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# LEVERAGING BLOCKCHAIN TECHNOLOGY TO CREATE A MORE RESILIENT SUPPLY CHAIN FOR ENERGY INDUSTRY

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**Leveraging Blockchain Technology to Create a More Resilient Supply Chain for Energy Industry**

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**Abstract**

**Purpose:** Blockchain is an evolving technology that has attracted considerable attention over the past few years from emerging businesses, energy supply enterprises, technology developers, financial institutions, government agencies, and academic institutions. Many references from these contexts describe blockchain as being capable of delivering substantial benefits and creativity. This paper aims to investigate the way in which blockchain technology is likely to influence future supply chain practices in energy sector.

**Methodology:** A systematic review of both academic and nonacademic literature was conducted to gain a deep insight on the possibilities of leveraging the blockchain technology to create a more resilient supply chain for oil & gas industry. Toward this goal, the theoretical foundations of numerous research papers published in high-profile scientific journals over the past few years, along with several reports generated by well reputable and prestigious consulting firms that have been used to outlook the potential and relevance of blockchain technology for energy industry applications.

**Results:** Blockchain can bring many opportunities to the oil & gas industry, such as reducing transaction costs and improving transparency and efficiency. However, since it is still in the early stage of the application, there are still many challenges, primarily technological, regulatory and system transformation. The development of blockchains in the oil & gas industry will move toward hybrid blockchain architecture, multi-technology combination, cross-chain, hybrid consensus mechanisms, and more interdisciplinary professionals.

**Unique Contribution to Theory, Practice and Policy:** This paper offers valuable insight for supply chain practitioners into how blockchain technology has the potential to disrupt existing supply chain provisions as well as a number of challenges to its successful spreading. To the best of the author's knowledge, this paper is one of the first studies in the Kingdom of Saudi Arabia to explore the possibility of leveraging the blockchain technology to create a more resilient supply chain for oil & gas industry. Blockchain is a promising breakthrough technology and is highly applicable to vast businesses. However, it is still hard to find empirical evidence to show the comparison between blockchain approaches and traditional approaches. In view of this, businesses should realize that blockchain technology has not yet reached an optimal level of maturity, and therefore thorough feasibility studies should be conducted before using this technology.

**Keywords:** *Blockchain; Technology, Supply Chain; Resilient, Trust, Smart Contract, Energy, Oil, Gas, Industry*

## INTRODUCTION

Blockchain is simply a system of recording information in a systematic way that makes it difficult or impossible to change, hack, or cheat the system. A blockchain is essentially a digital ledger of transactions that is duplicated and distributed across the entire network of computer systems on the blockchain. Each block in the chain contains a number of transactions, and every time a new transaction occurs on the blockchain, a record of that transaction is added to every participant's decentralized database (ledger), which known as Distributed Ledger Technology (DLT) (Euromoney Institutional Investor PLC., 2020).

Blockchain is a potent and versatile emerging technology that is only starting to live up and hold promise for both, manufacturers, the supply chain and many other businesses. Blockchain is a distributed database that fosters trust and lowers transaction costs, and has the potential to change how organizations operate. The challenge for organizations is threefold: understanding the technology, determining how blockchain can be molded to create value, and developing an approach that captures value early on, in order to fund the journey (Ganeriwalla, Casey, Shrikrishna, Bender, & Gstettner, 2018).

Blockchain technology offers a solution to the growing problem of how to manage increasingly complicated networks of manufacturers and suppliers at a time when transparency, speed, and agility are critical. Blockchain also offers a more decentralized approach to data management and sharing, can improve the transparency, speed, and responsiveness of these complex ecosystems by the following means:

- Time-stamping, tracking, and automating transactions, so that the events can be audited in real time.
- Minimizing the involvement of intermediaries such as bankers, insurers, and brokers.
- Setting up a wide range of self-executing contracts to automate repetitive processes such as billing and shipping.
- Establishing proof of quality, provenance, payment, and performance to minimize counterfeiting and fraud.
- Making it easier, faster, and cheaper to onboard new vendors and partners by assigning digital IDs.

From a narrow operational standpoint, blockchains are not, in and of themselves, more efficient than centralized data systems. After all, they require additional computation power but the technology is uniquely able to resolve important issues of trust and visibility in widespread, increasingly fluid manufacturing and supply networks. It promises to be a game-changer for companies that need more agile supply chains to keep up with changing customer demands, or that are making the transition from market player to platform provider.

