

According to the International Energy Agency (IEA), solar is on track to set records for new global deployments each year after 2022, with an average of 125 GW of new capacity expected globally between 2021 and 2025[69]. Solar photovoltaic generation increased 22% in 2019 and represented the second-largest absolute generation growth of all renewable technologies, slightly behind wind and ahead of hydropower, according to the agency[70].

Table 3: Top five countries for solar power capacity in 2019 (IEA)

Rank	Country	Total Capacity (Gigawatts)
1	China	205 GW
2	USA	76 GW
3	Japan	63 GW
4	Germany	49 GW
5	India	38 GW

Regarding Europe, net photovoltaic additions are expected to reach 16.5 GW in 2020, a 4% decline relative to 2019, which had been an exceptional year as Spain added 4 GW of utility-scale photovoltaics to meet support deadlines. Excluding Spain, where additions in 2020 have halved, Europe's annual additions are set to grow by 13% in 2020 and reach their highest level since 2012 despite lockdowns and social distancing measures. Most of the increase is driven by utility-scale deployment from auctions in Germany, France, and Poland. Higher growth also stems from the increasing attractiveness of net metering in Turkey, Poland, and the Netherlands.

Solar power already provides an important contribution to the European energy mix, with 3.6% of EU-28 gross electricity generation in 2017[71] . According to the International Renewable Energy Agency (IRENA), global solar power capacity will increase by 9% annually

[69] NS Energy, https://www.nsenergybusiness.com/features/solar-power-countries-installed-capacity/, Last accessed in May 2022

[70] International Energy Agency, NS Energy, Renewables 2020 Analysis and forecast to 2025, Last accessed in May 2020

[71] Eurostat, https://ec.europa.eu/info/research-and-innovation/research-area/energy-research-and-innovation/solar-energy_en#:~:text=Solar%20power%20already%20provides%20an,EU%20electricity%20demand%20in%202040., Last accessed in May 2022

between 2018 and 2050. During this time, the capacity will grow from 480 GW to more than 8,000 GW; current market trends estimate that solar has the potential to meet 20% of the EU electricity demand in 2040[72].

Germany is Europe's major solar market in 2021 with 5.3 GW of newly installed capacity, followed by Spain (3.8 GW), the Netherlands[73] (3.3 GW), Poland (3.2 GW) and France (2.5 GW). In 2021, the Top 5 markets in the European Union stayed the same. Among the Top 10, there are only two newcomers that are from northern Europe (Denmark and Sweden), replacing two established photovoltaic markets, one in central Europe (Belgium) and the other in the south (Portugal).

2.5.2 Technology

History

The discovery of the photoelectric effect dates back to the second half of the 19th century when Willoughby Smith, William G. Adams and Richard Evans joined forces to discover the impact of sunlight on selenium. That material, used for telegraph cables, emitted a slight discharge of energy when illuminated. Based on this discovery, the first solar panel was made in 1879 by Charles Fritts. the first photovoltaic system in history was installed in New York in 1884, driven by a panel consisting of a layer of selenium and a film of gold (with an energy conversion rate of around 1 to 2 per cent). Subsequently, studies were continued by various scientists, including A. Einstein, who won the Nobel Prize for Physics in 1921 for his studies on the photovoltaic effect. Modern photovoltaics dates back to 1954 when Bell Laboratories created the first silicon solar cell capable of generating measurable electricity.

How it works

At a solar plant, the sun's energy is channelled and used to produce energy. There are two types of solar power stations: photovoltaic and thermodynamic/concentrated. **Photovoltaic plants** take advantage of the photovoltaic effect to produce electricity, i.e., the ability of some semiconductor materials (when properly handled) to generate electricity when exposed to light rays. Photovoltaic power stations have many electrically interconnected photovoltaic

[72] Bloomberg NEF, https://about.bnef.com/, Last accessed in May 2022
[73] In 2021, the Netherlands has overtaken Germany for installations per capita, reaching 765 W/capita, 42% up from 2020

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modules that make up so-called strings, which are connected in parallel and to an inverter to supply electric current. Solar radiation is captured by all the solar panels in a power station's photovoltaic array. The inverter transforms the continuous current produced by the solar panels into an alternating current and converted by a transformer into a medium voltage current.

Thermodynamic solar plants (also known as *concentrated solar power stations*) use mirrors to concentrate the sun's rays in a precise point called a receiver, which contains a heat-carrying liquid that stores and transports the sun's heat. The heat transforms the receiver liquid into steam, channelled through a piping system to power a turbine. The mechanical energy produced by the turbine is then transmitted to an alternator that transforms it into electricity.

Pros and cons

Solar energy plants convert energy from the sun into thermal or electrical energy using one of the cleanest and most abundant renewable energy sources. They generally do not require high maintenance and last for about 20 to 25 years.

Solar energy has to be used "right away", or it can be stored in large batteries; these batteries, used in off-the-grid solar systems, can be charged during the day so that the energy is used at night even if the storage hardware is quite expensive.

Initial costs involved in financing solar power plants are high, and the installation requires a lot of space. Solar panels are a manufactured product, and there is considered an environmental impact, from the chemicals used to make the panels to transportation and beyond.

Solar panels can usually process 15% to 20% of solar energy into usable energy, depending on factors like placement, orientation, and weather conditions[74]. Compared to others, this is the less efficient energy transformation process.

2.5.3 Job roles and skills

Solar power plants, including BESS, employ personnel in a wide range of occupations, such as those listed below.

[74] „ Solar Panel Efficiency", Clean Energy Reviews, https://www.cleanenergyreviews.info/blog/most-efficient-solar-panels, Last accessed in May 2022

What is common with the positions listed below is that **knowledge of and/or skills in BESS technology, its design and related technologies** are required basically in all of them. Some jobs are similar to those with wind power sites and associated projects. Many positions appear such that while they existed in the context of solar-related job advertisements, it can be presumed that the positions involving batteries/BESS are very similar to comparable positions in other renewable energy sites.

- Solar Power Plant Development
  - **Renewable Energy Engineering Technician**
    - assist PV & BESS projects: feasibility, pre-constr./construction phases
    - Design commercial/utility-scale PV systems, energy storage, microgrids
    - develop energy production and power system models
    - Computer Drafting/Design, AutoCAD, Revit, SKM Power Tools, ETAP
    - knowledge of standards
- Solar Power Plant Construction and Project planning and development
  - **Project Manager (Renewables/Solar/BESS)**
    - responsibility for all stages of construction projects
    - experience in management and completion of large-scale projects
  - **Manager, Project Development**
    - development of solar and energy storage projects
  - **Engineering & Logistics Manager – BESS**
    - manage R&D, support product development and design
    - project management, coordinating & supporting engineering activities
    - coordinate project management team to project completion
    - Supervise sub-contractors
  - **Associate Project Analyst - Energy storage Development**
    - Strategically identify and drive project opportunities
    - Support the planning efforts to locate storage assets optimally
    - Evaluate financial models to determine business feasibility
    - knowledge of ISO-NE, PJM, MISO, ERCOT and NYISO processes, incentives and ancillary revenue streams

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        - engineering principles: power systems analysis, electrical interconnection, BESS, microgrid controls, data monitoring/reporting
    - **Renewable Development Specialist (**see Wind Power Plants)
    - **Project Engineer, Energy storage**
        - engineering, owner's engineering and technical due diligence services to renewable energy projects with a focus on BESS
    - **Renewable Energy Engineer**
        - drawings: development, installation/constr. and site plan (PV & BESS)
        - cover the solar and battery project life cycle
        - Perform solometric shading analysis and PVSyst models
        - knowledge of Data Acquisition platforms and controls systems
        - Power generation, power system protection and coordination, compliance and relay testing; knowledge of electricity & hazards
        - AutoCAD skills
        - develop, analyse, interpret electrical Single and Three Line Diagrams
- Solar Power Plant Operations and maintenance
    - **BESS Technician**
        - Operate & maintain batt. storage, mechanical/electric. maintenance
        - Complete Lock-Out-Tag-Out (LOTO), JSA's, Permit to Work and job-specific documentation to maintain and repair in a safe manner
        - Ability to lift over 50 lbs
        - Experience with SCADA systems, Skilled with testing equipment/tools
    - **Site Operations Manager** (see Wind Power Plants)
    - **Senior Integration Engineer** (see Wind Power Plants)
    - **Service Field Technician**
        - Prevent./Correct. Maintenance: storage cabinets, system applications
    - **Field Service Specialist**
        - technical support: installation, testing, maintenance, troubleshooting, overhaul, or repair of critical equipment
        - Develop/lead training programmes for the Solar and Battery Storage
        - Coordinate with Solar & BESS Engineers to develop maintenance plans

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- Root Cause, Asset Criticality and Failure Mode & Effect Analysis
- Medium & High Voltage 3-phase power systems, AC and DC power systems, inverters, instrumentation & digital control systems
- knowledge in the use of power plant-related test equipment

- **Lead PV Engineer**
  - Providing design drawings, including one-line and three-line diagrams, electrical layouts, AC/DC schematics, AC/DC cable schedule, wiring diagrams, grounding, trenching, and conduit details
  - Coordinating and collaborating with customers, contractors etc.
- **Manager, Operations and Maintenance** (see Wind Power Plants)
- **Solar Technician**
  - plan preventative & corrective maintenance: solar and BESS equipment
- **Supplier Quality Engineer** (see Wind Power Plants)
- **Reliability Technician**
  - Condition Monitoring, maintenance in Solar/BESS projects
  - Collect/Analyze/Interpret data from Condition Monitoring tech
- **Senior Procurement Manager - Solar & Battery Storage**
  - tendering, negotiating, executing EPC contracts: BESS/Solar Projects
  - knowledge of battery storage & solar EPC construction services market
  - project viability assessment: CAPEX budget numbers/financial models
  - Counsel, Litigation, Procurement; legal support for renewable projects

- Other Occupations in Solar Panel Installation and Maintenance
  - **Battery Technicians** (see Wind Power Plants)
  - **Solar and BESS Services Engineering Manager**
    - guidance: design, standards, systems, applicable engineering codes
    - develop recommendations for equipment and/or materials selection
- Support Occupations
  - **Renewable Energy Consultant** (see Wind Power Plants)
  - **Battery Energy storage Systems Specialist (Manager)**
    - business models & commercial frameworks for solar and BESS
    - Identify strengths & weaknesses of business models and incentives

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- Understand battery/BESS market trends in technology, applications etc.
- benchmark by analysing pricing mechanisms/costs in leading countries

- **Technical Asset Manager (Solar and Storage)**
  - Understand technical operations of Solar Farm and/or BESS projects
  - Health & Safety and Quality & Environmental management systems
- **Vice-President, Business Development**
  - develop business & market penetration strategies, BESS opportunities
  - Strong knowledge of BESS EPC Contracts and Projects
  - Basic technical understanding: Lithium-ion Battery Storage industry
  - Experience: Sales or Project Development in Energy storage or Solar

2.6 Power Plants Optimization: Energy Storage Systems

Storage systems are essential for the future of renewable energy. Their role is to store electricity and make it available when needed, balancing supply and demand and helping stabilize the network. In the coming years, photovoltaic, wind and all other renewable energy sources will have to grow a lot to allow governments to respect the commitments taken[75]. That raises the problem of their non-programmability in relation to the coverage of energy and storage needs. It is also necessary to optimize the economic efficiency of electricity production, and the energy storage topic will have to link up with an intelligent energy transport system (smart grid). Energy storage can take place in two ways: energy-intensive or power intensive:

- **energy-intensive:** systems aimed at alleviating grid congestion caused by excessive production from wind or solar sources in an area where the grid is unable to absorb all the production
- **power-intensive**: systems called to absorb and/or deliver a large amount of power in a very short time for relatively short periods precisely to respond to the need to modulate the production phases of photovoltaic and wind power

[75] Accordign to the limit global warming to 1.5 ° centigrade compared to the period prior to the Industrial Revolution and to achieve carbon neutrality by 2050 qill be possible with renewables energies

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The main electrical energy storage systems are[76]:

- electrochemical (batteries)
- electrical (supercapacitors)
- mechanical (flywheels, CAES, PHS and P2G).

Batteries

The batteries used as storage systems differ according to their chemical combinations. In general, the use of batteries, in the context of reducing the environmental impact of the latter, represents a valid prospect for the widespread and decentralized installation of many high-capacity and efficient systems that would upset the current business models of utilities.

Batteries are a fundamental component for systems isolated from the electricity grid. That is due to them having the task of accumulating the electricity produced in excess and returning it to users when the system is inactive. For example, at times of low insolation, at night or when seasonal water conditions do not allow adequate energy production.

Supercapacitors

Supercapacitors are made of two polarizable electrodes, a separator and an electrolyte. The electric field is stored in the interfaces between the electrolyte and the electrodes. The characteristics of supercapacitors include high power density and long life. Additionally, their benefits include the simplicity and reversibility of energy storage. Those qualities are emphasized when compared to conventional batteries. On the other hand, the disadvantage is linked to the quantity of accumulable charge, which is limited and depends on the electrode-electrolyte interface surface.

Flywheels

Vertical axis flywheels are located in sturdy cylindrical containers in which a certain degree of vacuum is maintained to reduce noise and aerodynamic friction of the rotor, thanks to the adoption of magnetic bearings. By using a converter, the rotor transfers energy to the grid in the form of alternating current with variable high frequency.

Compressed Air Energy Storage Systems (Caes)

They are those in which storage is achieved by converting surplus electricity into compressed air that can be stored in underground and hermetic caves, such as disused natural gas or salt

[76] Energy Storage Associaton, https://energystorage.org/why-energy-storage/, Last accessed in May 2022

quarries. Depending on its declination, adiabatic or not, this system can also be integrated with systems using fossil fuel for a surplus of power in the restitution phase.

Pumped Storage Hydropower (PSH)

These systems are based on transforming surplus electricity into hydroelectric potential using gravity. These systems provide electricity accumulation in low-demand periods by pumping water from the reservoir at a lower elevation to the one at a higher elevation. The generation of electricity is enabled during periods of high demand by letting the water come down and pass through a turbine.

The Energy Storage of The Near Future: Power-To-Gas (P2g)

A particularly promising technology is Power To Gas. It uses electricity to produce gaseous fuel by exploiting renewable resources, both controllable (for example, the biomass of plant origin) and non-controllable (for example, wind and photovoltaic), for the production process of hydrogen and synthetic methane. Its benefit is that it enables the production mentioned above cleanly with renewable sources, and the generated fuels can be transported through, for example, gas pipeline networks.

2.7 OTHER ENERGY SOURCES

2.7.1 Geothermal power plants

History

The first attempt to produce electricity from the energy contained in geothermal steam was made in Italy in 1904 when Prince Piero Ginori Conti experimented with the first geothermal generator at the Larderello site, where extraction of geothermal acids had begun. This experiment led to the lighting of five light bulbs. A half-century before, in 1852, Lord Kelvin invented the heat pump. In 1912, Heinrich Zoelly patented the idea of using the pump to extract heat from the earth. The geothermal heat pump was officially constructed (probably a 2.2 kW direct exchange system made by Robert C. Webber at home) not until the late 1940s. The official commercial geothermal heat pump has been designed by J. Donald Kroeker to heat the Commonwealth Building in Portland in 1946[77].

[77] "GEOTHERMAL HEAT PUMPS FOUR PLUS DECADES OF EXPERIENCE", R. Gordon Blomquist, 1999

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How it works

Geothermal energy uses the geological heat present in the Earth's subsurface to produce heating or electricity. This heat, in the form of steam, is naturally present in the crust and subsoil of our planet. The deeper you go into the Earth's subsurface, the higher the temperature rises: as groundwater flows under the Earth's crust, it comes into contact with rocks at high temperatures, where the steam develops. There are different types of geothermal energy sources, and the difference lies mainly in the depth at which the rocks heat the water and the temperature that is created. The steam produced by the earth's heat generates thermal energy, which can be converted into heating and electricity. The steam is drilled to the surface and fed into a turbine, which produces natural, clean energy with no harmful emissions into the atmosphere. This energy can be easily reused and replenished: the steam is recovered by the same turbines, and by injecting cold water at depth, the steam flow can be fed at full capacity, thus becoming constant. The most advanced technologies for using geothermal resources involve exploiting springs at different temperature levels[78]:

- **Low temperature** (15° < T < 90°). Various types of exploitation are possible in this temperature range for air conditioning and heating homes and greenhouses. High-efficiency air conditioning is achieved with so-called 'geothermal heat pumps (or probes)'. The basic principle of these systems is that the source of heat transfer or withdrawal is located at a certain depth underground, thus having a constant temperature in different seasons and very close to the typical summer/winter air conditioning temperatures (about 20°C).
- **Medium temperature** (90° < T < 180°C). Sources in this temperature range are ideal for producing electricity in small/medium (100 kW-10 MW) binary-type plants. In binary plants, the geothermal fluid is circulated in a closed circuit in a heat exchanger to vaporise a fluid with a low boiling point (50°C-80°C) before being injected back into the subsurface to return to the water table. Before being re-injected into the water table, the fluid still at a high enough temperature can be fed into a circuit for heating

[78] „geothermal_energy_and_the_risks_related to_its_exploitation“, https://www.researchgate.net/publication/275951511_L, Last accessed in May 2022

buildings and greenhouses, thus making possible the 'cogeneration' of electricity and heat.

- **High temperature** (180° < T < 390°C). The sources in this temperature range are optimally suited to generating electrical energy with medium/large plants (10 MW-100 MW). The process is mainly based on separating the steam fed into the turbine from the residual water. The steam can be fed into a binary cycle to produce further electrical (and possibly thermal) energy and then fed back into the water table. The steam from the turbines can also be re-condensed, and the resulting liquid is fed into a further binary cycle for electrical and thermal co-generation before being re-injected into the water table. The combined steam and binary cycle plants, which provide for the total re-injection of the geothermal fluid, and, like the binary plants, allow the production of electricity with almost no environmental impact, as virtually no geothermal gas emissions into the atmosphere and negligible impact on the water table.

European facts and figures

Geothermal power generation in Europe in 2019 stands at about 2960 MWe[79] installed capacity. The installed capacity of geothermal heating from medium to low-temperature sources exceeds 10'600 MWt, of which about half is used in district heating[80]; the European geothermal electricity market remains heavily dominated by three countries: Turkey, Italy and Iceland.[81]

Pros and cons

As there is no combustion process, power plants do not emit CO2 or other forms of particulate matter. Geothermal energy is, therefore, an alternative and clean energy because it does not produce emissions. In addition, compared to other renewable sources (such as wind and solar power), geothermal energy has more electricity (for the same installed power).

