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Digitization of the Energy Industry

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White Paper Contributors

About the Authors

Greg Bean

Greg Bean is the Executive Director of the Gutierrez Energy Management Institute in the Bauer College of Business at the University of Houston. Prior to joining Bauer, he spent over thirty years in global oil and gas management consulting after starting his energy career with ExxonMobil. He is a graduate of Texas A&M University.

Connor Davies

Connor Davies is a graduate of the University of Oregon with a degree in economics, and has four years of experience in energy consulting. He was trained as an Energy Scheduler and has professional experience in pricing analysis and congestion trading. He is pursuing a career in commercial trading and is currently an MBA candidate with a focus in energy and finance. Davies is currently a Graduate Student Assistant for the Gutierrez Energy Management Institute.

Editorial Board

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WEB DEVELOPER
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EXECUTIVE SUMMARY

Many new digitalization technologies are emerging that will affect all industries, driving new business growth and changing workforce skill requirements. The global energy industry is changing rapidly as it undergoes a transition to a low carbon future. Digitalization and data-enabled technologies will be important enablers of changes necessary in the global energy system. This topic was the focus of a recent symposium and workshop at the Bauer College of Business at the University of Houston. Technologies that are expected to be particularly impactful to the energy industry include advanced data analytics such as artificial intelligence (AI) and machine learning, cloud computing and open source data, digital workflow tools, data visualization tools, quantum computing, robotics, and a variety of safety applications (e.g., drones, wearables, natural language processing). All industry segments will be affected, with the electric power industry likely to experience the biggest impact. New players are likely to emerge, including industrial automation companies and firms with energy industry cloud services business models. Additionally, new business models will emerge, especially in the electric power sector. Start-ups are developing a spectrum of relevant digitalization service areas and technologies. Digital related skills are likely to be among the most needed in a modern professional landscape but other non-technical skills and competencies such problem solving under uncertainty, risk management and innovation will also be required. Today, there is a disconnect between how higher education is traditionally structured and the future needs of a digitalized energy industry. Universities need more focus on multi-disciplinary, real-world problem solving based on critical thinking, effective communication, and the ability to integrate digital skills.

INTRODUCTION

The global energy industry is changing rapidly as it undergoes a transition to a low carbon future. The International Energy Agency has noted the major changes that would be required to reach the key energy-related goals of the United Nations Sustainable Development Agenda in its Sustainable Development Scenario (SDS). The trajectory for emissions in the Sustainable Development Scenario is consistent with reaching global "net zero" carbon dioxide (CO_2) emissions in 2070. If net emissions stay at zero after this point, this would mean a 66% chance of limiting the global average temperature rise to 1.8 degrees Celsius (°C) above pre-industrial levels (or a 50% chance of a 1.65 °C stabilization). The SDS predicts that energy demand will be lower in 2040 than today, despite the world economy growing at an average of 3.4% per year. Gas demand is also predicted to rise to 2030 before falling back. A rising share of low-carbon energy is accompanied by a dramatic reduction in coal use, which is only one-third of current levels by 2030. An oil market of 65 million barrels per day (mb/d) in 2040 returns to a level last seen in the early 1990s.

In the Sustainable Development Scenario, around 20% more investment is needed than in the IEA Current Policies ("business as usual") Scenario. There is a significant reallocation of investment away from fossil fuels and towards renewables, energy efficiency and low-carbon technologies. The investment split on the supply side moves decisively in favor of power, which is 35% higher than the SDS scenario. Fossil fuel investment declines by nearly 50% and renewables spending increases by 250% versus current policies.[1]

One of the most important technological shifts in the energy industry that has led to significant improvements in efficiencies and the incorporation of disruptive changes has been the digital transformation. While there were significant attempts in the 90s and the early 2000s towards the digital transformation, the last decade has seen a demonstrable change in the development and deployment of data-driven technologies. Three fundamental drivers have been responsible for this change: availability of unprecedented computing power, the collection of vast amounts of data (big data) through the internet of things (IoT), and advancements in cognitive computing.