Looking forward, blockchain technology's potential impact across industries is even greater when examined in a larger context. The convergence of technologies such as predictive analytics, machine learning, robotics, 3D printing, and the industrial internet is already transforming manufacturing and the supply chain. The greatest value will come into play when companies combine a blockchain with a mix of these technologies for greater power and synergy.

Now that digital technologies have removed the physical constraints on data transfer, trust may be the last major barrier to optimizing the flow of information that market economies thrive on. Blockchain technology's ability to remove this barrier may allow us to finally unlock the real economic potential of our hyperconnected age. For supply chains, this could be revolutionary (Ganeriwalla, Casey, Shrikrishna, Bender, & Gstettner, 2018).

As energy organizations look forward to building more resilient and optimal procurement and supply chains for the future, it will be more important than ever to ensure that technology deployments are inclusive, interoperable, and have integrity. Leveraging advanced technologies such as the blockchain, internet of things (IoT), artificial intelligence (AI), robotics, and digital social networking (DSN) are designed to anticipate and meet future challenges. Blockchain technology started almost a decade back as a platform on which cryptocurrencies function. According to Don & Alex Tapscott, authors of Blockchain Revolution (2016), "the blockchain is an incorruptible digital ledger of economic transactions that can be programmed to record not just financial transactions but virtually everything of value."

As the development and spreading of blockchain technology is still in its infancy, a systematic review of current thinking is likely to assist both academics and managers' sensemaking, where they become aware of this technological innovation, sense its potential disruptive effect, make an initial exploration of its efficacy and decide whether to either embrace or ignore it. A systematic review will provide a solid foundation by cultivating a deep understanding of blockchain technology when its tangible benefits are unclear, disruptive effect unpredictable and its diffusion path ambiguous. A systematic review will separate the hype from reality by identifying evidence where the blockchain has potential to disrupt supply chains (both positively and negatively), identify challenges to its future diffusion and offer agendas for future research.

**Research Question (RQ) and Objectives (ROs)**

This research paper aims to address how to leverage blockchain technology to create a more resilient supply chain for energy industry? And in relation to this research question, this paper sets the following Research Objectives (ROs):

- RO# 1. To identify drivers to blockchain deployment within supply chains in energy sector.
- RO# 2. To identify areas where the blockchain provides the most value for supply chain management in energy sector.
- RO# 3: To map the potential of blockchain in improving supply chain performance.
- RO# 4. To investigate the challenges / barriers to further diffusion of the blockchain within the supply chain in energy sector.
- RO# 5. To develop elements of a future research agenda for the blockchain within the supply chain in energy industry.

This research paper is divided into four (4) main sections, and is organized as follows:

**Section 1** sheds some light on the research question and the main objectives of this research paper. It also provides a historical background and conceptual description of blockchain technology and its evaluation. This section discusses foundational principles of the blockchain technology, and different system architectures and consensus algorithms that determine critical technical characteristics of blockchain systems. A substantial amount of current knowledge on blockchains comes not only from traditional academic sources, such as journals and conference proceedings, but forums, blogs, wikis, white papers and industrial reports. The paper also briefly discusses the relationship between blockchain technology and digital transformation, the futuristic initiatives of blockchain technology, and where does it add value?

**Section 2** discusses in details the application prospects of blockchain technology and its influence in the energu industry.

**Section 3** provides a discussion on results, findings, limitations, market barriers, challenges, and future trends and development.

**Section 4** concludes this work with implications and recommendations.

**Blockchain Technology Historical and Conceptual Background**

Blockchain technology is one of the biggest novelties of the 21st century due to its significant impact on various sectors including but not limited to financial, manufacturing and education, as well as many other businesses. It might be unknown to many that the history of blockchain is dated back to early 1990s. The popularity of blockchain has increased during the past ten years. This section sheds some light on how did blockchain emerge and revolutionize over the past few decades.

**Early Years of Blockchain Technology (1982-2008)**

In his 1982, PhD dissertation 'Computer Systems Established, Maintained, and Trusted by Mutually Suspicious Groups' cryptographer David Chaum first proposed a blockchain-like protocol (Chaum, 1982). Further work on a cryptographically secured chain of blocks was described in 1991 by Stuart Haber and W. Scott Stornetta (Haber & Stornetta, 1991). In 1992, Haber, Stornetta, and Dave Bayer incorporated hash trees to the design, which improved its efficiency by allowing several document certificates to be collected into one block. The first blockchain was conceptualized by a person (or group of people) known as Satoshi Nakamoto in 2008 (Wikipedia, 2020). Using a Hashcash-like technique to time stamp blocks, Nakamoto significantly improved the design without requiring them to be signed by a trusted party and adding a difficulty parameter to stabilize the rate at which blocks are added to the chain. Since Satoshi Nakamoto left the scene and turned over the development of Bitcoin to other core developers, digital ledger technology has evolved, resulting in new applications that make up the history of the blockchain.