[79] Megawatts electric or MWe is one of the two values assigned to a power plant, the other being megawatts thermal or MWt. Megawatts electric refers to the electricity output capability of the plant, and megawatts thermal refers to the input energy required.[2] Power plants are assigned two values as most are heat engines, and therefore can't turn 100% of their input energy into electricity.

[80] „Summary of EGC 2019 Country Update Reports on Geothermal Energy in Europe", http://europeangeothermalcongress.eu/wp-content/uploads/2019/07/CUR-00-Summary-Europe.pdf, Last accessed in May 2022

[81] European Geothermal Energy Council, „2019 EGEC GEOTHERMAL MARKET REPORT Key Findings", 2020

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The further advantage is that it is renewable in the long term: thanks to the recycling of the steam produced, all the production waste is put back into circulation, saving money. Finally, energy production is continuous, irrespective of weather conditions and alternating day and night.

However, there are disadvantages as it is very difficult to identify deposits. The deposits are often located at very great depths, from which it is not always possible to draw. The power stations also have a major aesthetic impact, often causing unpleasant odours.

2.7.2 Biomass-based power plants

Biomass is the organic matter generated by plants and animals specially treated to be used as biofuel in power plants. Firewood residues, waste from agri-food industry processing, urban organic waste, green branches from forestry and agricultural activities, marine algae and farm waste are the materials of organic-vegetable origin from which energy is produced. When burned, biomasses release heat and emit a quantity of carbon dioxide similar to that emitted in nature during an ordinary photosynthesis process.

History

Historically, the energy released by biomass has been used since the dawn of time. Before the use of fossil energies in significant quantities, it was biomass, in the form of firewood, which provided humanity with the power necessary for its livelihood. Only when humankind discovered the use of coal and other fossil sources the energy produced from biomass was reduced to a marginal role, and fossil fuels are now used for the production of about 80% of all energy used on the planet Earth[82]. However, the interest in biomass energy has been awakened by the problems of environmental and economic sustainability linked to the quantity of fossil fuel deposits available (such as oil, other hydrocarbons, and coal fields) and by geopolitical instability issues deriving from their uneven distribution on the planet.

How it works

Biomass farms produce electricity due to the steam generated by the combustion of agricultural, industrial, and urban waste. The materials are burned in a combustion chamber,

[82] EESI, https://www.eesi.org/topics/fossil-fuels/description#:~:text=Fossil%20fuels%E2%80%94including%20coal%2C%20oil,were%20compressed%20and%20heated%20underground., Last accessed in May 2022

creating the necessary temperature to transform the water of a thermodynamic circuit into steam. The steam rotates a turbine which drives the rotor of an alternator that produces an alternating electric current. The water vapour at the exit of the turbine is transformed into the water with a condenser. After that, it is sent to the storage tank.

Biomass plants work by of solid or liquid waste:

- **Solid biomass power plants** are traditional machines that work through a combustion oven that produces the necessary temperature to transform the water of the thermodynamic circuit into steam.
- **Liquid biomass power plants** use generators or engines coupled to generators and work with vegetable oils and biodiesel to produce renewable energy.

The combustion process, in all cases, takes place at temperatures no higher than 800 °C to allow the transformation of biomass, solid or liquid, into energy through heat.

The boiler powered by the process can ensure the heating of the surrounding environment thanks to the exploitation of thermal energy or produce steam to generate electricity by operating a turbine. Biomass plants can also operate with the anaerobic digestion of diversified substrates, from manure to organic residues; it is a fermentation and methanization process that transforms waste in air absence by bacteria which produce methane gas and digestate.

Pros and cons

Among renewable sources, biomass is an abundant and easily available resource that reduces dependence on fossil sources and does not affect global warming and the levels of greenhouse gases released into the atmosphere. In this case, energy production can be regulated and controlled simply by reducing or increasing the organic material in the combustion chamber. The process and the technology are not particularly complex and expensive, and the use of agricultural, industrial and urban waste minimizes the filling of rubbish dumps.

Biomass is currently considered one of the sources of domestic heating with the highest particulate emission, a substance believed to be responsible for a very high number of deaths from pollution.

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2.7.3 Wave/tidal power plants

Wave and tidal power plants exploit the movement of the water masses caused by the tides and the wave motion caused by the winds to produce electric energy.

History

The exploitation of wave energy has recently been experimented with in various European research projects in the energy field; particularly, if the wave motion is exploited for electricity production, the system is called cimoelectric.

The first to take advantage of this enormous source of energy offered by our planet were father and son Girard in 1799, the year in which the first patent was filed to draw energy from the movement of the waves[83].

How it works

Marine energy is one of the main forms of renewable energy. Convertible into electricity by the mechanical force of water movements, the energy produced by the sea comes in various forms. The most common are:

- Cimoelectric energy, produced by wave motion
- Thalassothermic energy, produced by the temperature variation between the sea surface and the depth
- Osmotic energy[84]obtained from the difference in the concentration of salt between seawater and freshwater
- Tidal energy is produced by the movement of water caused by the tides

There are two main ways to transform the moving waves and tides into energy:

- **Tidal power stations (barrier systems)** are based on the horizontal displacement of large bodies of water and can be built along rivers or in the open sea. The water is collected inside an artificial or natural basin during the high tide phase. During the low

[83] Conserve Energy Future, https://www.conserve-energy-future.com/waveenergy.php, Last accessed in May 2022

[84] also known as salt gradient energy

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tide, the water flows through a series of hydraulic pipes inside which there are turbines connected to the electric generators moved by the passage of water.

- **Hydro generators**: these are marine turbines floating both in shallow water, near the coast, and in deep water, anchored to the seabed, or in mid-water. These plants exploit the kinetic energy contained in the water current to produce electricity.

Pros and cons

Hydro generators plant has a much lower environmental impact than tidal power plants (barrier system). The energy of the wave motion is the most constant of the renewable ones: unlike the sun and the wind, the sea never stops. It is also the ”densest” because it is nothing more than the concentration of the energy produced by the wind. That, in turn, concentrates the energy produced by the sun heating the atmosphere. The average energy power of the waves is in the order of 2-3 kW per m2, four to five times the power obtainable with wind and up to twenty times that of photovoltaics; tidal turbines are 80% efficient, which is higher than solar or wind energy generators. An installation of hydro generators is in Italy, and it is the Kobold turbine in Messina.

Despite the enormous advantage of being renewable energy, tidal energy has some disadvantages to be taken into consideration: tidal energy is dependent on the tides, therefore on a natural phenomenon that occurs periodically at regular intervals (Intermittent energy), only in a few areas in the world is there a difference in water level sufficient to operate the tidal power stations (Hightide difference), in the case of plants located at the mouth of a river, the functionality of the plant may be affected by sediment deposition (river sedimentation) and artificial maritime works have an impact on the natural flow of water that can lead to coastal erosion and consequences on the natural habitat (erosion and landscape). The barrier systems have a very high cost and a very high environmental impact (some applications of this type in France, such as the Rance and Saint-Malo river power stations).

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3 Heavy Work Machines

3.1 DRIVERS OF CHANGE

In our previous desk research deliverables, D4.1[85] and D4.4[86] , we identified and analysed the Drivers of Change macro areas and their subcategories that affect the battery value chain. Heavy work machines are affected by the climate goals, regulations, and environmental challenges macro area and underneath it by CO2 reduction and electrification that partly work hand-in-hand. Another previously identified macro area is globalization and access to raw materials that influence some heavy work machine categories underneath it.

Additionally, we recommend addressing *economic and population growth* as drivers of changes in this context. **Table 4**

Table 4. The drivers of changes affecting heavy work machines

HEAVY WORK MACHINE CATEGORY	Reducing CO2 emissions	Electrification and green energy	Access to raw materials	*Growth, economic*	*Growth, population*
Mining equipment	X	X	X	*X*	*X*
Forestry	X	X	X	*X*	*X*
Cargo handling	X	X	X	*X*	*X*
Heavy construction equipment	X	X		*X*	*X*

The manufacturers of the work machines are at the forefront of the development of the new technology. The green transition is seen as a great possibility for industry, research and development and developing the competencies. As the Finland-based SIX Mobile Machines coalition states: we are talking about the greatest technological revolution in the industry's history.

Heavy work machines generate CO2 emissions and thus contribute to climate change. For example, the mining industry contributes 2-3 % of global CO2 emissions[87]. As another example, construction-related machines generate approximately 400 Mt of CO2 annually

[85] D4.1 - Desk research and data analysis for subsector ISIBA - Release 1, https://www.project-albatts.eu/Media/Publications/5/Publications_5_20201106_123821.pdf

[86] D4.4 - Desk Research and Data Analysis for sub-sector ISIBA – Release 2, https://www.project-albatts.eu/Media/Publications/23/Publications_23_20210920_83914.pdf

[87] https://www.prnewswire.com/news-releases/global-electric-mining-equipment-market-is-projected-to-reach-usd-11-7-billion-by-2030--growing-at-a-cagr-of-19-6-during-the-forecast-period---as-per-tersus-strategy-report-301481438.html, last accessed in June, 2022

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(1.1% of the global CO2 emissions). Thus, the biggest OEMs that manufacture construction machines and the suppliers have regarded the electrification of the powertrain as the technology that enables zero emissions.[88] This trend is existing also in other heavy work machine sectors. For example, at the recent Business Finland event, SLUSH had major Finnish mobile work machine manufacturers from different sectors addressing the electrification of mobile work machines in December 2021. It was recognised that the electrification of the work machines would transform the whole industry and value chains.[89]

The green energy legislation with emissions regulations will push operators into complying with new standards by buying new environmentally friendlier machines. Potentially, at the same time, those regulations make machines with a combustion engine less affordable due to the need to apply emission-controlling systems. At the same time, governments potentially drive the electrification of the heavy machine industry with incentives such as subsidies, which encourage more environmentally friendlier ways to operate.[90]

As estimated by Cargotec[91] (the parent company of Kalmar that produces cargo handling equipment), global growth, urbanisation, rising economic wealth, and productivity shape the development of the world economy. The world's population is currently approximately 8 billion and is estimated to reach nearly 10 billion by 2050. The share of the world's urban population is forecasted to grow from 55 per cent to almost 70 per cent at the same time. Along with that process, the global GDP per capita is predicted to grow by approximately five per cent annually from 2020–2025. Consequently, global and economic growth increase consumption, world trade and the need for cargo transportation. Urbanisation needs infrastructure development and construction, with logistical services enabling sustaining city environments. In cities with high population density, load handling solutions must be silent, safe and generate low emissions.

[88] Electric Construction Machines Vital for Greener Construction, https://www.idtechex.com/en/research-article/electric-construction-machines-vital-for-greener-construction/26187, Last accessed in June 2022
[89] Mobile machines electrification at SLUSH!, https://www.six.fi/post/mobile-machines-electrification-at-slush
[90] Key Factors Driving the Rise of Electric Equipment and Heavy Machinery, https://blog.marketresearch.com/the-future-of-electric-equipment-and-heavy-machinery, Last accessed in June
[91] Megatrends drive growth, https://www.cargotec.com/en/about-Cargotec/strategy/megatrends/, Last accessed in June

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The impact of the Ukraine-Russia war

One of the drivers of changes in this context, Access to raw materials, is clearly emphasized by the ongoing Ukraine-Russia conflict that began with the Russian invasion on the 24th of February. That is a significant disruption to the supply of raw materials.

The conflict has caused the prices of mineral commodities to rise in the global commodity markets (Figure 15).[92] In anticipation of shortages from Russia and Ukraine. Some companies have started to look for alternative sources.

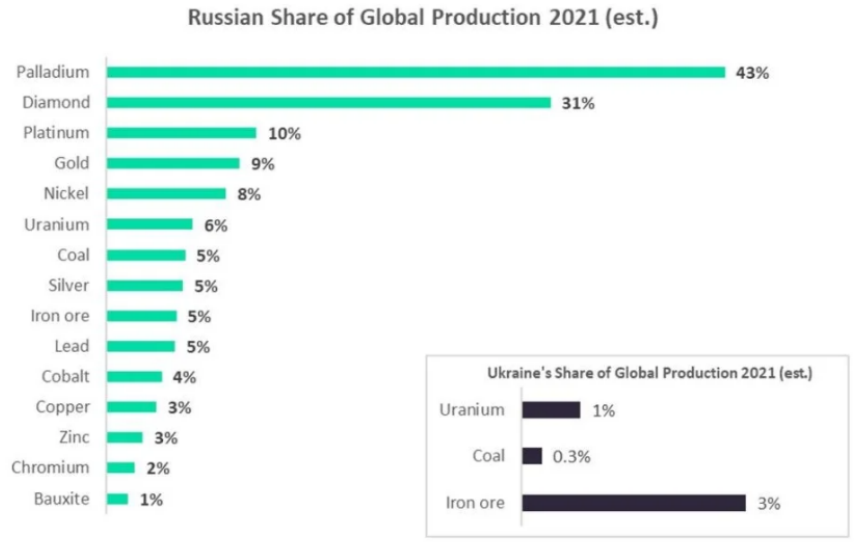

Figure 15. Russian Share of Global Production 2021 (est.)

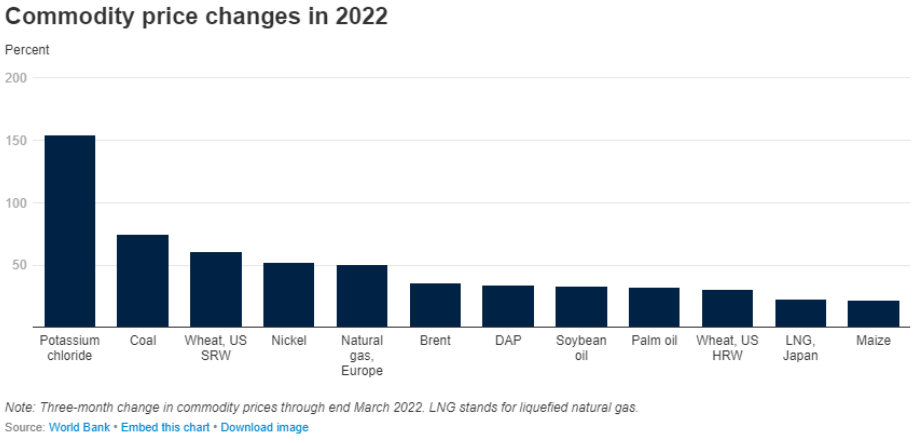

Figure 16. Commodity price changes in 2022 as a consequence of the Ukraine-Russia war

[92] Russian invasion of Ukraine: Potential impact on supply chains of mineral commodities, https://www.mining-technology.com/comment/supply-mineral-commodities/

Additionally, the crisis affects minerals and important commodities in general. Commodity price increases are expected to occur, as seen in Figure 16.[93]

It can be assumed that there will be implications to the heavy work machines business due to the Ukraine-Russia crisis, but what will those consequences be? It is difficult to forecast it, as when writing this, there were no clear forecasts and analyses of this side of the impact. The economic sanctions slapped on Russia by the West and like-minded countries in Asia and beyond are leading to the earlier mentioned situation in which companies need to search for alternative sources. In the case of minerals, for example, it can be speculated that this will increase demand in other areas (then Russia or Ukraine) which may lead to higher levels of investment into machinery used in production in different regions. In contrast, the exports of this machinery from the western and like-minded nations to Russia will go to zero due to the economic blockades.

3.2 INTRODUCTION TO HEAVY WORK MACHINES

Heavy work machines were chosen to be studied in this desk research based on their utmost importance to our present-day society and economy. Heavy work machines collect important raw materials such as minerals, timber, crops, etc., enabling the related logistics. They also construct buildings, bridges, roads, ports, and airports. Therefore, it can be stated that heavy work machines allow the way of life and the standard of living as we know it in Europe and beyond today. These systems enable the construction of our infrastructure, the technology we have access to and the food we have on our tables every day. At the same time, they contribute to the CO_2 emissions that endanger our planet's climate, thus making them an interesting target for electrification and batteries.

Currently, most large, heavy mobile machinery is powered by internal combustion engines. Their power systems and related designs have not seen many changes for decades. The eventual electrification of heavy machines, off-road mobile machinery aims to eliminate their emissions. [94]

[93] Commodity prices surge due to the war in Ukraine, https://blogs.worldbank.org/developmenttalk/commodity-prices-surge-due-war-ukraine last accessed on 7.7.2022

[94] https://www.tuni.fi/en/news/electrification-non-road-mobile-machinery-requires-comprehensive-planning-analysis-and last accessed on 7.7.2022

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While Work Package 4 focuses primarily on stationary battery applications, we considered that this area, with its potential electrification and consequent use of batteries, is too important to be left unstudied at this point. Work Package 5 already covers many other mobile solutions, excluding this one. The other factor is that we see heavy work machines as sort of a borderline area between stationary and mobile applications. While many of the heavy equipment do move to get to the location of operating, some of them do not move that much when they perform their work, and they are off-road systems. For example, forest machines and cranes stay put to a certain extent when they operate.