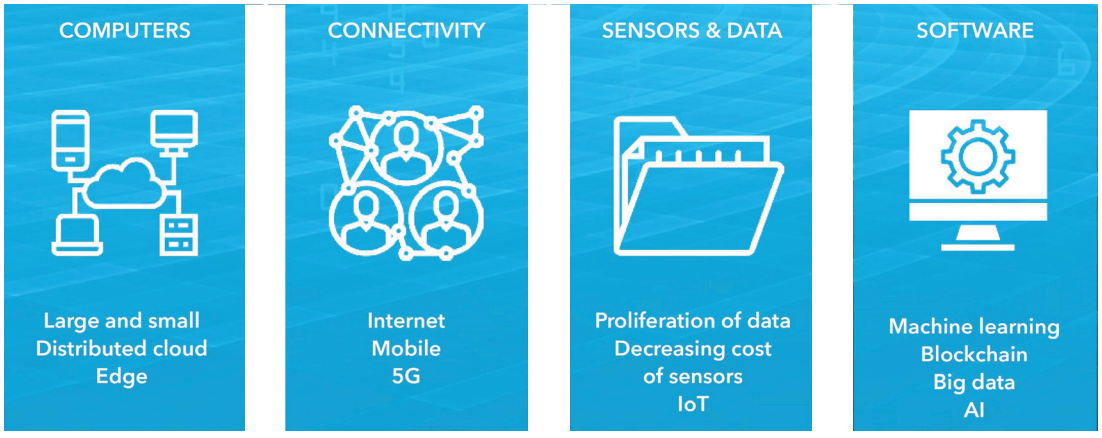
BACKGROUND

Digitization is Affecting All Businesses and Industries

The First Industrial Revolution used steam power to make mechanization an integral aspect of production facilities and would spark an ongoing technological revolution. Building upon the irst revolution, the Second Industrial Revolution would use the power of electricity to replace the steam functionality in mass production. Half a century ago, the Third Industrial Revolution would utilize information technology and electronics to automate the production line. Standing on the shoulders of the previous revolutions, industry is at the brink of the Fourth Industrial Revolution in which digitalization will revolutionize core business processes and efficiency measures across

> "One of the most important technological shifts in the energy industry that has led to significant improvements in efficiencies and the incorporation of disruptive changes has been the digital transformation."

Figure 1: Four Key Components of Digitization



Source: "Digitalization and the Future of Energy." DNV GL.

all sectors. Core business model improvements in this regard provide new revenue and value-producing opportunities.

In general, digitalization involves converting information and measurements to a format using numbers that can be electronically processed, stored, and transmitted. Figure 1 shows the four key components of digitalization.

Specific digital technologies include the following:

Advanced Analytics (including Artificial Intelligence and Machine Learning) – Advanced analytics is a part of data science that uses high-level methods and tools to focus on projecting future trends, events, and behaviors. The major areas that make up advanced analytics are predictive data analytics, big data, and data mining.[2]

Augmented Reality and Virtual Reality – Augmented reality is a technology that layers computer-generated enhancements atop an existing reality to make it more meaningful through the ability to interact with it. Virtual reality is an artificial, computer-generated simulation or recreation of a real-life environment or situation.[3]

Automation and Digital Workflow – Automating and digitizing business processes for energy companies, utility companies, generation power providers and transmission operators can have a significant impact, including making staff available for other projects, reducing errors and accidents and allowing for visibility into commercial decisions.[4]

Blockchain & Distributed Ledgers – Blockchains are shared and distributed data structures or ledgers that can securely store digital transactions without using a central point of authority.[5]

Cloud Computing – The delivery of computing services including servers, storage, databases, networking, software, analytics, and intelligence over the Internet ("the cloud") to offer faster innovation, flexible resources, and economies of scale.[6]

Coding – The basic act of writing, in a programming language, a script that a computer can understand. This script will tell the computer to behave in a certain way, to do a certain thing, and to, ultimately, perform the actions that you want it to.[7]

Cybersecurity – Cybersecurity is the practice of protecting systems, networks, and programs from digital attacks. These "cyberattacks" are usually aimed at accessing, changing, or destroying sensitive information; extorting money from users; or interrupting normal business processes.[8]

Data Visualization – Data visualization is the presentation of data in a pictorial or graphical format. It enables decision makers to see analytics presented visually, so they can grasp difficult concepts or identify new patterns.[9]

Distributed Computing – A distributed computer system consists of multiple software components that are on multiple computers, but run as a single system. Distributed systems offer many benefits over centralized systems, including scalability and redundancy.[10]

Drones and Unmanned Aerial Vehicles (UAVs) – Pilotless vehicles that operate through a combination of technologies such as computer vision, artificial intelligence, and object avoidance tech can be used in a variety of aerial ground, or water activities.[11]

Internet of Things (IoT) – The concept of connecting any device to the Internet and to other connected devices. The IoT is a giant network of connected things and people – all of which collect and share data about the way they are used and about the environment around them.[12]

Digitalization trends represent a major business growth driver. Five of the top ten drivers of business growth are related to digitalization as shown in Figure 2.

Figure 2: Trends set to positively impact business growth up to 2022

Increasing adoption of new technology
Increasing availability of big data
Advances in mobile internet
Advances artificial intelligence
Advances in cloud technology
Shifts in national economic growth
Expansion of affluence in developing economies
Expansion of education
Advances in new energy supplies and technologies
Expansion of the middle classes

Source: "The Future of Jobs Report 2018." Foro Económico Mundial.

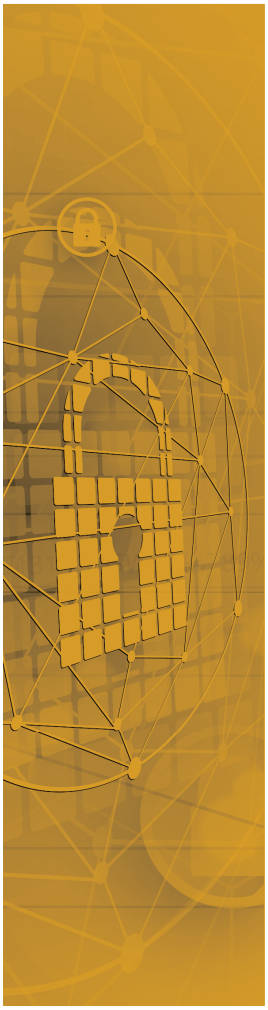
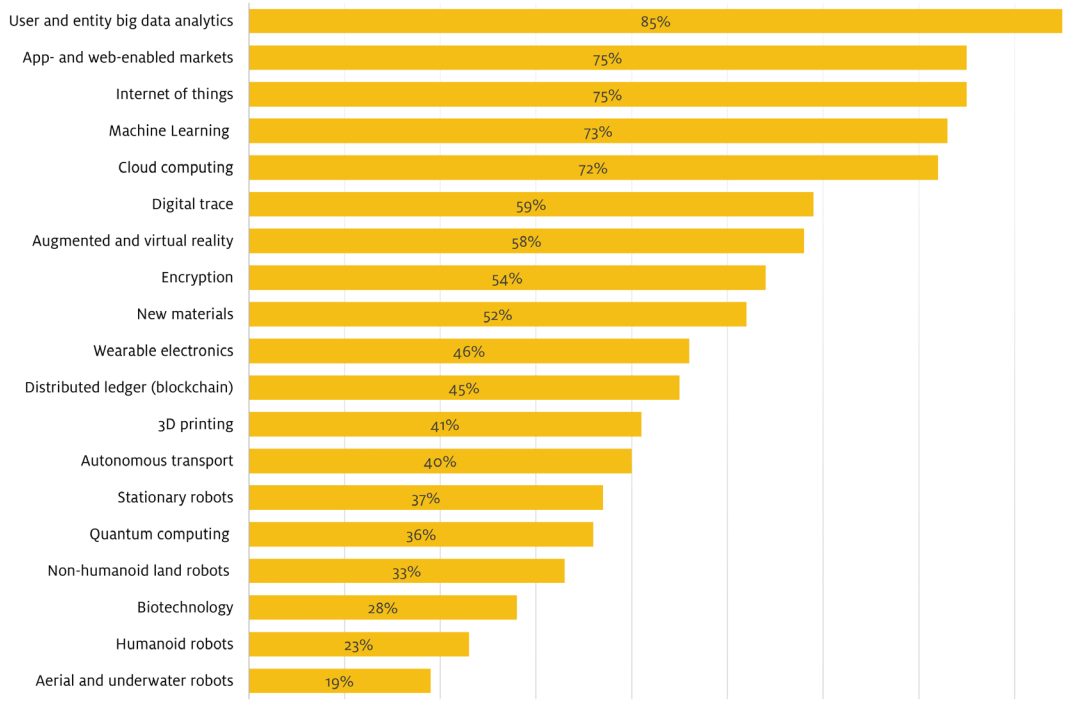


Figure 4: Technologies by Proportion of Companies Likely to Adopt Them by 2022 (projected)



Source: "Future of Jobs Survey 2018." World Economic Forum.

Many of the key technologies that companies are focused on adopting are associated with digitalization (Figure 3).

This translates in demand for many new digitalization-related roles as shown in Figure 4.

Figure 4: New Roles

Data Analysts and Scientists
AI and Machine Learning Specialists
General and Operations Managers
Big Data Specialists
Digital Transformation Specialists
Sales and Marketing Professionals
New Technology Specialists
Organizational Development Specialists
Software and Applications Developers and Analysts
Information Technology Services
Process Automation Specialists
Innovation Professionals
Information Security Analysts
Ecommerce and Social Media Specialists
User Experience and Human-Machine Interaction Designers
Training and Development Specialists
Robotics Specialists and Engineers
People and Culture Specialists
Client Information and Customer Service Workers
Service and Solutions Designers
Digital Marketing and Strategy Specialists

Source: "The Future of Jobs Report 2018." Foro Económico Mundial.

Digitalization is an Important Enabler of Changes in the Global Energy System

Digitalization has transformed the financial industry, medical technologies, and medical care, as well as automobiles and transportation. Most proximal to the oil and gas industry, the digital transformation has advanced the resilience and robustness of the electric grid and has advanced the safety of the downstream chemicals and refining industries. Oil and gas companies are planning to adopt many of the digital-related technologies as shown in Figure 5.

Figure 5: Technology adoption by industry and share of companies surveyed, 2018-2022

	Overall	Oil & Gas
User and entity big data analytics	85	87
App- and web-enabled markets	75	61
Internet of things	75	83
Machine learning	73	70
Cloud computing	72	78
Digital Trade	59	57
Augmented and Virtual Reality	58	65
Encryption	54	57
New Materials	52	83
Wearible Electronics	46	70
Distributed Ledger	45	48
3D Printing	41	57
Autonomous Transport	40	30
Stationary Robots	37	52
Quantum Computing	36	43
Non-Humanoid Land Robots	33	30
Biotechnology	28	39
Humanoid Robots	23	13
Aerial and Underwater Robots	19	52

Source: "The Future of Jobs Report 2018." Foro Económico Mundial.