An increasing number of heavy machines, such as mining, construction and agriculture, are electrified. The number of companies offering these machines is rising, and the prices are decreasing. It is expected, however, that we will witness a more rapid shift to electrification beyond 2030.[95]

The advantages of the electrification of these machines are, for example[102]:

- Lower fuel costs
- Increased operator safety due to lower levels of harmful gases (if compared to ICE systems)
- Less noise that improves comfort
- Lower maintenance costs due to simplified design of electric and hybrid machines
- Reduced idle time means less wear and care to the engine that helps to extend the life of a machine, which is a major advantage over machines with ICE

Heavy work machines discussed in this research include:

- Mining equipment
- Forest machines
- Cargo Handling
- Heavy construction equipment

[95] Key Factors Driving the Rise of Electric Equipment and Heavy Machinery, https://blog.marketresearch.com/the-future-of-electric-equipment-and-heavy-machinery, last accessed in June 2022

3.3 MINING EQUIPMENT

3.3.1 Stakeholders

Market, figures and players

The 2022 metals and mining industry outlook is about rebounding prices.[96] After the world economy recovered from the Covid pandemic in the second half of 2020, the metals and mining sector began to benefit from rising demand for most metals resulting from returning consumer spending, government stimulus efforts and global energy transition. Due to the rising demand, it can be expected that the mining equipment providers will benefit from the situation as well. The global market size of the mining equipment market was USD 112.23 billion in 2020. The forecasted market growth is from USD 114.61 billion in 2021 to USD 151.25 billion in 2028. That would occur at a CAGR of 4 % in 2021-28.[97]

Mining, mining technology, and mining equipment continue to be important in the European region. As an industrial sector, the mining industry is among Europe's most modern and innovative. The European market for mining equipment is forecasted to experience growth by 2027, registering a CAGR of 4.51%. Manufacturers are becoming more and more interested in eco-friendly and energy-efficient machines. The mining equipment market includes the six main countries: Germany, the UK, France, Italy, Spain, and Russia. The increasing use of electric machinery, especially in underground mining, is regarded as a driver for the market.[98] The global electric mining equipment market is forecasted to reach USD 11.7 billion by 2030 by growing at a CAGR of 19.6 % during the forecast period.[99]

[96] https://www.spglobal.com/marketintelligence/en/news-insights/blog/the-big-picture-2022-metals-and-mining-industry-outlook, last accessed in June 2022
[97] https://www.fortunebusinessinsights.com/mining-equipment-market-104970, last accessed in June 2022
[98] https://www.marketsandmarkets.com/Market-Reports/mining-equipment-market-99264577.html, last accessed in June 2022
[99] https://www.prnewswire.com/news-releases/global-electric-mining-equipment-market-is-projected-to-reach-usd-11-7-billion-by-2030--growing-at-a-cagr-of-19-6-during-the-forecast-period---as-per-tersus-strategy-report-301481438.html, last accessed in June 2022

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Table 5. The Top Five World Mining Equipment Companies Listed by Market Cap[100][101]

Rank	Company	Headquarters Country	Market Cap
1	CATERPILLAR	USA	115.440 Billion USD[102]
2	EPIROC AB (PUBL)	Sweden	26.445 Billion USD[8]
3	KOMATSU	Japan	24.133 Billion USD[8]
4	OUTOTEC OYJ	Finland	1.185 Billion USD[103]
5	NORTH AMERICAN CONSTRUCTION GROUP	Canada	0.405 Billion USD[8]

Examples of manufacturers of electric mining machinery

- Epiroc, Sweden
  - BEV, zero-emission mining machines
    - electric underground loaders
    - small trucks
    - batteries as a service
- Artisan Vehicles (Sandvik Group), USA
  - Lithium battery-powered Load/Haul/Dump (LHD) underground mining vehicles
- Caterpillar, USA
  - Lithium battery-powered Load/Haul/Dump (LHD) underground mining vehicles
  - electric mining trucks
  - mobile equipment chargers
- Sandvik, Finland/Sweden
  - battery-powered drill rigs
  - electric trucks
  - electric loaders
  - battery swapping stations
- ABB, multinational
  - batteries, drives and motors for battery-electric equipment
  - charging systems

[100] World Top Mining Equipment Companies by Market Value 2022, last accessed in June 2022
[101] These companies operate in a number of different fields and not only in the mining equipment business.
[102] Market Cap (Sep-01-2021)
[103] Market Value (Jan 1st 2020)

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- Prairie Machine, Canada
  - battery-powered crew and utility trucks for surface and underground mining
- Mine Master Ltd, Poland
  - Battery electric roof bolters
  - Battery electric drill rigs
- Volvo Construction Equipment, Sweden
  - battery-electric load carriers
- Komatsu, Japan
  - electric mining trucks
- Metso Outotec
  - track-mounted crushers featuring electric drives
- Jama, Sweden
  - battery-powered underground rock scaling machines
- Battery Power Industries, South Africa
  - large scale Li-ion battery back solutions for the electrification of mining vehicles and systems
- MacLean Engineering & Marketing, Canada
  - battery-powered underground mining equipment
- RDH-Scharf, Canada
  - battery-powered haul trucks
  - battery-powered mobile work platform
  - battery-powered loaders
- ETF Equipment, Slovenia
  - electric, battery-powered surface haul trucks

3.3.2 Technologies

Methods of mining and the machinery

Mining can be categorized into two areas: **surface and underground mining**. Surface mining, including strip mining, open-pit mining, and mountaintop removal mining, is a large area of mining in which, above the deposit of minerals, soil and rock are removed. In underground

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mining, the overlying soil and rock are left in place. Shafts or tunnels are created through which the minerals are extracted. [104]

Mining machinery in general

The mining machinery includes systems that aid surface and underground mining activities. They include and can be categorized as follows[105]:

- Mining Machinery, By Category
  - Crushing, pulverizing, screening machinery
  - Mineral processing Backhoe Loader
  - Surface mining machinery (crawler excavators, crawler dozers, motor graders, rigid dump trucks, and articulated dump trucks)
  - Underground mining machinery (electric shovels, hydraulic excavators, wheeled loaders, mining dozers, mining trucks, and drills)
- Autonomous Mining Machinery, By Mining Category
  - Surface mining
  - Underground mining
- Electric Mining Machinery, By Type
  - Mining Truck
  - LHD (Load-Haul-Dump loader)
- Electric Mining Machinery, By Battery Type
  - Lithium-ion
  - Lead-acid
  - Others (lithium-ion phosphate, lithium titanite oxide, lithium manganese oxide, nickel-metal hydride, and solid-state battery)

Electric mining machinery

Many surface mines around the globe have driven the diesel mining machinery market by propulsion. Currently, mining companies are using diesel-operated machinery for surface

[104] https://www.marketwatch.com/press-release/global-surface-mining-equipment-market-forecast-2022-is-predicted-to-grow-at-a-cagr-of-34-top-countries-data-and-covid-19-impact-analysis-boosting-the-growth-worldwide-analysis-of-key-players-and-research-forecast-till-2026-2022-05-12, last accessed in June 2022

[105] https://www.marketsandmarkets.com/Market-Reports/mining-equipment-market-99264577.html, last accessed in June 2022

mining, while alternate fuel operated/hybrid machinery is predominant in underground mining. Industry experts expect that the electrification of underground mining machinery will be more probable if compared to surface mining machinery. That includes trucks, mining dozers and hydraulic excavators etc.[106] For example, when it comes to battery-powered electric vehicles, they are important in the context of cutting greenhouse emissions in mining sites. Diesel-powered vehicles generate 30-50 % of the greenhouse gases in mining locations. The dangerous fumes, which are generated by diesel machinery in the underground mining processes, are harmful to operators. Using battery-operated or electric mining machinery improves working conditions. They will become safer as a consequence of zero exhaust. Additionally, the operational costs will be lowered, and ventilation-related problems will be solved.

As an example of the benefits of applying batteries in underground loaders[107]:

- less heat
- high-energy-density batteries ensure continuous underground mining
- zero emissions and consequent reduction in the costs related to ventilation
- Battery-powered machines are very powerful – a battery-powered machine can have twice the power of the similar size diesel machine[108]
- Battery swapping systems enable quick battery replacements[24]
- the other benefits mentioned in chapter 4.2, Introduction to Heavy Work Machines

[106] https://www.marketsandmarkets.com/Market-Reports/mining-equipment-market-99264577.html, last accessed in June 2022
[107] https://www.marketsandmarkets.com/Market-Reports/mining-equipment-market-99264577.html, last accessed in June 2022
[108] Bird in The Mine – Technology development enabling electrification journey, Sandvik, https://youtu.be/JUyUSq3OG40, last accessed in June 2022

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Figure 17. An image of an underground electric loader, source Asset: Epiroc

Figure 18. Electric boomer, source: Asset: Epiroc

Equipment examples and descriptions[109]

Mining Drills

Drills are common examples of mining equipment. They are a vital part of underground mining operations. Drilling is needed to place explosives in the excavation process. Underground mining is conducted when the desired minerals are located deep underground, and they are required to be brought to the surface. The equipment used in underground mining includes trucks, loaders, diggers etc. They are used to extract minerals. The excavated material is transported to the surface for further processing. This hauling is conducted with skips or lifts.

[109] New to the Mining Industry? Make Sure You Know the Most Common Types of Mining Equipment, https://www.thermofisher.com/blog/mining/new-to-the-mining-industry-make-sure-you-know-the-most-common-types-of-mining-equipment/, last accessed in June 2022

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Earth Movers

Earth movers remove waste from the mining processes, enabling the excavators to collect the desired material or mineral. Above ground mining, these systems move loose soil and earth. They are essential in the mining industry, as they are designed to conduct major earth-moving and mining projects for a more efficient process.

Crushing Equipment

Crushing equipment is used for crushing rock and stone. Mining crushing equipment exists in a number of different types for a range of jobs. They are designed for maximum productivity. Crushing equipment breaks down the hard rock matter or gravel to a manageable size enabling appropriate transportation or conveying. They are valued equipment by the industry due to their ability to reduce the costs related to handling larger materials. They also ensure efficient extraction of interesting elements in the downstream processing.

Mining trucks[110]

Mining or haul trucks move dirt, minerals, metals, and other materials. They are used in both underground and surface mining operations. One of the biggest (at least the biggest when it was introduced) electric vehicles is a mining truck designed by the German manufacturer Kuhn Schweiz. The machine is a one-of-a-kind machine. The speciality of that machine is that it does not need recharging due to its regenerative braking system.[111]

3.3.3 Job roles and skills

During the process, we encountered, for example, the following job roles and skills related to mining equipment and batteries[112][113][114]:

- **Technical Specialist – Battery Technology**
  - develops technical competencies and provides quality technical support
  - technical training and support
  - feedback to factories to enable improvement

[110] https://www.marketsandmarkets.com/Market-Reports/mining-equipment-market-99264577.html, last accessed on July, last accessed in July 2022
[111] https://www.bigrentz.com/blog/electric-construction-equipment, last accessed on 12.8.2022
[112] https://www.home.sandvik/en/careers, last accessed in June 2022
[113] https://www.epirocgroup.com/en/careers, last accessed in May-June 2022
[114] https://artisanvehicles.com/careers/, last accessed in May-June 2022

- reviews spare parts recommendations and develop Machine Life Operating Costs (MLOC)
- Investigates and compiles data on warranty claims
- assists factories with field-testing and trials of new products
- performs equipment demonstrations in a safe manner
- assists in the training of distributors

- **Driveline system engineer, Battery electric vehicles**
  - experience of electric drive lines and batteries, for example, in mobile machinery, trains, cars, trucks
  - design or control an electric distribution or transmission power system, optimizing its components
  - understanding how to develop, design and control a driveline
  - knowledge of system design
- **Electrical Engineer**
  - analyse the field problem reports and develop solutions to rectify the problem
  - participates in a cross-functional team to develop new products
  - prepares Bills of Material (BOM) and provide purchasing department with specifications for ordering electrical components
  - ensures product compliance with design formation during installation and testing as well as delivery requirements
  - maintains engineering documentation
  - working knowledge of large batteries, 700 VDC including power transfer, filters, low voltage power conversion, and safety concerns
- **Electro-Mechanical Engineer**
  - electro-mechanical systems for large-scale battery-electric mining vehicles
  - support development of High Voltage (HV) systems and/or subsystems for electric vehicles, batteries, battery chargers and test equipment
  - Coordinate build and testing of prototypes for electric vehicles, batteries, battery chargers and test equipment
  - experience with development and design of high voltage or power electronics
  - Strong knowledge of electrical & electronic design principles

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- Strong understanding of vehicle systems, including HV battery management system preferred
- Experience in analysis, testing, troubleshooting, diagnostics and root cause analysis of electromechanical systems
- Basic power electronics circuit design and analysis preferred

- **Electrification Applications Engineer**
  - supporting customers in fleet and grid optimization:
    - How much energy will my electric fleet consume
    - What's the net increase in energy use considering ventilation savings
    - What will the total cost of ownership be compared to a diesel fleet
    - Optimal configuration of underground battery swap and service space
    - PROs and CONs: battery swapping vs. fast charging vs. trolley solutions
  - functions as a liaison between equipment Engineering, Business Development, local Applications Engineers, and Customers
  - global in-house expert in underground mining electrification techniques and the application of electric trucks and loaders in real-world environments
  - providing technical expertise and robust communication in sales processes
  - Develop strategies for deploying BHEV to customer projects
  - Responding to technical questions regarding the application of BHEV
- **Mechanical Engineer**
  - designs, analyses and troubleshoots mechanical and electromechanical products and systems by developing specifications and methods from concept to manufacturing release
  - Strong knowledge of mobile vehicle systems including powertrain control & battery management systems, electronic design, analogue circuit design, electromechanical design, high-speed digital circuits
- **Sr. Systems Engineer (Wiring), Manufacturing Engineer, Manufacturing Product Engineer and Mechanical, Electro-Mechanical Engineer**
  - In these positions solid background in-vehicle systems development including powertrain control & battery management systems is needed
- **Parts Release Engineer**

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- Locate parts required by Parts and Service Support Team to repair machines, batteries and chargers when the parts are not easily identifiable
- Identify additional parts anticipated to be required by reviewing each system in the machine and battery

- **Mining Applications Engineer**
  - The Mining Applications Engineer's function is to support the Global Sales Teams relative to BEV trucks and LHDs
  - develop the battery electric applications engineering function/department including the establishment of tailored processes, ways of working and commercial tools
  - Support global sales teams with battery electric studies for mines
- **Factory Product Specialist**
  - repair direction & training: technicians and machine operators
  - support to customer fleets of all Battery Electric Equipment and Assets, new units coming to the market and support trials.
    - Assists with remote diagnosis and repair guidance.
    - Co-develops training materials, case studies, Engineering Change Requests, and creation of service documents.
  - Plan Battery Charge Bay infrastructure with mine sites
- **System Integration Engineer**
  - responsible for the documentation, integration and validation of features, subsystems and functionality for electric vehicles and various supporting tools
  - validation of components, subsystems and control algorithms involved in vehicle controls, battery management systems and powertrain controls
- **Technical Support Engineer**
  - analyses and troubleshoots mechanical and electromechanical products and systems by developing and testing specifications and methods from concept to manufacturing release
  - responsible for multiple commodities, including battery systems, batteries, high voltage, charging systems, powertrains, heavy-duty mobile equipment and raw materials

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- knowledge of mobile vehicle systems including powertrain control & battery management systems, electronic design, analogue circuit design, electro-mechanical design, high-speed digital circuits

- **Field Trainer & Senior Product Master**
  - a member of an Aftermarket Support Team, and responsible for ensuring assigned mine sites are trained and equipped to support Artisan machines
  - assists technicians remotely to sustain proper operation of all machines, chargers and batteries. Provides remote diagnosis and repair guidance
  - co-develops training materials, case studies, Engineering Change Requests, and creation of service documents
  - Plan Battery Charge Bay infrastructure with mine sites

3.4 FOREST MACHINES

3.4.1 Stakeholders

Market, figures and players

The forest machine market is expected to grow due to increasing interest in forest preservation and management in many developed and developing countries. Additionally, the shift from manual work to operations supported by mechanized and automated machinery is expected to boost the demand for forest machines in 2020-30. [115]

The rapid growth of the demand for wood and wood-based products is increasing the demand for forest machines. Europe is the number one forest machine market and the fastest growing. And it is expected to remain in that position within the foreseeable future. The common agricultural policy (CAP) provided to rural areas, and the EU countries' measures to encourage forestry activities with the help of national development programmes continue to uphold forest machine sales in the region. Additionally, increasing worldwide demand for food has boosted farming. That has led to the conversion of forests into farmland.[116]

[115] https://www.factmr.com/report/3732/forestry-machinery-market, last accessed in June 2022
[116] https://www.mordorintelligence.com/industry-reports/forestry-machinery-market, last accessed in June 2022

The global forest machine market size was USD 9.2 billion in 2019. It is estimated to grow at a CAGR of 4.0% between the period 2020-2027.[117]

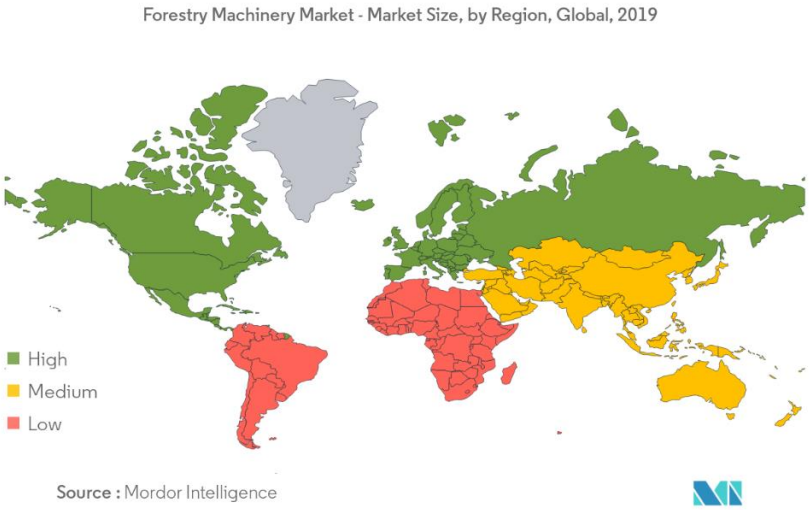

Figure 19. Forestry Machinery Market - Market Size, by Region, Global, 2019

The biggest companies in the forest machine market[118][119]:

- Hitachi Construction Machinery Co. Ltd., Japan, Market Cap 4.514 Billion USD[120]
- Deere Construction & Forestry (Deere & Company), USA, 1.095 Billion USD[6]
- Epiroc AB, Sweden, Market Cap 26.445 Billion USD[121]
- Komatsu Ltd., Japan, Market Cap 24.133 Billion USD[6]
- Sandvik AB, Sweden, Market Cap 22.340 Billion USD[6]
- LiebherrInternational AG, *Turnover 11,908* Million USD[122]
- Volvo Construction Equipment (Volvo AB), Sweden, Market Cap 36.892 Billion USD[123]

Examples of manufacturers of purely electric machines are hard to find, with desk research potentially indicating that the electrification of forest machines remains in its early prototype

[117] https://www.grandviewresearch.com/industry-analysis/forestry-equipment-market, last accessed in June 2022
[118] https://www.grandviewresearch.com/industry-analysis/forestry-equipment-market, last accessed in June 2022
[119] These companies operate in a number of different fields such as mining and not only in the forest equipment business.
[120] Yahoo Finance - Stock Market Live, Quotes, Business & Finance News, last accessed on 5.8.2022
[121] World Top Mining Equipment Companies List by Market Cap as on Jan 7th, 2022, World Top Mining Equipment Companies by Market Value 2022
[122] https://www.liebherr.com/en/nzl/about-liebherr/company-profile/dates-facts/facts-and-figures.html, last accessed on 5.8.2022 (market cap not found, turnover used instead)
[123] https://markets.ft.com/data/equities/tearsheet/profile?s=VOLV%20B:STO, last accessed on 5.8.2022

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stage, but there are a number of hybrid system manufacturers. For example, the following companies have provided hybrid systems[124]:

- Logset Oy, Finland: hybrid harvesters
- Agama a.s., Czech Republic: hybrid harvesters, wood trailers
- ProSilva Oyj, Finland: hybrid harvesters
- Koller GmbH, Germany: hybrid excavators
- Komatsu, Japan: hybrid excavators
- New Holland, USA: hybrid excavators
- Hitachi Ltd., Japan: hybrid excavators
- Elforest AB, Sweden: hybrid forwarder
- Rong-Feng, Taiwan: hybrid harvesters
- Kesla Oyj, Finland: woodchipper
- Edilog, Sweden: hybrid log stackers

3.4.2 Technologies

Methods and forestry machinery in general[125]

Foresters and loggers need different tools and equipment to conduct the process of cutting and processing trees. Some of them are briefly described here. **Forwarders and skidders** (a forwarder carry logs while a skidder drags them[126]) move felled logs to a roadside landing. **Harvesters** are self-propelled machines, wheeled or tracked, used to cut trees with a cutting head. They can do both, felling trees and further processing. These systems function well when used together with forwarders and self-loading trucks. **Log loaders** of various kinds are used to sort and stack logs into piles. When the piles are big enough, they are moved onto transport trucks by loaders.