SYMPOSIUM FOCUS

In October 2019, the Gutierrez Energy Management Institute in the Bauer College of Business at the University of Houston held a symposium and workshop on the potential nature and impact of digitalization in the energy industry. The World Economic Forum has estimated a potential $2 trillion impact over ten years for oil, gas, and electricity. The purpose of the symposium was to deepen understanding of emerging trends and debate potential business opportunities and challenges.

Participants included high-level executives from the oil and gas, renewable energy and power industries as well as representatives from UH colleges, industry research firms, investment banks, and energy-related non-profits.

The session began with context-setting remarks by several topic experts. Participants worked in small groups, under Chatham House rules, to exchange ideas and develop insights in several key areas. Under Chatham House Rules, the free exchange of ideas is facilitated by an agreement not to reveal the names or affiliations of participants and not attribute any statements to individuals.

Potentially High Impact Energy Industry Applications:

Advanced data analytics, AI, and machine learning are already changing how firms make decisions and will change the status quo for all activities along the energy supply chain. Relative to upstream activities, this digital technology development will inform new methods for oil and gas exploration. In the midstream, firms are changing how the grid is managed and maintained with technologies such as predictive maintenance. Downstream operations of trading, procurement, and marketing strategies are subject to change as decisions will be increasingly supported by new AI technology.

Cloud computing and open source data will be pivotal in emerging analytics-heavy applications as the new software will deliver real-time data and analytical capabilities that are reinforced by the supercomputing power of cloud technology. With progressively more complex business environments, cloud computing will also augment business practices such that it makes it easier to manage multi-stakeholder capital projects. Cloud computing will allow firms to manage their costs flexibly and transparently while at the same time providing the requisite scalability as shown in Figure 6. Cloud technology will also offer more value to the customer by allowing firms to implement initiatives that engage their consumers such as the firm's ability to demonstrate "green" branding that is backed by real-time environmental impact monitoring.

Data visualization tools are revolutionizing how information is being accessed and shared. Programs like Tableau allow firms to streamline the reporting process into a user-friendly experience where previously the task of delivering a quality report involved cleaning up the data and interfacing with several programs to create the deliverable. Firms such as ExxonMobil have seen reductions of up to 95% in the time spent on the reporting of key business metrics by using data visualization software.[13]

Blockchain and distributed ledger technologies could be applied to a variety of use cases related to the operations and business processes of energy companies, including wholesale market management, commodity trading transactions, and risk management. Blockchain systems are currently also being developed for green

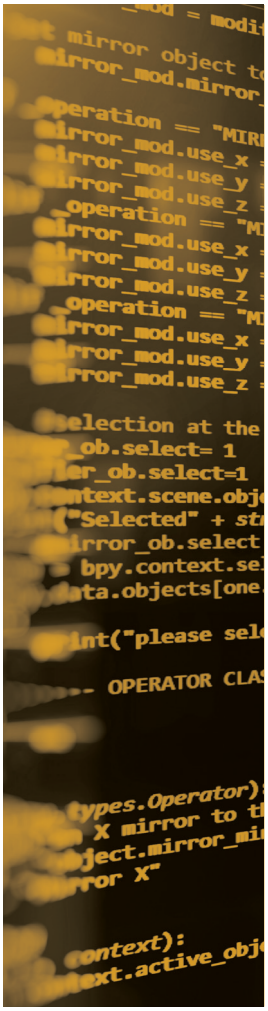


Figure 6: Cloud Computing

Cloud Feature	Potential Benefit
Capital Expedentiures (Capex) to Operating Expenses (Opex)	Reshaping IT finance to take advantage of the as-a-service and on-demand features of the cloud business model Economies of scale help reduce unit cost of ownership
Flexibility and agility with reduced sunk investment	Trials without material can sunk investment Reduced cycle time, changes implemented faster at lower cost
Unlimited compute and advanced analytic capabilities	Responsive operational performance in minutes rather than days Access to the latest technology and innovations such as hyperscale compute, in-memory compute and big data analytics
Transparency and real-time reporting	Supports contracting, joint venture and alliance arrangements
Ability to deliver new products and services quickly and efficently	Faster deployment of infrastructure and IT services Shorter application development cycles Enables bringing new, innovative products and services to market

Source: "What's Driving Utilities to the Cloud?" Accenture.

certificates trading.[14]

From the perspective of training, the rise of ***safety applications*** enabled by digitalization will have major implications on the safety of employees. Relative to employee training, firms can deploy digital training modules that allow safety trainers to deliver training to anyone that has access to the internet. Developments for the safety of onsite workers are continuously evolving, along with new technologies such as wearable devices that can communicate certain physiology metrics of an employee in real-time. A 2014 online survey found that 24% of Americans stated increasing safety would be the number one major factor in their willingness to use wearable technology.[15] Drones are another developing technology that acts as a key part of mitigating employee risk by making tasks like job site safety inspections not only more effective, but safer and more comprehensive.[16] Finally, unstructured data is approximately 80% of the data that organizations process daily.[17] Using natural language processing allows a firm to better analyze safety data to reduce risk and improve operations.