[124] Technical Solutions of Forest Machine Hybridization, Václav Mergl, Zdravko Pandur, Jan Klepárník, Hrvoje Kopseak, Marin and Marijan Šušnjar, May 13 2021, https://www.researchgate.net/publication/351562407_Technical_Solutions_of_Forest_Machine_Hybridization
[125] https://www.forestryequipmentguide.com/article/43277-overview-of-forestry-equipment, last accessed 7.7.2022
[126] https://www.petestirestore.com/Four-Types-of-Forestry-Equipment_b_75.html, last accessed 7.7.2022

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Future electrification of the forest machines[127][128][129][130]

As stated earlier, with fully electric forest machines, we concluded that there are possibly not many, if any, out there in the market yet. Electrification is a trend with heavy work machines in general. Thus we can speculate that there is potentially electric, battery etc. powered forest machines in the drawing boards and prototype stage, but not much information is publicly available yet. However, there are known research projects aiming at the electrification of these and other heavy machines, such as the ones undertaken in Finland by researchers at Tampere University and LUT University, as well as the Sustainable Industry X initiative and in Sweden by RISE (Research Institutes of Sweden).

The potential lack of electric forest machines in the market may be related to the challenges faced by the electrification of these machines, as described by Sweden-based Regal Components AB. Forest machines operate in remote areas, often off-grid, with limited or no access to charging infrastructure. The downtime due to charging is not acceptable. At the same time, duty cycles, long operating hours and seasonal use are obstacles to the electrification of forest machines. The battery costs are high. Additionally, some of these machines are very specialized, which means using them for a particular task only or for a limited time. Thus the low utilisation rate emphasizes the cost of battery electric systems profoundly.

A modular battery swap system[10][131] could solve the issues mentioned earlier. It would increase efficiency by reducing downtime as a used battery is replaced with a charged one. Potentially they could be shared among different machinery, enabling using the charged ones in the machines in operation. Additionally, a possible rental model could be a solution to seasonal use issues.

[127] https://www.tuni.fi/en/news/electrification-non-road-mobile-machinery-requires-comprehensive-planning-analysis-and last accessed on 7.7.2022
[128] https://www.six.fi/mobile-work-machines last accessed on 7.7.2022
[129] https://regal.se/insights/electric-forestry-and-agricultural-machinery/ last accessed on 7.7.2022
[130] https://www.forestry.com/editorial/malwa-its-electrifying/ last accessed on 10.7.2022
[131] https://www.ri.se/en/what-we-do/projects/modular-battery-swap-system-as-an-enabler-for-fossilfree-mobile-work-machines last accessed on 7.7.2022

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Electric forest machine prototypes and concepts

Malva Forest AB, Sweden[132][133][134]

Malwa Forest AB introduced a prototype of the world's first 100 % electric forest machine. It's a combi machine harvester and forwarder based on a production model, Malwa 560 C. The machine has two electric motors powered by two batteries, 30 kWh and 11 kWh. The bigger one can be easily replaced. An operator can switch from an empty one to a fully charged battery in less than a minute—the purpose of the small battery to the crane when the big one is not connected.

Figure 20. Pictured Malwa 560C Combi, on which the electric prototype is based. Source: Malwa Forest AB

The prototype has been developed in a research project related to an initiative of RISE (Research Institutes of Sweden). According to Malwa, a commercial version of the machine will not be available until later in the future. The next step is to test and compare its performance with a diesel-powered counterpart. The comparison will also include energy consumption. Currently (in June 2022), the system can operate with a single battery charge for around 2 hours. According to the manufacturer, there will be no compromises done with the Electric Combi on the performance. Regarding hydraulics and traction, the efficiency will remain the same as with the traditional diesel-powered machines. The system can be seen, and its low noise level is heard in action on YouTube: https://www.youtube.com/watch?v=Ar_Z4NECOss.

[132] https://www.lesprom.com/en/news/New_100_electric_logging_machine_of_Malwa_Forest_operates_for_two_hours_on_single_charge_103491/ last accessed on 10.7.2022
[133] https://www.youtube.com/watch?v=IBIH2bj2I74 last accessed on 10.7.2022
[134] https://www.forestry.com/editorial/malwa-its-electrifying/ last accessed on 10.7.2022

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Ponsse Plc and EPEC, Finland[135]

Also, Ponsse and EPEC have recently introduced a Ponsse EV1, an electric forest machine concept (August 2022). It will be available for customers later. The concept has been developed for forwarders with a load-carrying capacity of 15 tons. A fully electric powertrain, EPEC's power distribution unit and a hybrid control unit are featured in the machine. Batteries power the powertrain.

Figure 21. Pictured Ponsse EV1. Source: Ponsse Plc

Hybrid forest machines

Several machine manufacturers have already introduced electro-hybrid systems such as 12H GTE HYBRID by Finland-based Logset (Figure 22), as listed on page 83. The applied accumulator types include various batteries and supercapacitors (Table 6).[136]

[135] https://www.ponsse.com/en/web/guest/company/news/-/asset_publisher/P4s3zYhpxHUQ/content/ponsse-launches-new-technology-an-electric-forest-machine#/, last accessed on 18.8.2022

[136] Technical Solutions of Forest Machine Hybridization, Václav Mergl, Zdravko Pandur, Jan Klepárník, Hrvoje Kopseak, Marin and Marijan Šušnjar, May 13 2021, https://www.researchgate.net/publication/351562407_Technical_Solutions_of_Forest_Machine_Hybridization

Figure 22. A harvester, LOGSET 12H GTE HYBRID. Source: Logset

The hybrid forest machines described later in this chapter can help solve such challenges as fuel consumption reduction (thus decreasing harvesting costs) and decreasing emissions. It has been calculated that electro-hybrid solutions can reduce fuel costs from 10 to 50 %.[137] For example, the electro-hybrid machine by Logset Oy generates a fuel economy reduction of 25 %. Logset's systems use supercapacitors instead of batteries.[138]

The most common drivers of hybrid drive applications in forest machines are, for example

- low emissions and noise,
- high performance,
- fuel efficiency,
- regulations (emission standards for non-road diesel engines: EU and US EPA with continuous restriction), and
- public image.

Two types of electric hybrid systems are applied: electro-hybrid and electro-hydraulic hybrid. The latter system combines an electro-hybrid system with a hydraulic hybrid system. Figure 23 describes the hybrid drives.[139]

[137] Technical Solutions of Forest Machine Hybridization, Václav Mergl, Zdravko Pandur, Jan Klepárník, Hrvoje Kopseak, Marin and Marijan Šušnjar, May 13 2021, https://www.researchgate.net/publication/351562407_Technical_Solutions_of_Forest_Machine_Hybridization
[138] https://www.forestry.com/editorial/logset-12h-gte-electric-hybrid-harvester/ last accessed on 7.7.2022
[139] Technical Solutions of Forest Machine Hybridization, Václav Mergl, Zdravko Pandur, Jan Klepárník, Hrvoje Kopseak, Marin and Marijan Šušnjar, May 13 2021, https://www.researchgate.net/publication/351562407_Technical_Solutions_of_Forest_Machine_Hybridization

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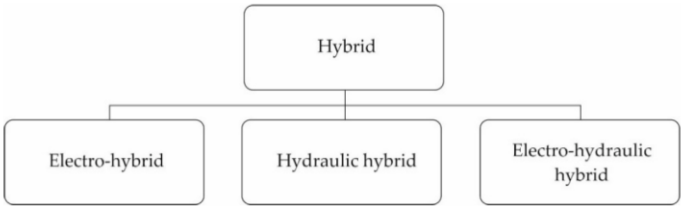

Figure 23. Hybrid drive classification[140]

Hybrid drives of such forest machines as **harvesters, forwarders, and skidders**, are based on technologies that have origins in the automotive industry. So-called "engine downsizing" is applied in this context: emissions are reduced by scaling down engine sizes. Regarding this, the most used hybrid drive design involves electricity to boost the power of a smaller engine. This kind of mechanism is applied, for example, in harvesters. The hybridization of this kind, its configuration variations illustrated in **Figure 24**, is referred to as the electro-hybrid drive. The electro-hybrid drive consists of an electrical storage device, an electric motor, a generator, and an inverter. The first electro-hybrid harvester, 12H GTE HYBRID (**Figure 22**), was introduced to the market by Finland-based manufacturer Logset Oy. [141]

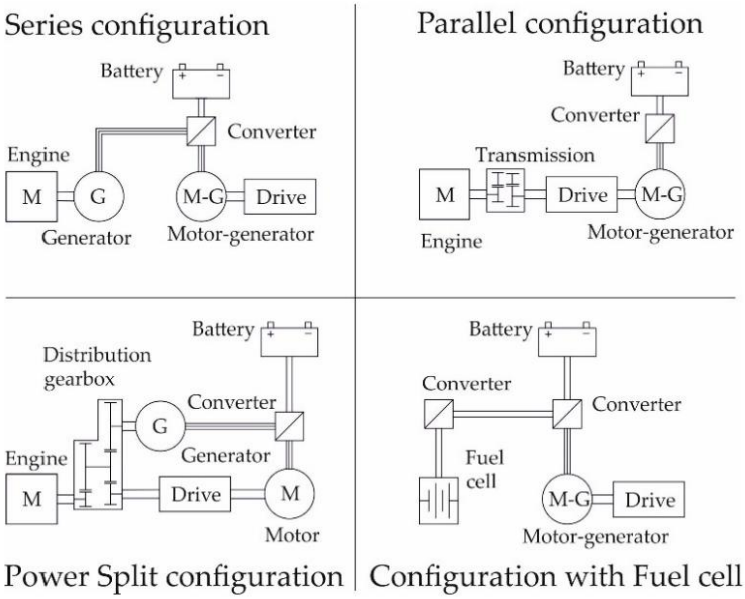

Figure 24. Types of electro-hybrid drive arrangement. Source: Technical Solutions of Forest Machine Hybridization

As explained earlier, another possibility is that we can also encounter electro-hydraulic hybrids, illustrated in Figure **25**, in the future.

[140] https://www.forestry.com/editorial/logset-12h-gte-electric-hybrid-harvester/ last accessed on 7.7.2022
[141] Technical Solutions of Forest Machine Hybridization, Václav Mergl, Zdravko Pandur, Jan Klepárník, Hrvoje Kopseak, Marin and Marijan Šušnjar, May 13 2021, https://www.researchgate.net/publication/351562407_Technical_Solutions_of_Forest_Machine_Hybridization

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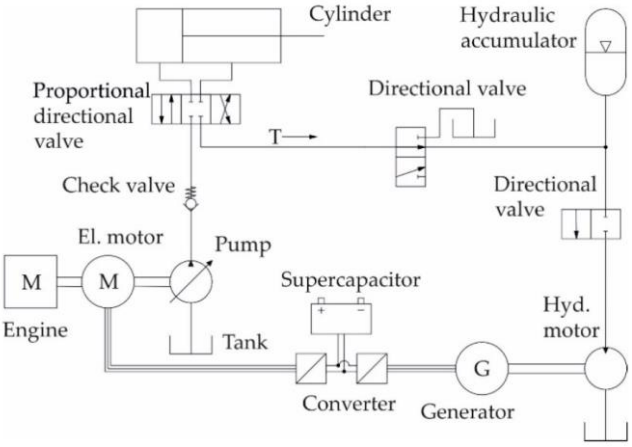

Figure 25. An example of an electro-hydraulic hybrid[142]

Table 6 lists further information about the characteristics of various machines from different manufacturers. There are **benefits** such as low fuel consumption and lower emissions as well as **weaknesses** such as the high purchasing price and more demanding maintenance of hybrid machines. Table 7 describes the pros and cons of the hybrid technologies further.

Table 6. Characteristics of hybrid forest machines[143]

Type of Hybridization	Machine Type	Fuel Consumption Reduction [%]	CO_2 Emission Reduction [%]	Power of Combustion Engine [kW]	Power of Hybrid System [kW]	Accumulator Type/Capacity
Electro-hybrid	8H GTE Hybrid by Logset Oy (harvester)	up to 25	15–30	214	104	Supercapacitor/-
	12H GTE Hybrid by Logset Oy (harvester)	up to 25	15–30	214	175	Supercapacitor/-
	Harvester by Agama a.s. (harvester)	-	-	-	23	Battery/82 Ah, 12 V
	910EH by ProSilva Oyj (harvester)	40	-	60 *	60 (2 el. motors)	Battery/-
	KX 800e by Koller GmBH (excavator based yarder)	-	-	212	800 per winch	Supercapacitor/-
	HB365 By Komatsu (excavator)	20 (average)	20 (average)	202	-	Supercapacitor/-
	E70 by New Holland (excavator)	40	40	27 **	20	Li-on battery/288 V
	ZH210LC by Hitachi Ltd. (excavator)	around 20	around 20	122	-	Double-layer supercapacitor/-
	F14 by Elforest AB (forwarder)	20–50	-	60	30 per wheel	Battery/84 V
	Harvester by Rong-Feng [24] (harvester)	-	-	60	60 per bogie axle	Li-on battery/105 kW
	AGA LV 10 HP by Agama a.s. (wood trailer)	35	-	97	18	Li-on battery/16 kWh
	C 860 H by Kesla Oyj (wood chipper)	20–35	20–35	160	-	Supercapacitor/-
Hydraulic hybrid	Caribou S10 by Ponsse Plc. (forwarder) ***	28	-	91	-	Hydraulic accumulator/20 L
	Caribou S10 by Ponsse Plc. (forwarder) ****	36	-	91	-	Two hydraulic accumulator/10 L × 2
	FORWARDER 2020—HSM 208F 12t by HSM forest (forwarder)	30	-	185	-	Two hydraulic accumulators/-
	HSM 405H2 by HSM forest (harvester)	20	-	205	90	Hydraulic accumulator/60 L
	Ergo by Ponsse Plc. (harvester)	-	-	210	71	Hydraulic accumulator/50 L

* Engine downsizing from 155 kW to 60 kW. ** Engine downsizing from 40 kW to 27 kW. *** Hybrid without a pump–motor with logic valves. **** Hybrid with multi-pressure system.

[142] Technical Solutions of Forest Machine Hybridization, Václav Mergl, Zdravko Pandur, Jan Klepárník, Hrvoje Kopseak, Marin and Marijan Šušnjar, May 13 2021, https://www.researchgate.net/publication/351562407_Technical_Solutions_of_Forest_Machine_Hybridization

[143] Technical Solutions of Forest Machine Hybridization, Václav Mergl, Zdravko Pandur, Jan Klepárník, Hrvoje Kopseak, Marin and Marijan Šušnjar, May 13 2021, https://www.researchgate.net/publication/351562407_Technical_Solutions_of_Forest_Machine_Hybridization

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Table 7. Strengths and weaknesses of hybrid machines in forestry[144]

Strengths	Weaknesses
Lower fuel consumption	Purchase price (30–50% higher than conventional)
Better ergonomics (less noise, vibration, and exhaust emission)	Electrical storage
Smooth variable continuous power to wheels, drums, hydraulic pump, etc.	Heavier and more complex systems
Environmentally friendly operating (less GHG * and PM ** emissions)	Low energy density of battery and supercapacitor
Easier operating (automated or remote operation control)	Overheating of energy storage devices
Lower physical workload	More demanding maintenance
Lighter machines	Life cycle of battery and supercapacitor
Improved energy storage technology (smaller, lighter batteries, supercapacitors, and hydraulic accumulators with higher energy density)	Increase in battery and supercapacitor price
	Shortage of raw materials for battery and supercapacitor production
	Environmental impacts for production and disposal (recycling) of batteries, supercapacitors
Better efficiency of propulsion motors	Potential hazard of fluid leakage to environment
Shortage of fossil fuels	

* GHG—greenhouse gas. ** PM—particulate matter.

3.4.3 Job roles and skills

The job roles and some of the skills identified[145] in the process are listed below. Due to the current status of the electrification of the forest machines, as explained earlier, they could not be found plentifully yet. Since they resemble other heavy machines, we can speculate that forest machines will likely need similar job roles with similar skill requirements.

- **Application Engineer**
  - Battery sizing and selection
  - battery cooling systems
  - charging systems
- **Design Engineer - Battery Technology**
  - Battery Systems Development (as described below)
  - Define validation requirements for battery systems
  - plan tests requiring innovative approaches
  - review results for design compliance
  - oversee engineering evaluations of battery systems
  - battery cell chemistry evaluation and selection
  - Plan innovative changes to existing designs or conceptual thinking to new designs

[144] Technical Solutions of Forest Machine Hybridization, Václav Mergl, Zdravko Pandur, Jan Klepárník, Hrvoje Kopseak, Marin and Marijan Šušnjar, May 13 2021, https://www.researchgate.net/publication/351562407_Technical_Solutions_of_Forest_Machine_Hybridization
[145] Indeed, www.indeed.com, last accessed on June 2022

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- Recognize and document new intellectual property that differentiates manufacturer's products (from competition)
- Provide technical expertise and direction related to battery standards and regulations
- Provide specifications and analysis for battery thermal management systems (BTMS)
- Develop and maintain understanding of the battery management systems (BMS), including necessary operational analysis.

- **Shop Mechanic, Shop Service Technician, Field Technician**
  - recharging batteries when repairing and maintaining electric equipment
- **Shop Service Technician, Field Technician**
  - replacing and recharging batteries when repairing and maintaining electric equipment
- **Motor Pool Technician**
  - working on and operations of battery-powered equipment and vehicles
  - experience with battery chargers

3.5 CARGO HANDLING

3.5.1 Stakeholders

Cargo handling equipment (CHE) plays an important role in port operations, distribution centres and heavy industry, the economy, and air quality. Cargo handling, especially at ports with a lot of activity, is a significant area to use Li-ion batteries and achieve the carbon-neutral demands in Europe[146].

The CHE sector encompasses a wide variety of equipment types such as yard tractors, electric forklifts, and cranes used for moving cargo around a port or other freight terminal and on and off marine vessels, railcars, and trucks[147]. In this Desk Research, 3the main target is to write about Li-ion battery-driven cranes, electric empty container handlers/ masted container handlers, electric heavy forklift trucks, electric reachstacker, terminal tractors and shuttle/straddle carriers.

The charging infrastructure needs to be planned well at the harbour to support battery-operated machines and charging stations and minimize peak power consumption[148].

[146] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en last accessed on 7.7.2022

[147] https://www.epa.gov/ports-initiative/cargo-handling-equipment-che-best-practices-improve-air-quality last accessed on 6.7.2022

[148] https://www.kalmarglobal.com/491467/globalassets/media/216119/216119_FastCharge-WP-2019-WEB.pdf, last accessed on 6.7.2022

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The global market size of cargo handling equipment brands handling mobility of goods was assessed in Market Report at USD 22.6084 billion in 2020 and is expected to increase at a CAGR of 3.04 per cent from 2021 to 2028, to reach USD 27.4474 billion by 2028[149].

Companies

The cargo handling equipment market is dominated by a few globally established companies such as Kalmar (Finland), Konecranes (Finland), Liebherr (Switzerland), Hyster (US), Sany (China), ZPMC (China), Lonking (China), Anhui Heli (China), CVS Ferrari (Italy), and Hoist Liftruck (US). The first two companies use lithium-ion batteries in their equipment, and trucks are not considered cargo handling equipment in this DR3.

Table 8. The Cargo handling equipment companies, Source: Publisher in 2018

Rank	Company	Country	Equipment with Li-ion batteries
1	Kalmar	Finland	x
2	Konecranes	Finland	x
3	Liebherr	Switzerland	(x)
4	Hyster Hyster-Yale Materials Handling	USA	
5	Sany	China	
6	ZPMC	China	
7	Lonking	China	
8	Anhui Heli	China	
9	CVS Ferrari	Italy	
10	Hois Liftruck	USA	

Kalmar

Cargotec's Kalmar business area started in 1997 when Partek Corporation acquired the Finnish state-owned Sisu Ltd[150]. The business activities of Sisu focused on container handling, heavy lift trucks and terminal tractors.

[149] https://www.verifiedmarketresearch.com/blog/top-five-cargo-equipment-brands/, last accessed on 6.7.2022
[150] https://www.cargotec.com/en/about-Cargotec/our-story-and-history/kalmar/ last accessed on 7.7.2022

The Technology and Competence Centre in Tampere, Finland, was inaugurated in 2012. The centre focuses on developing energy-efficient, safe, and intelligent machinery and automation solutions.

Cargotec's Rainbow-Cargotec Industries Co Ltd (RCI), a joint venture established in China, became ready in 2012. RCI produces rubber-tyred gantry cranes (RTGs) and quay cranes.

In December 2021, Kalmar delivered a fully electric portfolio by launching three electrically powered solutions – the Kalmar Electric Reachstacker, the Kalmar Electric Heavy Forklift and the Kalmar Ottawa Electric Terminal Tractor.

Cargotec's business areas, Kalmar, Hiab and MacGregor, offer products and services. Kalmar's offering comprises industry-shaping, sustainable cargo handling equipment, automated terminal solutions, software, and services. These are used in ports, terminals, distribution centres and various industries. Kalmar's product range includes ship-to-shore cranes, rubber-tyred and rail-mounted gantry cranes, straddle and shuttle carriers, reachstackers, empty container handlers, terminal tractors, forklift trucks and automated guided vehicles. Kalmar's offering also covers maintenance contracts, technical support, spare parts, training, and crane upgrades.

Battery storage

Solar panels can produce additional renewable energy at the port or terminal power station. If production exceeds consumption during sunlight hours, energy can be stored in battery packs, which can be drawn when green electricity is unavailable from the grid. When the system is designed as a complete infrastructure, the result is a sustainable electric energy value chain that encompasses everything from renewable power sources to on-site charging management and even Li-ion battery recycling.[151]

Today, the potential power options for container and cargo handling equipment range from conventional diesel, biodiesel and compressed natural gas (CNG) to emerging fuels such as Hydrotreated Vegetable Oil (HV100) and hydrogen, all the way to fully electric equipment.

[151] https://www.kalmarglobal.com/news--insights/articles/2021/20211125_towards-eco-efficient-cargo-handling-operations-part-2-creating-an-infrastructure-strategy/ last acessed on 4.7.2022

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Kalmar has made an eco-efficiency step to achieve cargo handling operations with electric-powered equipment. A key decision is to choose the best power options for future cargo handling equipment while using renewable energy whenever possible.

- *Create a vision and targets, a roadmap and identify the gap between the current and target state*
- *Infrastructure and charging strategy, availability of energy sources, costs, sustainability of energy supply chain*
- *Eco-efficient solutions, local regulations, availability of maturity of solutions, operational requirements*
- *Operational scenarios and business case, future, determine the optimal fleet, TCO and ROI calculation*
- *Implementing and optimization, driver training, proactive data-driven maintenance, monitoring progress towards the target state*

Konecranes

Konecranes is one of a world-leading group of Lifting Businesses™, serving a broad range of customers, including manufacturing and process industries, shipyards, ports, and terminals. Konecranes provides lifting solutions and services for lifting equipment of all makes. In 2021, Group sales totalled EUR 3.2 billion. The Group has around 16,600 employees in 50 countries. Konecranes was established in 1973, roots in 1883. Konecranes Port solutions achieved an order intake of EUR 1. 112.7 million for 2021[152] and personnel 4 876 2021.

Konecranes business is divided into three Business Areas - Service, Industrial Equipment and Port Solutions - each contributing approximately one-third of Group sales. The Group's brand strategy is based on the corporate Konecranes master brand, complemented by the Demag and MHE-Demag brands and a portfolio of freestanding power brands, including R&M, SWF Krantechnik, Verlinde and Donati. On top of that, TBA Group is also part of the Konecranes Group's brand portfolio.

Konecranes Service offers maintenance services and spare parts for all types and makes of industrial cranes and hoists. Konecranes Industrial Equipment provides an extensive range of

[152] https://investors.konecranes.com/sites/default/files/AR2021/annual_review_2021.pdf last accessed on 16.8.2022

industrial cranes, from components and light duty applications to demanding process use and solutions. Konecranes Port Solutions includes equipment, software and service for the container handling industry.

Konecranes is offering a battery-driven RTG as part of Ecolifting. In some countries, state subsidies can be won for purchasing hybrid or battery RTGs: the political climate favours port decarbonization[153]. The Konecranes B-RTG works either with a charging station or with a manual plug-in to the mains for charging. That will depend on the particular work processes of the customers' container terminal. Fully electric RTGs powered via busbar or cable reel systems require yard infrastructure adjustments that are not feasible for all container terminal operators.

Konecranes has battery-driven container handling machines: the Konecranes Battery RTG, the Battery Konecranes Noell Straddle Carrier, and all-electric Konecranes Gottwald Generation 6 Mobile Harbor Cranes[154]. Figure 26

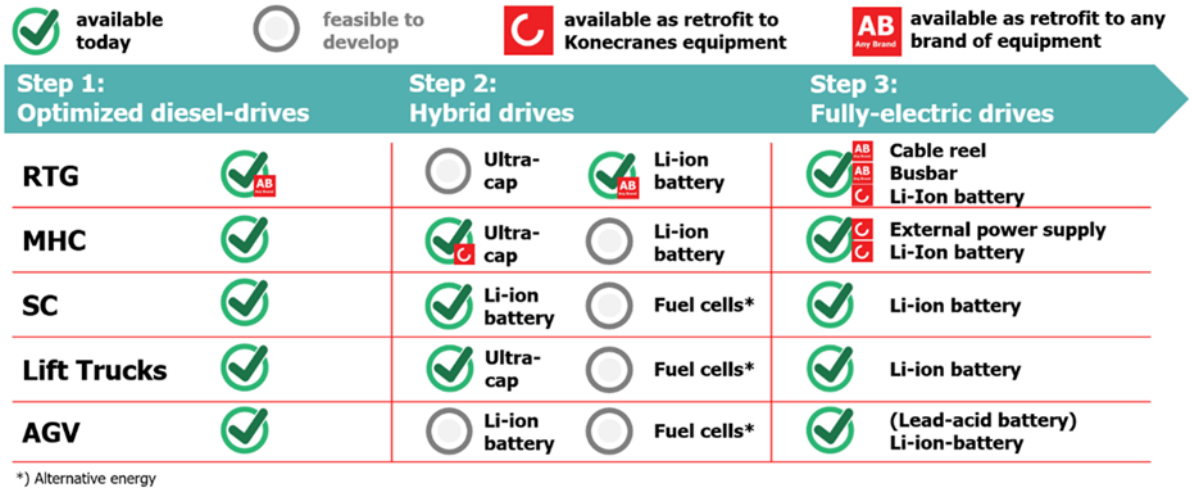

Figure 26. Different models of alternative energy at Konecranes. Source TRADE PRESS RELEASES 15.06.2022 - 16:00 EEST

[153] https://www.konecranes.com/sites/default/files/2022-06/Battery%20RTG_Tech%20Spec_EN.pdf last acessed on 6.7.2022

[154] https://www.konecranes.com/press/releases/2022/konecranes-puts-the-battery-in-rtgs-straddle-carriers-and-mobile-harbor-cranes-with-ecolifting (June 15 2022) last accessed on 8.7.2022

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3.5.2 Technologies

Examples of cargo handling equipment

Kalmar

Electric empty container handler/ masted containers handlers

An electric empty container handler is quiet to operate, making it better for the user and ideal for working in built-up areas where excessive noise may be a concern. Figure 27

Using Li-ion batteries as a power solution gives some benefits:

- fewer moving parts and lower maintenance costs
- container handler is smooth to drive and strains drivers' bodies less

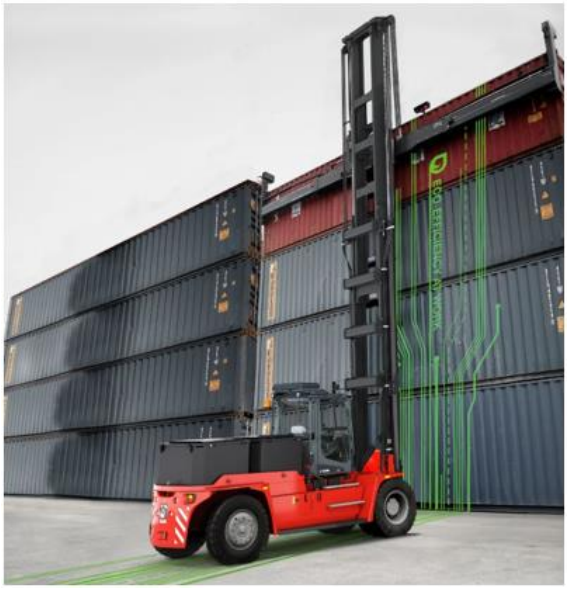

Figure 27. Electric empty container handler boomer. Source: Kalmar

Kalmar Insight provides employees with operational information direct from the electric empty container handler in real-time to review and analyse, allowing them to take action that will help improve overall operations immediately.

Technologies:

Lithium-Ion batteries are permanently fitted to the electric empty container handler and can be charged as an electric car. This plug and charge technology can be used to fully charge the batteries between shifts or charge batteries during idle time or breaks. That is called opportunity charging by Kalmar.

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- Lithium-Ion batteries feature:
- Last for 2,400-4,000 cycles
- Battery efficiency – 95%
- Is charged in-situ
- Does not require a ventilated space
- Requires minimal maintenance
- Can be opportunity charged for multi-shift operation
- Charging time - estimated 1% per one minute – dependent on charging solution chosen

Electric Heavy Forklift Truck 18-33 tons

A Kalmar Electric Heavy Forklift can move containers, slabs, billets, pipes, coils, lumber, pulp, biomass material, concrete, building material and parts. **Figure 28**

Technologies:

Power source [kWh] Li-ion 163,245, 392.

Kalmar has a modular system for battery charging solutions, which is a big investment that will match companies' operational requirements.

- four different charging solutions with charging capacities from 50-350 kW
- three different Li-ion capacities to choose from
- battery solutions have a 5-year warranty
- and they have an expected 10–12-year life*
- depending on your company's work cycles, one battery option and charging solution is better than one other
- lifting capacity is from 18-33 tons with the right mast and attachment fitted
    - three different lifting masts
    - a range of forks and mounts
    - an extensive range of attachments for most heavy lifting requirements

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Figure 28. Electric Heavy Forklift Truck 18-33 tons. Source: Kalmar

- Battery Monitoring System BMS monitors:
  - voltage V
  - temperature Celsius/Fahrenheit
  - coolant
  - current flow mA

Kalmar Electric Reachstacker

A Kalmar's electrically powered reachstacker with lifting capacities of 45 tonnes can help improve companies' eco-efficiency while maintaining productivity and safety. Figure 29

With an electric powertrain, drivers will notice a difference with faster and smoother acceleration and more responsive handling while still being able to lift to 45 tonnes efficiently and safely.

Technologies:

The power source is Li-ion batteries with four options (245 kWh-587 kWh).

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Figure 29. Kalmar Electric Reachstacker. Source: Kalmar

Less time will be spent servicing and maintaining an electrically powered reach stacker as it has fewer moving and mechanical parts.

The equipment will be able to keep it running within a range of temperatures with Kalmar's Thermal Management System fitted as standard, which keeps the core battery temperature at 25-30°C.

- Minimum -30°C
- Maximum 40°C.

OPERATIONAL HOURS		Small	Medium	Large	X Large
DRIVE CYCLE	Light	4	5.5	7	10
	Medium	3.5	5	6	8.5
	Heavy	3	4	5	7.5

Figure 30. Kalmar electric reachstacker's operational hours in the drive cycle. Source: Kalmar

There are four different battery options in the electric reachstacker:

- 245 kWh
- 326 kWh

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- 407 kWh
- 587 kWh
- year warranty and have an expected 10–12-year first life [80% capacity left].

Kalmar Insights is a performance management tool for cargo handling operations that gives Turning data on real-time information from multiple sources[155].

Terminal tractors, Batteries Li-ion 152kWh, 184kWh

Kalmar has electrically powered terminal tractors (also known as shunt or yard trucks) equipped with Lithium-ion batteries.

Yard Trucks, Shunt Trucks, RoRo Tractors and Terminal Tractors are the same machine used for cargo handling at ferry terminals (RoRo), ports and terminals, and industrial facilities are used in different parts of the world. Figure 31

Figure 31. Terminal tractor with Lithium-ion batteries. Source: Kalmar

Four models are available to choose from, two specifically designed for container ports and terminals and two for distribution applications. With an on-road version available for North America. In the Kalmar are three different charging solutions with charging capacities of 24, 90 and 180kW and two different Li-ion battery capacities to choose from. The battery

[155] https://www.kalmarglobal.com/equipment-services/kalmar-insight/ last accessed on 7.7.2022

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solutions warranty is five years, with an expected 10-12 year life*[156]. The Li-ion batteries are 152 kWh or 184 kWh. Charging solutions are covered for two years and batteries for up to 5 years.

Kalmar FastCharge™ Shuttle Carrier

Charging System Kalmar FastCharge Energy storage Lithium-ion battery (LTO)

Kalmar FastCharge™ can move containers around a terminal using battery power units, and it can be charged during operation in the yard when using Kalmar FastCharge. The shuttle carriers enable decoupling container movements from the quayside to the landside in the container terminal or yard, allowing the cranes to operate. Kalmar Shuttle Carriers can pick up and place containers directly on the ground so that other cranes can move containers.

Kalmar Shuttle Carriers can

- pick and place one 20ft to 53ft container at a time anywhere around a terminal
- be fitted with an extendable twin-lift spreader allowing to handle two 20ft containers at once
- decouple quayside and landside operations as they pick and place containers directly from or on the ground
- FastCharge power unit source has zero emission
- Shuttle carriers (**Figure 32**) have servicing intervals of up to 1,000 hours
- Shuttle carriers are fitted with:
    - an active stability control system
    - continually monitoring speed
    - turning radius
    - spreader position
    - prevents accelerating when required

[156] https://www.kalmarglobal.com/4946e2/globalassets/media/268794/268794_Kalmar-Ottawa-Electric-Terminal-Tractor-T2E-_Brochure-web.pdf.pdf last accessed on 7.7.2022

- Shuttle carriers feature a rope hoist system with eight pulleys, making them efficient, safer, and easier to maintain than other lifting system alternatives
- Charging the shuttle carrier at strategically located charging stations is fully automated and can take 30-180 seconds, allowing charging stops to become part of employee's normal work cycle

Figure 32. Shuttle Carrier at a Port. Source: Kalmar.

Kalmar FastCharge™ Straddle Carrier

Straddle carriers organise and manage the container storage and load and unload the containers to a truck or chassis on the land side of the terminal. Straddle carriers have been successfully automated for many years. From the point of view of energy management, straddle carriers pose some challenges for electrification, as the amount of energy needed by the machine can vary significantly depending on the weight of individual containers and the travelling distance during a given duty cycle[157].