Quantum computing is largely regarded as the next evolution of computing capabilities. It has the ability to solve problems that traditional computers simply aren't equipped to handle. The value quantum computers offer is their ability to address computationally challenging problems across a variety of applications, including the potential to optimize a country's power grid, and perform more predictive environmental modeling and highly accurate quantum chemistry calculations to enable discovery of new materials for more efficient carbon capture.[18]

Robotics is transforming the way the energy industry is approaching the manufacturing, handling, and inspection of equipment, including solar panels and wind turbines. Robots are also revolutionizing the way gas pipelines are inspected as well. Bots that can move throughout a gas distribution system and use sensors to measure wall thickness and stress can dramatically reduce the amount of excavation required to inspect a pipeline system, and some robots can even operate in live mains.[19]

ENERGY SECTORS IMPACTED

Overall, energy companies expect digitalization to have a significant impact on improving efficiency and reducing costs, as shown in Figure 7.

In terms of functionality, Figure 8 shows that energy companies expect a significant impact on asset operations and management, as well as capital projects.

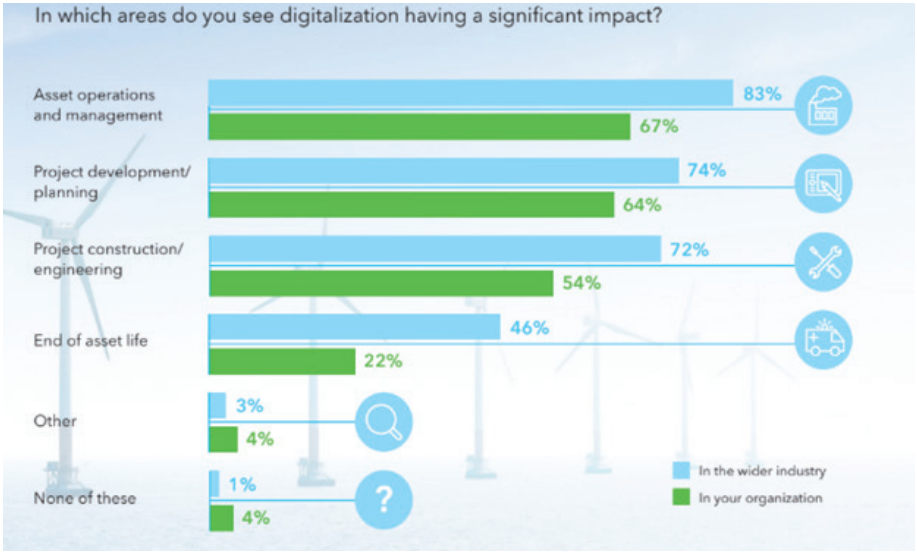
Upstream Oil and Gas

Relative to industry sub-sectors, upstream oil and gas is expected to generate significant value through digitalization by reducing the costs associated with data interpretation, as well as improving production metrics by using predictive maintenance to increase uptime, as shown in Figure 9.[20]

Figure 7: Efficiency and Cost are Main Goals of Digitization

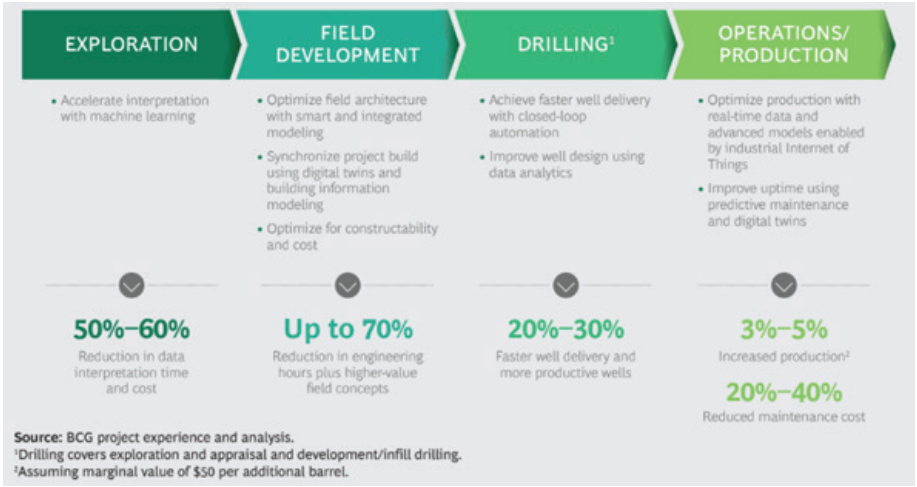
Source: "Digitalization and the Future of Energy." DNV GL.

Figure 8: Digitization has impact on Asset Management



Source: "Digitalization and the Future of Energy." DNV GL.

Figure 8: Digital can Unlock Significant Value in Upstream Activities



Midstream Oil and Gas
The oil and gas midstream sector faces particular challenges, especially regarding ageing infrastructure, and geographically dispersed assets. These challenges create complex optimization opportunities but also subject systems to "license to operate" issues. In particular, obsolete assets are vulnerable to theft and cyberattacks, potentially leading to outages and health, safety, and environmental damage costs to operators. In terms of pipelines, opportunities exist in the digitalization of gathering line systems, processing facilities, trunk lines, and terminal operations.

Terminal operations, a continuous system of process controls and operational procedures to facilitate the storage and delivery of products, are already at a digitalization stage to the extent that a typical medium-size terminal has more than 1,500 transfer operations a day, and countless sub-operations. In many firms, however, there are opportunities to better integrate Enterprise Resource Planning (ERP) systems with the inventory and cargo management process.[21]

Downstream (Refining and Chemicals)
Refineries and chemical plants, due to the complexity of their processes and operations, were the first to embrace digitalization and automation. These segments are now at the leading edge of implementation of robotics and VR technologies in the energy industry.

Electric Power
Electric power is likely to have the biggest impact of all energy sectors, and it is the source of the largest net increase in jobs as a result of digitalization. The industry is going through a significant change with new forces at play such as changes in fuel prices and fuel availability, an influx of variable renewable generation sources, and an increased risk of cyberattacks.[22]

Relative to the electric power market, digitalization provides opportunities in four areas:

- Asset life cycle management: Technology solutions can enable real-time, remote-control or predictive maintenance to extend the life cycle or operating efficiency of the generation, transmission or distribution assets, and infrastructure.
- Grid optimization and aggregation: Grid optimization is possible through real-time load balancing, network controls and end-to-end connected markets, enabled by connected assets, machines, devices, and advanced monitoring capability.
- Integrated customer services: Innovative digitally enabled products and services relating to energy generation and energy management are bundled into an integrated customer service.
- Beyond the electron: Hyper-personalized connected services beyond the electricity value chain, that adapt to the consumer. Electricity moves from being a commodity to becoming an experience.[23]

POTENTIAL NEW BUSINESS MODELS AND PLAYERS

New Players
Industrial automation companies such as ABB, Siemens, Schneider, and Emerson are transitioning from hardware production to include digital services in their offerings. The offered digital services from automation firms are about mitigating the risks associated with cybersecurity, plant monitoring, and plant optimization typically with a suite of applications specific to the firm.

Firms with energy industry cloud services such as Amazon, Google, and Microsoft will play a pivotal role in how energy firms interact with their customers. Industry cloud has various applications within the energy sector, though it's most commonly used for customer relationship management (CRM), providing real-time data, and hosting software.[24]

Given the state of emerging technologies in the energy sector, it is reasonable to expect partnerships develop similar to the ExxonMobil-IBM partnership to develop practical applications of quantum computing.

New Business Models

Potential Electricity Industry Restructuring
The electricity industry is likely to see the biggest change in business models of the major energy industry segments. Relative to the electricity industry as a whole, new business models with a focus on green energy, EV support, and home and business-related services will increasingly be a priority. Shifting focuses to clean energy coupled with digitalization will enable new electricity industry models such as the following:

Virtual utility – A virtual utility aggregates power

> "The offered digital services from automation firms are about mitigating the risks associated with cybersecurity, plant monitoring, and plant optimization typically with a suite of applications specific to the firm."

from various distributed systems and acts as the intermediary with energy markets. A virtual utility also acts as an integrator of non-traditional assets and services that third parties provide to customers, e.g., distributed energy resources outside its traditional service territory.

Grid developer – Utilities in this model acquire, develop, construct, own, and maintain transmission assets that connect decentralized generators to local distribution system operators. Grid developers constantly assess the system's ability to meet current and future needs and seek new assets and asset renewal opportunities.

Network manager – The network manager operates distribution assets and provides access to its networks to generators, interconnectors, and retail service providers. A potential new role could be platform optimizer, providing data and services such as the integration of distributed energy resources.[25]

Texas deregulation of the retail electricity market could provide a platform for innovation on this front.

Innovative Digitally-Enabled Services across segments

Across all energy industry segments, startups with value propositions in the digital services segment relating to the energy sector are beginning to proliferate as well, as shown in Figure 10. These services range from the ability of a smart car to autonomously pay for parking, to climate awareness platforms in which an individual or firm can monitor and buy carbon credits. The following table outlines the spectrum of relevant service areas and technologies that are being developed by start-ups in the energy area.