Charging system Kalmar FastCharge Energy storage Lithium-ion battery (LTO) Figure 33

[157] https://www.kalmarglobal.com/491467/globalassets/media/216119/216119_FastCharge-WP-2019-WEB.pdf last accessed on 7.7.2022

Figure 33. Kalmar FastCharge™ Straddle Carrier. Source: Kalmar Images.

Straddle carriers can

- handle two containers at a time and stack up to four containers high, lifting to 60 tonnes
- FastCharge Straddle power unit source has zero emission
- have a strong frame in the industry with a streamlined yet extremely rigid design which requires no external bracing
- shuttle carriers have servicing intervals of up to 1,000 hours
- shuttle carriers are fitted with:
    - an active stability control system
    - continually monitoring speed
    - turning radius
    - spreader position
    - prevents accelerating when required

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- Shuttle carriers feature a rope hoist system with eight pulleys, making them efficient, safer, and easier to maintain than other lifting system alternatives.

Kalmar FastCharge shuttle and straddle carriers are charged with an inverted pantograph direct current charging system, fully automated and similar to systems used on electric buses. The location of the current collector on the upper frame or side pillar of the vehicle adds to the safety of the solution and protects it from damage.

On-site energy storage

The fast-charging system can also be augmented with additional stationary battery storage, which acts as an energy buffer parallel to the charging station. The energy storage can be charged with small power from the grid over a flexible period, which means that power peaks for charging don't affect the grid, but only the battery storage. That helps to decrease the grid-side load, stabilise the terminal distribution grid and increase the overall quality of electric power at the terminal. The energy storage unit can be located close to the charging station to reduce the effect of power peaks or as a more general augmentation to the entire electricity system of the terminal[158].

Example of Kalmar case study: DP World London Gateway

DP World is a leading enabler of global trade, operating multiple related businesses from marine and inland terminals, maritime services, logistics and ancillary services to technology-driven trade solutions. The company operates 78 marine and inland terminals supported by over 50 related businesses in over 40 countries across six continents. DP World London Gateway is the UK's most integrated logistics hub, a state-of-the-art, globally connected deep-sea port and rail terminal on the same site as an expansive land bank for the flexible and fast development of logistics facilities and warehouses. With its tri-modal combination of a deep-sea port and logistics park, DP World London Gateway provides an efficient link between oceanic shipping and the largest consumer markets in the UK.

[158] https://www.kalmarglobal.com/491467/globalassets/media/216119/216119_FastCharge-WP-2019-WEB.pdf page 12 7.7.2022

Kalmar has delivered an extensive container handling solution for DP World London Gateway, including a joint FastCharge shuttle carrier development project. Kalmar deployed 40 automatic stacking cranes and 28 shuttle carriers, with commercial operations starting in 2013. In the second phase of 2014, 20 automated stacking cranes and 12 hybrid shuttle carriers were added. The FastCharge joint development project started in July 2017, and the live operation began in April 2018. Kalmar modified an existing hybrid shuttle carrier to a fully electric FastCharge shuttle carrier.

The shuttle carrier charges during idle periods under the principle of opportunity charging, and the charging time is between 30 to 180 seconds at full charging power. The charging system consists of the charging station and pantograph charging contact, with the containerised charging station connected to the local power grid. The charging system is located between two ASC blocks at the waterside in the maintenance aisle. The charging sequence is fully automated, and the driver must only engage the parking brake to begin the charging procedure[159].

Konecranes

Konecranes Battery RTG (B-RTG) Rubber-Tired Gantry Cranes

The Konecranes B-RTG works either with a charging station (seen at right) or with a manual plug-in to the mains for charging. That will depend on the particular work processes of your container terminal.

The Konecranes B-RTG utilizes Li-ion technology that is field-proven in Konecranes Gottwald Automated Guided Vehicle (AGV) systems and hybrid Konecranes RTGs. The performance track record is excellent. On the left, you see an illustration of the energy management RTG ENERGY system[160].

Battery packs are available in two types. The first type is liquid-cooled with 4-hr = 222kWh capacity. The second type is passive air-cooled with 8-hr = 370kWh capacity.

[159] https://www.kalmarglobal.com/491467/globalassets/media/216119/216119_FastCharge-WP-2019-WEB.pdf page 21, last accessed on 15.7.2022

[160] https://www.konecranes.com/sites/default/files/2022-06/Battery%20RTG_Tech%20Spec_EN.pdf last accessed on 7.7.2022

Battery life The design life of the battery pack is eight years. The design life limit is 70% of the remaining battery capacity. Battery life depends upon the B-RTG workload concerning the work shift. More detailed information can be given in discussion with the customer about work processes involving charging and discharging* cycles. Figure 34

Figure 34. Battery RTG (B-RTG) Rubber-Tired Gantry Cranes. Source: Web. Port Cranes

Battery Konecranes Noell Straddle Carrier

The battery-driven Noel Straddle Carrier can be used for a wide variety of tasks, ranging from horizontal transport to stacking in the container stack to loading and unloading of trains or road trucks.

The Battery Konecranes Noell Straddle Carrier (Figure 35) is a system that includes a charging station[161]. Similar Li-ion battery technology is used as in Konecranes Gottwald AGVs, from which a large body of field experience has been drawn regarding 24/7 operation and battery lifetime.

[161] https://www.konecranes.com/press/releases/2022/konecranes-puts-the-battery-in-rtgs-straddle-carriers-and-mobile-harbor-cranes-with-ecolifting last accessed on 8.7.2022

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Figure 35. Konecranes Noell Straddle Carrier. Source Konecranes.

Konecranes Gottwald Generation 6 all-electric Mobile Harbor Cranes

Konecranes Gottwald terminal vehicles include uncrewed, automated container transport vehicles, or Automated Guided Vehicles (AGVs), used for container transport between the quayside and the container yard. The management and navigation software to operate the AGVs and Lift AGVs is also a supplier of lithium-ion battery technology. Figure 36

Generation 6 is designed to use external power sources and to work independently of the grid with consumption-optimized diesel-generator sets

and modern hybrid drives. Renewable energies such as wind and solar power from the on-shore grid enable continuous zero-emission operation[162].

The modular drive concept offers flexibility in using external power sources of different voltages. In addition, all cranes have frequency-controlled three-phase drives for efficient and power-optimized crane motions with negligible grid reactions when using external power sources.

[162] https://www.konecranes.com/sites/default/files/2022-04/KC_GEN6_brochure_web_EN_FINAL_220222.pdf page 10, last accessed 18.7.2022

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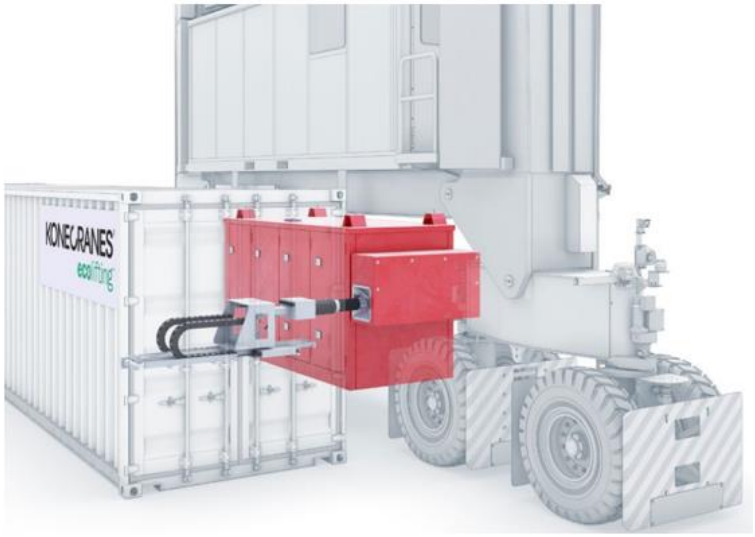

Figure 36. Konecranes Docking at the charging station of gantrying the B-RTG to the station, where the charging connection is made. Source Konecranes.

Figure 37. Konecranes Gottwald automated guided vehicles (AGVs). Source Konecranes

Technologies:

- Constructed as an AGV or Lift AGV with battery-electric or diesel-electric drive unit
- Payload 70 tons
- Precise “according to plan” sequence via a computer control system
- Precise control using management and navigation software and transponders in the terminal road surface

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- Positioning to +/- 25 mm accuracy
- Battery-electric drives for zero exhaust emissions in the terminal

3.5.3 Job roles and skills

Current training provided by the example companies, Kalmar and Konecranes

Regarding cargo handling equipment, Desk Research 3 focuses on the companies Kalmar and Konecranes because they are leading cargo equipment providers that use lithium-ion batteries. Material and information have been collected from their homepages. Kalmar and Konecranes are training the customer, who have acquired cargo equipment at several levels. Kalmar Training Academy provides training courses for different audiences in Finnish and English in Tampere, Finland.

Konecranes Training Institute in the US has regional seminars and online courses throughout the continent. In Hyvinkää, Finland, Konecranes gives training courses for both technicians and operators, on-site, on your machine, stationary MHC Simulator in Düsseldorf, and mobile version for on-site training. In the US, the P&H® Institute has renamed the Konecranes Training Institute in 2010, and the first online course was launched in 2017. Training is also given in Spanish and French.

Training courses

Kalmar and Konecranes provide technical, automation, driving, maintenance, operation, product, and systems training for customers, employees, and dealers. Electrical, mechanical, hydraulics, digital and safety training courses are provided in both companies for all types of equipment. The duration of the courses varies from four hours to five days.

Technical training courses take place at training centres and combine theory and practice to ensure technicians can solve all potential issues in their daily work, from scheduled maintenance to troubleshooting and repairs[163].

Konecranes has a crane operator selection test, which gives a quick indication of the natural operation abilities of candidates on a simulator. Konecranes is providing training on-site or at training centres. Virtual 360° tour training gives the trainee visual support for descriptive maintenance procedures, including the physical layout of the crane and the components, an

[163] https://www.kalmarusa.com/equipment-services/training/ last aceessed on 18.7.2022

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insight when starting to work on the crane[164]. There is a variety of simulators that replicate crane control systems at the training facilities. The trainees can exchange and switch learning modules depending on their experience and needs. Recognized Konecranes Port Solutions training course certificate helps the employees to verify skills.

An example of a Shuttle Carrier's training (a Kalmar 7/10 course)

The course is intended for service engineers (including those in senior positions), and the duration is three days. The training includes both theoretical and practical sessions.

After this training, the person should know how to change a hybrid unit's battery module and understand Lithium-ion battery charging. A very important part is to be familiar with the functionality of the hybrid machine and its battery system and to be able to perform the rectifier auto-tune. After this course, the person is familiar with the PLS software, diagnostics, fieldbus communication and tracing,[165] only to mention a few competencies.

The training duration of the Konecranes straddle/sprinter carrier operators is five days. It provides knowledge and skills to operate safely and productively. The requirements are good hand-eye coordination, and the training takes place on-site[166].

These courses are intended for operators, senior service engineers, electrical engineers, service mechanics, technicians, supervisors, commissioners, project staff, new employees in sales, service- and spare part organizations, and terminal operators. Please see an example of a course structure and content below.

Common Courses: Intro for new technical staff

Course No. 490-001

An introductory course for technical service personnel within Kalmar. Presentation of the Kalmar product range. Basic knowledge of products, components and documentation.

Duration

One day Product Training

Purpose

On completion of the training, the participant should:

- Be able to recognize the Kalmar product ranges
- Have a basic knowledge of different components
- Be able to understand Kalmar manuals and understand J2008
- Be able to read and understand electric and hydraulic diagrams
- Be able to understand different electric and hydraulic symbols

[164] https://www.konecranes.com/resources/port-equipment-operator-digital-training last aceessed 18.7.2022
[165] http://apd.kalmarglobal.com/ last accessed 18.7.2022
[166] https://www.konecranes.com/sites/default/files/2021-01/Operator%20Training_PDF_2020.pdf last accessed on 18.7.2022

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- Be able to understand different control systems
- Have knowledge about the importance of safety

Intended for

New employees in Sales-, Service- and Spare Part Organizations; Service Engineer; Service Mechanic; Service Technician

Examples of job roles and related skills

Kalmar and Konecranes' job advertisements were studied on their home pages in August 2022. In none of these career advertisements (including the examples below), batteries are specially mentioned. However, based on the level of electrification, for example, described in this chapter, it is clear that battery skills have begun to be an essential part of the job roles that are, example described below. That will be even more the case in the future. The chapters covering the other heavy machines categories also describe roles with battery skills that can be speculated not to be that different from those needed with the cargo handling equipment. At Konecranes, they believe diversity drives business success and is the foundation for company growth. At Konecranes, they welcome different backgrounds and skills that enrich the community and promote a place where all can be themselves.

Konecranes are developing the future generation of heavy industrial trucks and industry of non-road mobile machinery. Industrial trucks contain various technologies, such as powertrains, electric drives, electric energy storage, hydraulics, vehicle automation, HMI/GUI, machine control, and digitalization. The company works globally, with staff in Italy, Sweden, France, China, and partners worldwide.

Electric vehicle Engineer - Developer R&D

- Motivated
- Adopt solutions use the state of the art of engineering
- Model-based design approach
- Use the most advanced techniques for functional safety and simulation
- The new resource will be employed in an international team to develop and design the electric vehicle in the material handling market.
- Main tasks and responsibilities:
- Electric powertrain design and development
- High voltage vehicle distribution design and development

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- Electric system integration
- Electric safety for mobile equipment
- Testing and Validation (EMC, Safety and standards)
- Simulation (Matlab)
- International team

Electrical Design Engineer

Key Responsibilities

- Electrical Design Engineer responsible for electrical order engineering for industrial crane, ETO.
- Preparing crane electrics according to internal design instructions:
  - single line diagram
  - schematic diagram
  - panel layout
- Calculations for crane electrics (cables, festoon etc.)
- Electrical Order Engineering for various crane applications
- Prepare crane electrics by studying customer requirements
- Verifying electrical drawings and documents before releasing for production, purchase requisitions etc.
- On-time and effective engineering delivery
- Active communication with Electrical Leading Engineers, Project Managers and Factory that are related to project deliveries
- Keeps the supervisor informed on problems relating to the area of responsibility
- Ready to travel abroad on sites if required.

Expected education

- Bachelor's or Higher technical degree in electrical engineering/technology with 2 to 5 years of industrial experience
- Proficient in reading electrical schematics drawings
- Experience in electrical design in the crane industry and material handling industries has added advantages etc.
- Requires a good understanding of protective devices, electrical switchgear, frequency drives and motor controls

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- Proficiency with electric design software (E3 schematic, EPLAN, AutoCAD Electrical or similar), Microsoft Excel, and Word.
- Basic Understanding of mechanical drawing
- Awareness about ISO 14001, 45001 requirements

Behavioural competencies

- Self-motivated, Team oriented, Target oriented
- Positive attitude, good team player, but also capable of working individually
- Ability to take ownership and responsibility
- A good verbal and written communication

Service Technician / Service Engineer international (m/f/x)

Key responsibilities

- travel globally
- work in all ports of the world with our field Task Force Team for Mobile Harbor Cranes
- performing planned activities in a timely and professional manner
- cooperate successfully with both the project management team and your colleagues from the assembly and service stations on site
- a good team leader
- the opportunity to qualify as a team lead
- able to complete the mechanical and electrical assembly of crane systems following the Accident Prevention Regulation (UVV).
    - assembling the crane components and connecting and installing electrical components
    - provide the project management team with (assembly) reports, documentation, and deviation reports to ensure result-oriented transparency
    - check tool lists and put together assembly aids and manual equipment
    - checking on-site whether individual components have been delivered in full and free of transport damage
    - manage customer meetings and report on the results of the respective assembly

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- the final acceptance of the cranes, you will apply the highest product quality standards, and your commitment will ensure that the conditions for satisfied customers are consistently met
- you will meticulously:
  - log safety-relevant test results
  - prepare final reports
  - update the revision plans
  - report fault diagnoses to the quality management and project management teams.
- as a future site manager and supervisor company will support your professional development toward this goal
- by performing planned activities in a timely and professional manner, you cooperate:
  - the project management team
  - your colleagues from the assembly and service stations on site

3.6 HEAVY CONSTRUCTION EQUIPMENT

3.6.1 Stakeholders

Market, figures and players[167][168][169]

The world's construction equipment market is forecasted to expand from USD 208,3 billion (2021) to USD 250,4 billion by 2026 (3,8 % CAGR). Developing countries are investing in developing their infrastructure to deal with such issues as increasing population, high manufacturing costs, and ageing transportation infrastructure. At the same time, developed countries are improving their infrastructure with, for example, new transportation systems, residential construction activities etc. For instance, in Europe, where the construction industry currently generates 9 % of the EU's GDP, construction growth is ongoing due to transport infrastructure development.

[167] Construction Equipment Market Trends & Forecast Report | 2026 (marketsandmarkets.com), last accessed on 9.8.2022
[168] Europe Construction Equipment Market - Growth, Trends, COVID-19 Impact, and Forecasts (2022 - 2027) (researchandmarkets.com), last accessed on 9.8.2022
[169] Europe Construction Equipment Market Price 2026 | Sales & Demand Forecast (graphicalresearch.com), last accessed on 9.8.2022

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A boost factor resulting from the post-COVID-19 era infrastructure investment surge is expected to generate increased demand for construction equipment while challenges remain. The demand fell globally during the pandemic, during which construction decreased. Construction was among those industries that were severely affected by the pandemic. Some construction projects were delayed or cancelled.

The increasing number of construction equipment has raised diesel consumption. The growing burden on the environment has pushed governments to establish regulations to control NOx and SOx emissions, encouraging OEMs to look into hybrid and fully electric vehicles. Similar to the other heavy machines covered in this report, electric versions also produce less vibration, noise, and heat. Additionally, the electric construction equipment is simpler than their construction, and their operating costs are cheaper due to the use of electricity compared to diesel machinery.

Consequently, electric (and also autonomous) construction equipment is regarded as an opportunity. Companies are introducing technologically advanced construction machinery to the market to reduce emissions caused by diesel engines to comply with, for example, the EU's emission regulations. For instance, in Europe, Volvo Construction Equipment launched its new compact electric excavator and wheel loader, ECR25. Volvo CE started the Go Electric project in 2019 and decided that all compact loaders and excavators must be electric; by 2030, 30 % of their sales ought to be electric. The electric construction market is forecasted to be 105 billion USD by 2042. [170]

Table 9. The Top Five World Construction Equipment Companies Listed by Market Cap[171][172]

Rank	Company	Headquarters Country	Market Cap
1	CATERPILLAR	USA	115.440 Billion USD
2	DEERE & COMPANY	USA	118.130 Billion USD
3	ATLAS COPCO AB	Sweden	81.730 Billion USD
4	HITACHI	Japan	54.345 Billion USD
5	ASHTEAD GROUP	UK	35.560 Billion USD

[170] https://www.assemblymag.com/articles/97053-electric-tractors-tackle-off-highway-jobs, last accessed on 18.8.2022
[171] World Top 1000 Companies by market value as on Jan 2022, last accessed on 9.8.2022
[172] Market Cap (Sep-01-2021)

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Examples of manufacturers of and service providers related to electric construction machinery[173][174][175]

- Volvo Construction Equipment
  - loaders
  - excavators
- Suncar HK AG
  - electrification solutions for manufacturers (construction machines and beyond)
- Electric Construction Equipment
  - electrification solutions for manufacturers (construction machines)
- Caterpillar
  - excavators
  - forklifts
- Doosan Bobcat
  - excavators
  - loaders
- Hyundai CE
  - excavators
- JCB
  - excavators
- Wacker Neuson
  - loaders
- Schäffer
  - loaders
- Toyota
  - forklifts
- CNH Industrial
  - backhoes
  - excavators
- Solectrac
  - light-duty utility tractor

3.6.2 Technologies

Construction equipment in general

Construction equipment is essential in any infrastructure or structural engineering-related operations. Heavy equipment and construction vehicles are used in such tasks as excavation and digging of earth, compacting and levelling, transferring materials, placing materials and the actual construction processes.[176]

[173] https://www.volvoce.com/europe/en/products/electric-machines/, last accessed on 9.8.2022
[174] https://www.suncar-hk.com/en/, last accessed on 9.8.2022
[175] https://www.bigrentz.com/blog/electric-construction-equipment, last accessed on 10.8.2022
[176] https://www.sciencedirect.com/topics/engineering/construction-equipment, last accessed on 11.8.2022

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Construction equipment includes wheel loaders (Figure 39), backhoes, excavators (Figure 38), trucks, cranes, and forklifts.

Figure 38. Excavator. Source: Pixabay.com

Figure 39. Wheel loader. Source: Pixabay.com

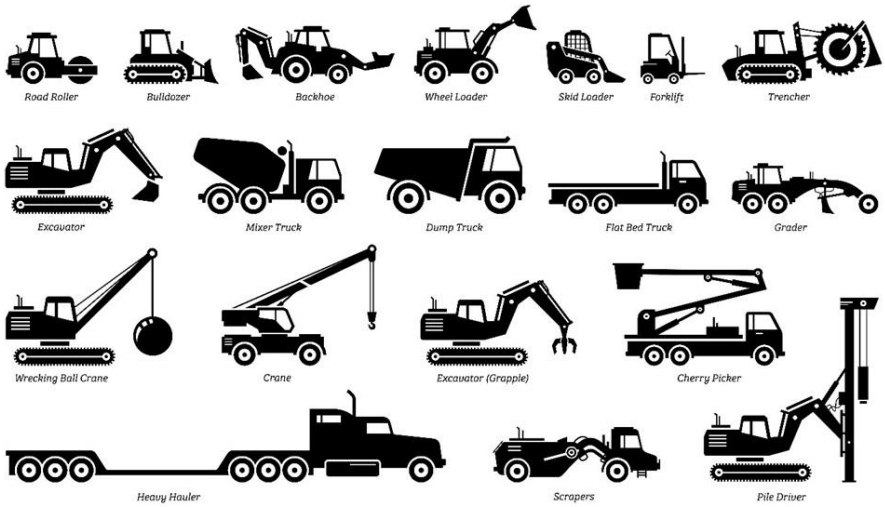

Figure 40. The types of construction equipment. Source: MCR Safety.[177]

[177] https://www.mcrsafety.com/blog/construction-equipment, last accessed on 11.8.2022

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Electric construction equipment[178][179]

More sustainable construction practices have increased over recent years. In the process of making construction operations more sustainable, the manufacturers of heavy machinery are launching versions of construction machines that are fully electric. Electric construction machinery is not a new concept since hybrid electric machines have been on the market for years. For example, fully electric excavators, loaders, and forklifts are currently available.

Most heavy machinery in construction sites is still diesel-powered. However, fully electric versions are becoming more common. These machines' performance is nearly compatible with their diesel equivalents. The most significant differences between electric and diesel machines can be found internally. Instead of a diesel engine etc., the electric machinery has Li-ion batteries. In some electric versions, the hydraulics have been replaced with electromechanical linear actuators.

The manufacturers have started with compact machines[180], as that is where the demand has been expected to begin, but eventually, heavier equipment will be developed.

The top benefits of fully electric construction machinery (if compared to their diesel-powered version):

- **zero CO_2 emissions**
- **lower vibration**
- **less noise**
  - improves the comfort
  - improves safety due to enabling better communication between workers
- **less maintenance**
  - lower costs of operating and maintenance with electric components
  - less downtime
- **instant torque**

[178] https://www.bigrentz.com/blog/electric-construction-equipment, last accessed on 11.8.2022
[179] https://theconstructor.org/construction/heavy-construction-equipment-types/26305/, last accessed on 11.8.2022
[180] https://www.assemblymag.com/articles/97053-electric-tractors-tackle-off-highway-jobs, last accessed on 18.8.2022

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Equipment examples and descriptions

Excavators

Excavators are extensively used machines in construction projects. They are primarily used for excavation, heavy lifting, demolition, dredging, and cutting trees. There is a cabin section with a long arm that has a digging bucket. The whole arrangement is 360 degrees rotatable.

Electric excavators were among the first fully electric construction machines to be brought into public awareness. Volvo CE revealed the EX02 compact electric excavator prototype in 2017. The machine was a zero-emission system with two Li-ion batteries totalling 38 kWh for operating for eight hours before needing to be charged. The production models include ECR25, EC28 and ECR18 Electric excavators **Figure 41**. Additionally, other manufacturers have launched electric excavators, and the demand is expected to increase. Case Construction Equipment has developed[181] an electric excavator, CX15 EV, a 2900-pound (mini) excavator equipped with a 16-kW electric motor and a 21.5 kWh Li-ion battery.

Figure 41. Volvo EC18 Electric. Source: Volvo CE

Loaders

Loaders load materials such as excavated soil, demolition waste onto trucks etc., on construction sites. Loaders have large buckets at their fronts with short moving arms.

Wheel loaders come in various sizes and formats. They are normally present on most construction sites. The manufacturers of these machines have been rapidly developing fully electric versions. Companies such as Volvo CE (**Figure 42**), Wacker Neuson and Schäffer have

[181] https://www.assemblymag.com/articles/97053-electric-tractors-tackle-off-highway-jobs, last accessed on 18.8.2022

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developed electric machines recently. Electric track loaders such as T7X by Doosan Bobcat[182] are fully electric, replacing all hydraulics with a drive system consisting of electric cylinders and drive motors. The loader sports a 62 KW Li-ion battery. Its power management systems are programmed to sense the increased loads to automatically back off power when not required. That preserves energy and extends the runtime. Due to the all-electric system, instantaneous power and peak torque are available at every operating speed.

Figure 42. VOLVO L20 ELECTRIC. Source: Volvo CE

Backhoes are widely used equipment. In this machine, the hoe arrangement is provided in the back. The loading bucket is in the front. For example, the machines are used for excavating trenches and loading materials. For instance, Case Construction Equipment has developed an electric backhoe equipped with a 480-volt, on kWh Li-ion battery pack that enables up to eight hours of operating.

Dump Trucks

Dump trucks transport larger quantities of material in construction sites from one place to another. These trucks are generally off-road vehicles on large construction sites. These machines have large wheels to enable manoeuvring in any terrain, and naturally, they have a large space for materials.

Several manufacturers have released electric dump trucks and mining trucks. The biggest electric vehicle in the world is a one-of-a-kind truck used in mining operations. Mining trucks are discussed more in chapter 4.3.

[182] https://www.assemblymag.com/articles/97053-electric-tractors-tackle-off-highway-jobs, last accessed on 18.8.2022

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Forklifts

Forklifts are used to lift and move items and materials over short distances. Due to the smaller size of forklifts (compared to other heavy machinery), it is easier for companies to create fully electric models. The competition has thus slowly increased in the market as more products have been introduced. Service reminders, self-diagnostics systems etc. have been added to increase competitiveness.

3.6.3 Job roles and skills

When studying the industry's job advertisements, we encountered a number of job roles and skills related specifically to construction equipment[183][184][185]. What is common with these positions is that they often involve such (basic) battery knowledge/skills as

- fundamentals of battery design
- Li-ion or similar battery chemistry, technology
- Experience in Battery Systems incl. charging

We also discovered the occasional occurrence of the following knowledge/skills

- understanding of directives, regulations, and standards applicable to batteries
- Understand Li-ion battery and related technology trends (BMS, applications etc.)
- Understanding and analysing data (for example, related to battery performance)

One of the most interesting findings represents a potentially new kind of knowledge or skills:

- Artificial intelligence and/or machine learning methodologies and application to BMS.

Examples are listed below:

- **(Senior) System Design Engineer**
  - design, development, validation of Electrical & Electronic systems and controls
  - design calculation: Electrical Load requirements, Battery sizing, Harness design
  - NPD process, life cycle processes for E&E system components, Batteries
  - Low and High Voltage electromobility systems, components, architecture
- **System engineer Thermal management**

[183] https://www.volvogroup.com/en/careers/job-openings.html, accessed in August 2022
[184] https://careers.caterpillar.com/en/jobs/, accessed in August 2022
[185] https://www.deere.com/en/our-company/john-deere-careers/, accessed in August 2022

- Thermal management systems: active cooling for electromobility, batteries, fuel cells etc.
- working with the system functionality for both SW and the electrical components
- system design/engineering, mechatronics/system tools: AD/PLM/Calibration/SW dev.

- **Product Specialist - Driveline and Electromobility**
  - responsible for resolving hardware and software-related problems
  - experience in product development from Engine, Transmission and or BEV,
- **Materials Technology Engineer – Electrical Hardware and batteries**
  - stakeholder strategies and devise solutions to boost competitive advantage
  - failure analysis, prototype & prod. parts: electronics, contactors, battery cells
  - material knowledge for electrical hardware components, batteries, analytical equipment
  - experience: battery pack degradation, MSc or PhD in materials science
- **(Senior) Engineer – Battery Modelling and Analysis**
  - contribute to projects via Simulation, development and Validation of complex electrical systems pertaining to battery management and battery chemistry
  - Battery modelling (Comsol, GTLion 1D/3D, Amesim), simulation, and test validation
  - graphical and computational modelling tools like MATLAB/Simulink/Simscape
  - Battery cycler data analysis, battery performance metrics: SoC, SoH, etc.
  - Battery Management control system, Battery Thermal simulation
- **Battery Module Performance Engineering Specialist**
  - battery module performance: ensuring cooling/heating/charging and discharging HW and SW align with customer requirements and design technical specifications
  - Develop performance test plans, collaborate with internal and external test facilities to execute, analyze results, compare results to project/program requirements
  - Experience with electric drivetrain components

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- **Regulatory Project Lead for Batteries, Power Systems Regulatory Engineer**
  - understand applicable directives, regulations and standards that must be met along with other compliance considerations by product and region
  - transportation & storage of HV battery packs, Battery Reuse/Recycling
- **Performance Engineer**
  - contribute to projects that support and enhance product performance, durability, reliability, quality, and serviceability
  - vehicle dynamics, linkage kinematics, and machine/soil interaction to optimise compact wheel loader performance, incl. battery electric models with electric motor drivetrains
  - model machine performance with tools such as Dynasty, SIMULINK or AMESIM
  - operate constr. equipment while simulating performance and resolving customer issues
- **Battery Management System Lead/Engineer**
  - support product electrification projects: lead and execute the development of Li-ion BMS
  - design, develop, test, integrate BMS in energy storage systems incl. Li-ion batteries
  - experience in the production and/or product launch of lithium-ion battery systems
  - BMS experience: algorithms incl. SOC, SOH and Safety Functions, software development & validation, hardware design, development, testing, integration EV applications
  - experience on thermal and ageing models using Matlab / Simulink
- **(Senior) Battery Software Architect**
  - architect embedded software for BMS and integrate control algorithms with appropriate engineering tools and considering the BMS overall requirements
  - experience in developing software solutions, BMS experience (the same as above)
  - Artificial intelligence and/or machine learning methodologies and application to BMS

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- **(Senior) Battery Systems Engineer**
  - Develop system, component, and sub-component specifications for energy storage systems, including functional, performance, safety, compliance req.
  - Analyse design: electrical capability, battery life, thermal, isolation/creepage, clearance
  - Develop an energy storage solution strategy incl. batteries, controls, associated HW
  - product development, lead technical projects, Li-ion batt. design, MATLAB/Simulink
- **(Senior) Battery Cell Engineer**
  - Own key elements of cell design and interface directly with cell manufacturers, mechanical designers, systems engineers to ensure integrated battery system
  - Design, develop, execute test methods to evaluate lithium-ion battery cell chemistries
  - Identify cell degradation, cell test data to supp. control/estimation BMS algorithms
- **Supply Base Manager, Supply Management Specialist (Supply Chain integration)**
  - source/procure components: Li-ion batt. solutions, batt. packs, other components, cells
  - price and contract negotiations, mitigate supply chain risks
  - market conditions, tech roadmaps, supply/demand challenges/opportunities
  - ERP experience, quality systems and controls: DPAR, PPAPs and Six Sigma
- **Virtual Design & Verification Engineer - Dynamic System Modelling**
  - develop DSM of thermofluid systems and integrate with subsystems & controls
    - Experience in design or modelling of hybrid or battery electric vehicle systems

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4 Bess in Residential Applications

4.1 DRIVERS OF CHANGE

In recent years, electricity production has shifted from non-renewable sources – coal, oil, etc. – to renewable energy sources (RES) – wind, PV, hydro, etc. The interest in increasing the number of carbon-neutral buildings attracts attention to installing RES in residential areas. The combination of BESS with PV in a residential context shows a reduction in the electricity bills and increases the self-sufficiency of electric power of the owner. These drivers attract private and small group investors (like condominiums) to install BESS in their facilities.

Countries like Germany are implementing policies and incentive programs to stimulate the growth of this technology. These policies include subsidization of the purchase of BESS and amending double taxation, which leads to predicting the German market's substantial increase in the next few years, Figure 43.[186]

With the application of the policies, home energy storage is no longer seen as a luxury. It is a response to the actual energy crisis and a result of the policies that emerged after the conflict between Russia and Ukraine. As a result, the residential sector covers half of the BESS business revenues.[187]

Contrary to the trend in Germany, some countries and regions are heavily investing in PV systems to increase renewable production and self-consumption. However, surplus energy being produced can lead to two different situations: voltage rise and deviations due to the intermittent nature of the generation, which compromises the power quality and stability of the grid.[188,189]. In Hawaii, one in nine homes have installed rooftop PVs. This level of PV penetration has caused voltage disturbances, resulting in downtime for PV systems because the inverters disconnect.[190] A BESS coupled with the PV can store the surplus energy and discharge it when needed without compromising the grid's power quality and ensuring higher

[186] https://powertechresearch.com/key-drivers-of-the-german-residential-energy-storage-market/ Last accessed on 23.06.2022

[187] https://www.energy-storage.news/german-energy-storage-market-2021-residential-dominates-but-utility-scale-bess-grows-nearly-6x/ last accessed on 27.06.2022

[188] M.van Werven and M. J. J. Scheepers, "The changing role of distribution system operators in liberalized and decentralising electricity markets"

[189] C. L. Masters, "Voltage rise: the big issue when connecting embedded generation to long 11 kV overhead line" Power Eng. J., vol. 16, no. 1, pp. 5–12, Feb. 2002

[190] https://www.greentechmedia.com/articles/read/residential-storage-growth-drivers last accessed on 15.07.2022

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PV generation efficiency.[191] The BESS can simultaneously handle the PV intermittency and load fluctuations and improve grid resilience.[192]

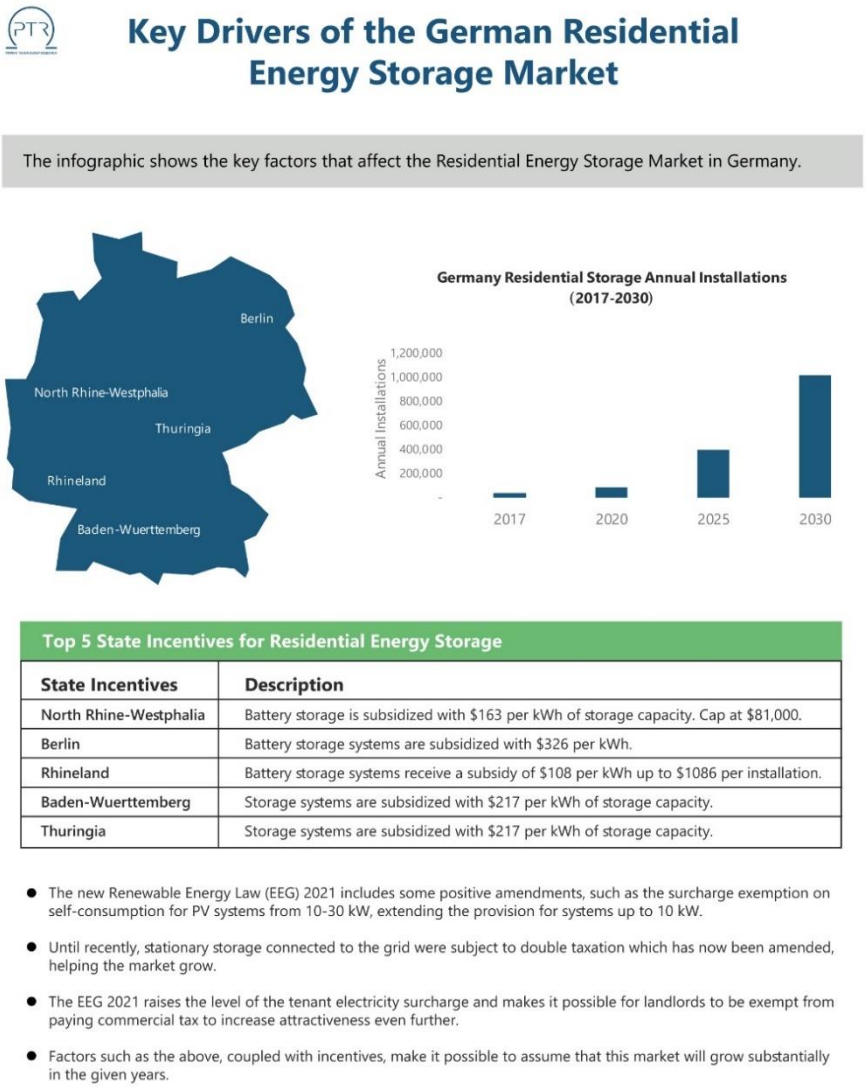

Figure 43. German political incentives and policies for the installation of residential BESS[193]

[191] Afxentis, S. Florides, M. *et al*, "Residential battery storage sizing based on daily PV production and consumption load profile characterization", 2018

[192] S. H. Metwally, X. Zhang, S. Ali and H. S. Krishnamoorthy, "Solar PV and BESS based Home Energy System," 2019 IEEE Texas Power and Energy Conference (TPEC), 2019, pp. 1-6, doi: 10.1109/TPEC.2019.8662202.