Challenges and Barriers

Despite the range of technological advances, there are barriers to overcome before some of these technologies can be adopted. The following is a set of identified challenges to the future of digitalization in the energy sector:

- *Regulation* – Unmanned operations via drone technology among other technological advances are subject to a variety of government regulations.
- *Data Standardization/Sharing* – It is unlikely that firms will be willing to share data (especially in exploration), thus creating a barrier to data standardization in the industry.
- *Inability to Experiment Quickly* – Given the fact that digital innovation is now advancing at an unprecedented speed, businesses now have to be able to react and adapt to this ever-changing landscape.
- *Legacy Systems* – Digital transformation represents a major overhaul in the way an organization works. However, failure to change legacy systems for the adoption of new technology will continue to act as a significant barrier to project success.
- *Systems Integration* – In a siloed business, different teams compete for resources and funding, and communication is scarce. And whilst this organizational structure may once have worked, these behaviors are not conducive to digital transformations, which require change across the entire end-to-end business.
- *Lack of Talent* – Without the right skills in a business, organizations will remain fundamentally unable to complete their digital transformation projects.

Figure 10:

Service Area	Technology		
Carbon	Carbon Management	Carbon Credit	-
Data	Data Management	-	-
Energy	Energy Effieciency	Energy Savings	Domestic Applications
EVs, Grid	EV Sharing	Fleet Management	Smart Changing & Parking
Grid	Grid Services	Grid Performance	Grid Monitoring
Platforms	P2P Energy trading	Storage	-
Smart	Metering	Billing & Switching	-
Financing	Financing by Project	Cryptocurrency	Climate Finance

- *Cybersecurity* – businesses need to be able to protect themselves as more and more information is moved to the cloud, and as organizations become increasingly reliant on technology.[26]

Skill Sets and Competencies

In general, digital related skills are among the most needed in a modern professional landscape (Figure 11).

Other sets of skills and competencies that will be needed in a digital environment are as follows:

Sustainability and Sustainable Business Models – To meet sustainability targets, innovation on the business model level is required to align incentives and revenue mechanisms to leverage sustainable solutions.[27] With the global push towards sustainable goals, whether it be carbon free energy or responsible drilling practices, a competency in sustainable operations relative to the energy sector will be extremely beneficial to future job seekers.

Risk Management – Deregulated and decentralized energy markets will increase in complexity and introduce new risks. New job force participants in the energy sector will need an in-depth understanding of risk management if they are to provide immediate and constructive value to firms.[28]

Innovation and Entrepreneurship – Innovation is the ability to come up with new solutions that are either brand new, or are practical improvements of existing ideas. As it relates to entrepreneurship in the energy sector, job seekers need to be equipped to identify opportunities for improvement and be able to effectively market the idea.[29]

Problem Formulation and Problem Solving under Uncertainty – Job seekers need to have a foundation of problem-solving skills in nearly every aspect of the energy sector. Complex skills like Systems Thinking will be needed to identify patterns of behavior and to surface underlying structures that drive those events and patterns.[30]

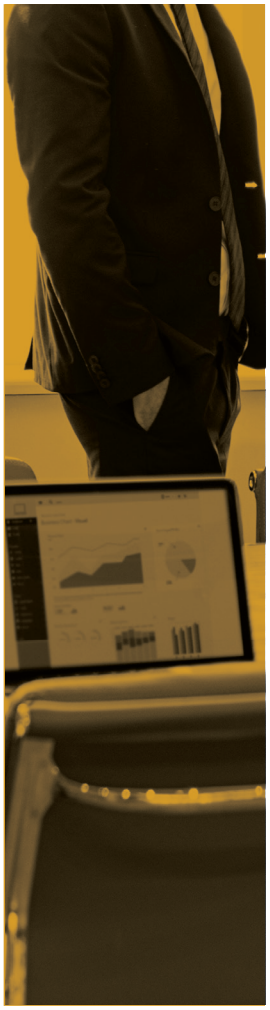
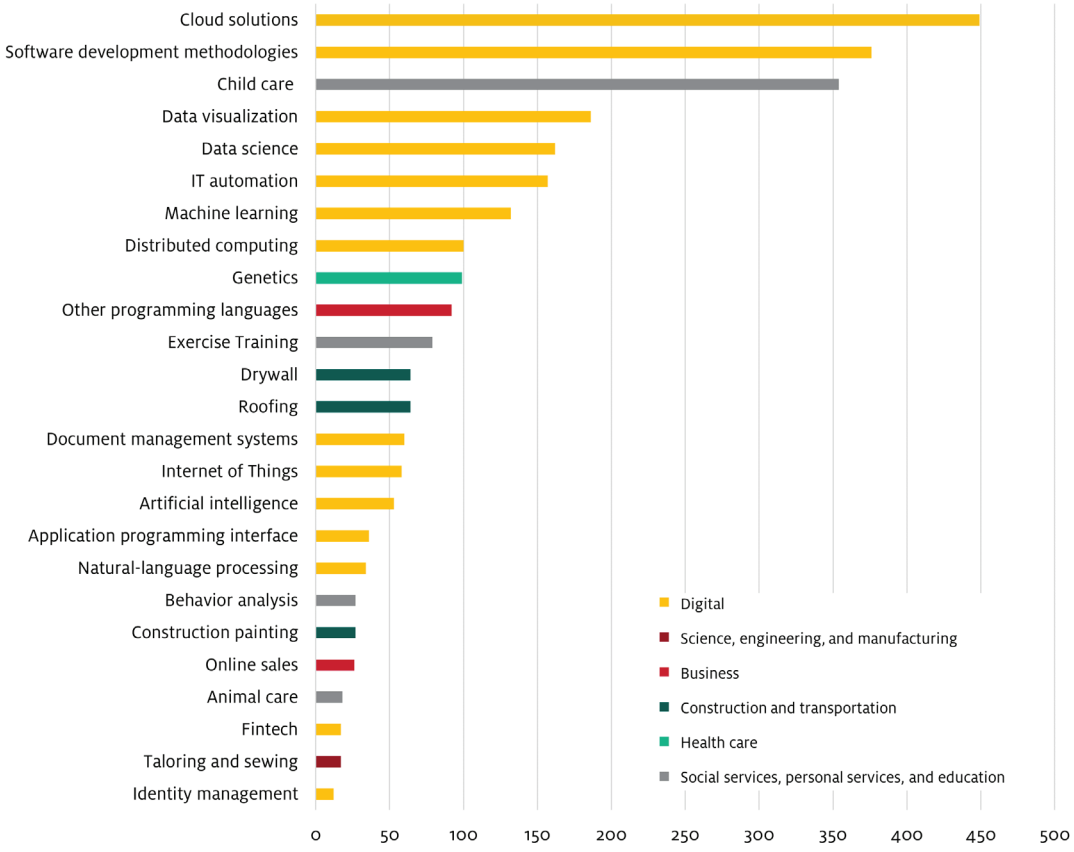


Figure 11: Top Fast-Growing Skills Ranked by Mentions in Online Postings



Source: "What's Trending in Jobs and Skills." BCG

Critical Thinking Pertaining to Data – Every day, the energy grid gets smarter and kicks off an increasing amount of data, especially in a deregulated market. For instance, in the California ISO, there are thousands of locational pricing nodes updating databases every five minutes. This data is driving decisions in everything from production output to infrastructure development. The ability to convert big data to useable information is a necessity as a professional in a modern energy sector.

Continuous Learning – Corporate learning departments are changing from education providers to content curators and experience facilitators, developing innovative platforms that turn employee learning and development into a self-driven pursuit. In a 2016 report by Deloitte, more than eight in 10 executives (84 percent) view learning as an important (40 percent) or very important (44 percent) issue.[31] Beyond the firm's culture shift towards self-learning, the employee has to at least be comfortable with independently learning new concepts and skills.

Multi-Disciplinary Collaboration and Teamwork – As organizations adopt new technologies, they're finding that virtually every job must change, and that the jobs of the future are more digital, more multidisciplinary, and more data- and-information-driven.[32] To maximize the productivity of teams in a deregulated market that is based on principles of supply and demand (concepts grounded in technical specifications of infrastructure), a multidisciplinary understanding of a problem improves team efficiency and efficacy.

Bridging the Academic Gap

There is a disconnect between how higher education is traditionally structured and the future needs of a digitalized energy industry as shown in Figure 12.

Universities need to make significant changes regarding their approach to making the student body marketable in a modern workplace. The following are dimensions in which universities can take measures against this widening gap:

- Focus on experiential learning for undergraduate and graduate students – these include student research and consulting projects, internships, and team competitions
- More PhD research internships in industry
- Stackable certificate programs
- Joint Industry-University projects (e.g., Prototyping)
- Matching computer language with industry hardware, workflow via better industry familiarization
- More flexible curriculum with more focus on specific and granular skills and needs

POST SCRIPT

As we move into an era of unprecedented weakness in demand and a supply glut of oil and gas, the need to improve efficiencies, reduce costs, maximize the use of existing capital equipment and minimize risk, is going to result in a higher dependence on disruptive digital technologies. Eliminating high-risk exposures for people, such as in offshore production, by the employment of remotely controlled robots that can inspect, maintain and repair the facility will become a reality in the near future on platforms designated as "nominally unmanned platforms".

"There is a disconnect between how higher education is traditionally structured and the future needs of a digitalized energy industry."

Figure 12: The Higher-Ed Disconnect

Current System	Desired System
Disconnected from Industry Pressures & Objectives	Understanding Business Objectives & Values
Competition	Collaboration
Individual	Team-work
Single-number answers	Uncertainty
Strict Assumptions	Fuzzy Complexities
Multi-disciplinary, Real-world, Problem Solving Based on Critical Thinking, Effectively Communicating & Integrating Digital	

Source: "Digital and Automated: Transforming the Energy Industry." Ramanan Krishnamoorti, University of Houston.

FOOTNOTES

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