[193] https://powertechresearch.com/key-drivers-of-the-german-residential-energy-storage-market/ Last accessed in 23.06.2022

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4.2 STAKEHOLDERS

Market Insights

Until 2020, the European residential BESS market is growing exponentially. In 2020, 3 GWh of batteries were installed (Figure 44). Germany is leading the market with 70% of the installed energy, followed by Italy, the UK, and Austria[194] (Figure 45). In Germany, 60% of new PV home systems have battery systems. In 2019, the growth registered was 51%, which is remarkable since the German Development Bank (KfW) subsidy program ended in 2018. Italy is benefitting from second place in Europe thanks to the strong incentive created to fight the crisis from the COVID-19 pandemic, namely the SuperBonus 110% and the tax deduction of 50% for installing residential BESS+PV. In England, the feed-in tariff incentive at the end of 2019 rose the PV residential installations, and the Smart Export Guarantee provides concessions for prosumers equipped with battery storage. The Austrian government encourages the installation of the BESS with the Mission2030 program. It is an incentive programme expected to expire at the end of 2022.

According to even pessimistic predictions, this market will continue growing until 2025, with each country remaining with about the same share of the market (Figure 46)[195].

Other sources[196] claim that the European solar and storage forecast is set to grow over 400% from 3 GWh to 13 GWh in 2025. Since the energy crisis of the winter of 2021, it was demonstrated that residential PV+storage is an effective way to reduce the cost of electricity, with the users benefiting from a levelized energy cost of 0,12 €/kWh – 1/3 of the typical electricity price – which can lead to a more exponential growth than previously predicted.

[194] https://www.vpsolar.com/en/european-market-for-residential-battery-storage-forecast-annual-report/ Last accessed on 24.7.2022

[195] https://www.energyforum.in/fileadmin/user_upload/india/media_elements/Presentations/20211203_Intersolar2021/SPE_Battery_storage.pdf Last accessed in 25.7.2022

[196] https://www.solarpowereurope.org/insights/thematic-reports/european-market-outlook-for-residential-battery-storage-2021-2025 Last accessed in 25.7.2022

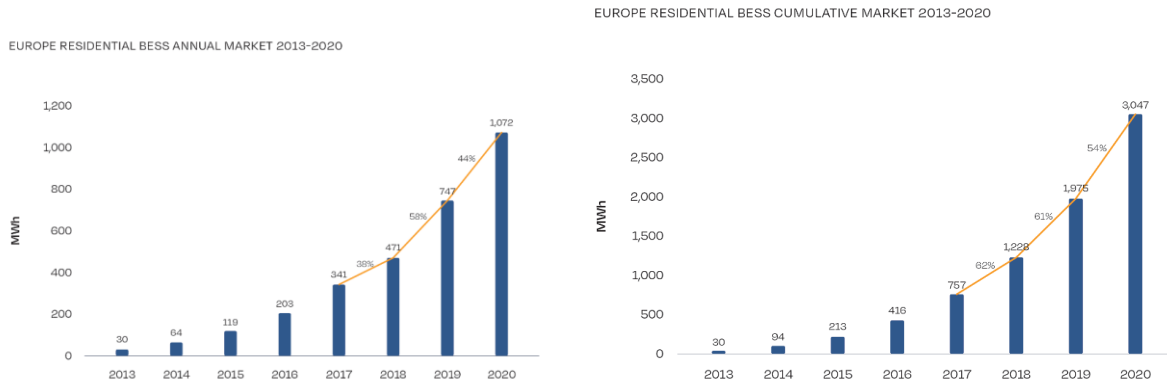

Figure 44. European Residential BESS Market: annual (left) and cumulative (right)

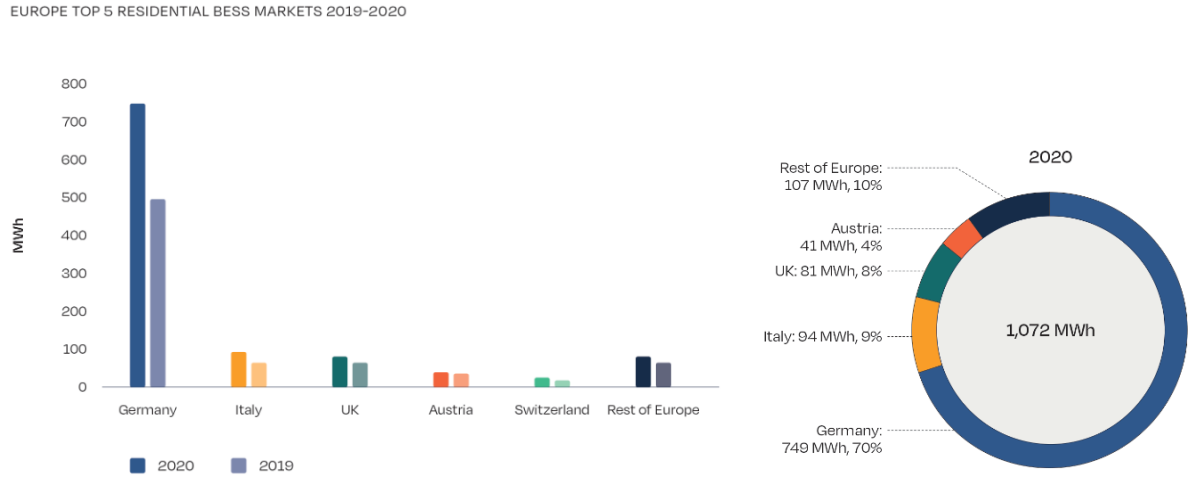

Figure 45. Top 5 Residential BESS market

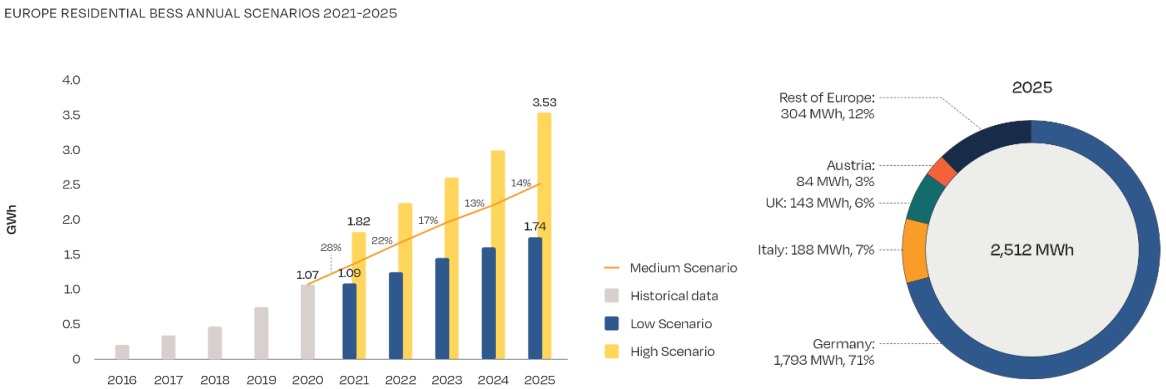

Figure 46. Residential BESS European Market forecast

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The bigger stakeholders in the residential battery market are[197][198][199]:

- LG Chem
- Sonnen
- Simpliphi Power
- Lithionics Battery
- Panasonic
- Rolls Battery Engineering
- Electriq Power
- SMA America
- Blue Planet Energy
- Crown
- Enphase
- Generac
- Humless
- POM Cube
- Sensata
- Sol-Aark
- SolarEdge
- NextEra Energy
- Toshiba
- Tesla
- General Electric GE
- Siemens
- ABB
- Johnson Controls
- Fluence
- Samsung SDI
- RES
- Eversource Energy
- Invenergy LLC
- Xcel Energy
- Austin Energy
- National Grid
- Georgia Power
- Duke Energy
- AES Corporation
- Entergy
- DTE Energy
- NV Energy
- CPS Energy
- CMS Energy
- PECO
- Cypress Creek Renewables
- Imperial Irrigation District
- Ameresco
- SunPower
- Borrego Solar Systems
- Exelon
- Con Edison
- Avangrid
- Hecate Energy
- Tucson Electric Power
- FuelCell Energy

[197] https://solarbuildermag.com/news/residential-storage-buyers-guide-2020/ Last accessed on 8.8.2022
[198] https://instylesolar.com/blog/top-5-battery-storage-companies/ Last accessed on 8.8.2022
[199] https://www.ysgsolar.com/blog/top-50-energy-storage-companies-2021-ysg-solar Last accessed on 8.8.2022

4.3 TECHNOLOGIES

Residential Battery Energy Storage Systems (BESS) are battery systems that are installed and store electricity locally for home use. As stated in the previous desk research[200], it is more profitable when the BESS is installed closer to the end-user[201] , making the residential BESS an interesting solution to explore.

Residential battery systems are used mainly to support the distributed generation model, combined with on-site generation from technologies such as photovoltaic (PV) and wind energy. They can virtually eliminate blackouts and diminish the curtailment or commercialization with the grid operator of the unused energy produced – see **Figure 47.**[202]

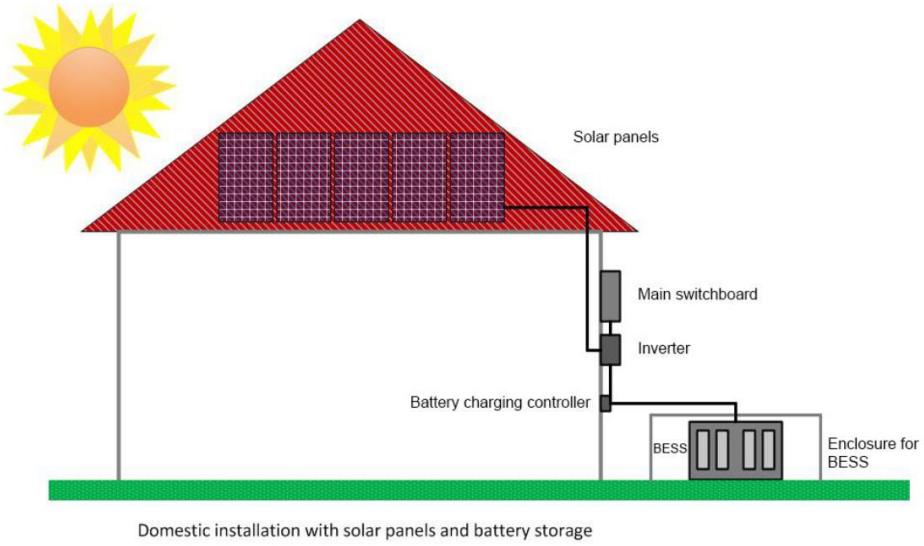

Figure 47. Schematics of a Residencial BESS[203]

4.4 JOB ROLES AND SKILLS

Residential application BESS majorly require the same job roles, competencies, and skills as Industrial BESS, already studied in previous Desk-Research and deeply explored in the workshops. However, the particularity of the place of installation of residential BESS requires a different set of skills, mainly in safety, product development and design of the systems. Like

[200]D4.4 - Desk Research and Data Analysis for sub-sector ISIBA – Release 2, https://www.project-albatts.eu/Media/Publications/23/Publications_23_20210920_83914.pdf

[201]https://www.eurobat.org/images/news/publications/eurobat_batteryenergystorage_web.pdf Last accessed on 20.8.2021

[202]Eum, J. "Analysis on Operation Modes of Residential BESS with Balcony-PV for Apartment Houses in Korea". https://doi.org/10.3390/su13010311

[203]https://www.commerce.wa.gov.au/sites/default/files/atoms/files/battery_energy_storage_systems_0.pdf Last accessed in 25.7.2022

any BESS and as mentioned, residential battery systems require certain skills and job positions that are similar to battery storage systems and a few of them are mentioned in the list below:

Power Conversion

- Bidirectional power conversion
- Hardware engineers
- Power electronic engineers
- Control Engineers

High Voltage Systems

- Qualification and training in high voltage systems
- Materials researchers and Engineers

System Design

- Mechanical Engineers
- Design Engineers
- Product Engineers

BMS

- Algorithm
- Communication Protocols
- Hardware requirements
- Electrical Engineers
- Computer and IT engineers
- IT technicians

Current and Voltage Sensing

- Communication and hardware Engineers

Risk and Safety

- Risk assessment
- Safety legislation knowledge
- Electrical Engineers specialized in electrical safety equipment and procedures
- Certified Electricians

New Battery Materials and Technologies

- Researchers
- Materials Engineers and Scientists
- Chemical Engineers and Chemists
- Electrochemical Engineers and Scientists

Residential application BESS majorly require the same job roles, competencies, and skills as Industrial BESS, already studied in previous Desk-Research and deeply explored in the workshops. However, the particularity of the place of installation of residential BESS requires a different set of skills, mainly in safety, product development and design of the systems.

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Like any BESS and, as mentioned, residential battery systems require certain skills and job positions similar to battery storage systems, such as **power conversion**, **high voltage systems**, **system design**, **BMS** building and implementation and **current and voltage sensing** [204].

Power conversion allows the conversion of electric flow from DC to AC. In PV plants, the power converters are unidirectional. However, **a bidirectional power conversion approach is necessary to avoid unnecessary modules and subsystems that raise the system's cost. Hardware, power electronics and control engineers** with specific knowledge in the area are critical for the system's success.

Usually, batteries in residential application work on 48 V, but the shift to 400 V is becoming popular with the rise of the electric vehicles (EV) sector and the demand for higher energy densities. This switch requires the electricians to be **qualified** to work with **high voltages**. Also, the power conversion equipment must work in this voltage range with security and high efficiency. New materials are being used as silicon carbide and gallium nitride, requiring new skills to be adopted in **materials research and engineering**.

The design of the BESS is thoroughly thought to create a sleek wall-mounted inverter and optimised batteries in terms of **space** and **cooling**. The role of the **Mechanical, Design and Product Engineers** in the optimization of the design of the BESS enables a harmonious and functional design.

The BMS is an important piece of the system's security and operation. **Algorithmics**, **communication protocols,** and **hardware requirements** are the skills needed by **electrical engineers**, **computer and IT engineers,** or **IT technicians** that will develop the BMS.

The power conversion at high frequencies and the safe functioning of the BMS and other controls require that the challenge of current and voltage sensing be surpassed. **Communication and hardware engineers** will contribute to the development of fast and accurate pieces of equipment able to provide the precise readings needed for the correct functioning of the system.

As BESS numbers in residential blocks and homes, safety is a growing concern and with relatively higher importance than in commercial/industrial stationary installations. Safety risks include errors in installation and operation, electric shock, fire, flash burns, explosion or

[204] https://www.ti.com/lit/wp/slyy207/slyy207.pdf?ts=1658767316177&ref_url=https%253A%252F%252Fwww.google.com%252F Last accessed on 24.7.2022

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exposure to hazardous chemicals and released gases.[205] **Risk assessment skills** are crucial in battery companies, and training should be provided to workers and clients of the BESS. The BESS must also be equipped with safety functionalities that allow it to safely shut down to avoid further damage. Therefore **Electrical Engineers** specialising in **electrical safety equipment and procedures** must be incorporated into the product's design. These Engineers should also be knowledgeable of the **safety legislations** in place. [206]

The installation of the BESS should only be performed, as it is required by law in most countries, by **certified electricians** that should follow the directives provided by the battery and other equipment manufacturers.[206]

Although the numbers presented in Section **Virhe. Viitteen lähdettä ei löytynyt. Virhe. Vi itteen lähdettä ei löytynyt.** look promising for the residential sector, the implementation of residential BESS is expected to plateau until 2027 due to lithium scarcity[207]. To counteract this tendency, efforts to recycle existing batteries and **second-life systems** are a solution that allows reusing the already mined lithium. That also means there is an opportunity for **research in new emergent battery technologies** such as Sodium-ion[208] or Redox Flow batteries[209], with **Materials, Chemical, Electrochemical Engineers and Scientists** having a major role in the success of these new technologies.

[205] https://www.commerce.wa.gov.au/sites/default/files/atoms/files/battery_energy_storage_systems_0.pdf Last accessed on 21.7.2022
[206] https://energystorageforum.com/news/energy-storage/residential-bess-installation-safety Last accessed on 21.7.2022
[207] https://www.energy-storage.news/european-battery-energy-storage-deployments-set-to-plateau-over-2024-27-over-lithium-scarcity/ Last accessed 26.7.2022
[208] https://cen.acs.org/business/inorganic-chemicals/Sodium-comes-battery-world/100/i19 Last accessed in 27.7.2022
[209] https://www.dnv.com/article/can-flow-batteries-compete-with-li-ion--179748 Last accessed in 27.7.2022

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5 Job Roles and Skills

We found a lot of material in the form of job advertisements when studying our topic areas. That was especially the case with some renewable power farm and heavy work machine categories. For example, based on the volume of job advertisements mentioning battery energy storage systems in the context of solar and wind power plant-related positions, the demand for battery-related skills and knowledge of variable renewable energy systems is significant.

The job roles and skills-related information is addressed at the end of each chapter/subchapter that covers this deliverable's main topic areas. We provide examples of discovered positions with related descriptions of what skills/knowledge is expected from the applicants. Further, a deeper analysis and summary of the job role and skill material will be provided in D4.8 - Sectoral Intelligence definition for sub-sector ISIBA - Release 2.

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