## Evolution of Blockchain

### Phase 1 - Transactions (*2008-2013: Blockchain 1.0: Bitcoin Emergence*)

Some people believe that Blockchain and Bitcoin are the same thing, however this is not the case. The first major application of blockchain technology was bitcoin which was released in 2009. Bitcoin is a cryptocurrency and the blockchain is the technology that underpins it. A cryptocurrency refers to a digital coin that runs on a blockchain. As stated earlier that the Bitcoin came into being in 2008 as the first application of Blockchain technology. Satoshi Nakamoto in his whitepaper detailed it as an electronic peer-to-peer system. Nakamoto created a genesis block from which other blocks were mined and interconnected, resulting in one of the largest chains of blocks carrying various pieces of information and transactions. Since the inception of Bitcoin, a number of applications have been developed and all of which aim to leverage the standards and capabilities of the blockchain technology. As a consequence, blockchain history includes a long list of applications that have come into being with the evolution of the technology.

### Phase 2 – Smart Contracts (*2013-2015: Blockchain 2.0: Ethereum Development*)

Bitcoin's limitations motivated the developer, Vitalik Buterin, to start working on what he felt would be a more flexible blockchain that can perform various functions in addition to being a peer-to-peer network. Ethereum was born as a new decentralized blockchain in 2013 with added features similar to Bitcoin, a breakthrough that turned out to be a crucial moment in the history of Blockchain. The new feature has extended the Ethereum scope from just a blockchain to becoming a forum for creating decentralized applications as well. Ethereum blockchain was introduced in 2015 and has been evolved to become one of the main applications of blockchain technology due to its ability to endorse smart contracts used to execute different functions. Ethereum blockchain platform has also managed to bring together an active developer community that has seen the establishment of a true ecosystem.

### Phase 3- Applications (*2018: Blockchain 3.0: The Future*)

Over the last few years, a variety of schemes have built up all the capabilities of blockchain technology applications. New initiatives have aimed to solve some of the limitations of Bitcoin and Ethereum in addition to developing new applications to take advantage of blockchain capabilities. Some of the new blockchain projects include NEO, the first open-source, decentralized and blockchain network inaugurated in China. Despite the fact that the nation has outlawed cryptocurrency, it remains active when it comes to blockchain technology. NEO has already gained the blessing of Alibaba CEO Jack Ma, as the Chinese Ethereum is planning to have the same impact as Baidu in China. In a quest to accelerate the economic expansion of the internet of things, some developers have been able to use blockchain technology and IOTA (an open-source distributed ledger and cryptocurrency designed for the internet of things) was part of the process. The cryptocurrency platform is constructed for the decentralized internet of things, with the aim of delivering zero transaction charges as well as unique authentication processes. It also provides a solution to some of the scalability issues that are related to Blockchain 1.0 Bitcoin. The second generation of blockchain technologies have a significant impact in the market. Monero Zcash and Dash blockchains have been established as a means to resolve some of the security and scalability

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issues that are related to early blockchain applications. Other cryptocurrencies, Altcoins, aim to provide a high degree of privacy and protection when it comes to transactions.

**Blockchain Technology Conceptual Background**

**The Concept of Blockchain**

A blockchain is a database that is shared across a network of computers. Once a record has been added to the chain it is very difficult to change. Essentially, blockchain is a kind of mode to realize and manage transaction processing through transparent and trustworthy rules to construct non-forgeable, non-tampering and traceable blockchain data structure in peer-to-peer (P2P) network environment (Zheng, Xie, Dai, Chen, & Wang, 2017). It is a new application mode combining computer technologies such as distributed data storage, consensus mechanisms, P2P transmission, and encryption algorithms. The biggest innovation of blockchain technology is that transactions are no longer stored in the central database, but are distributed to all participants. Figure I depicts the Transactional Models, (a) Traditional model, and (b) Blockchain model.

(a) Traditional model (b) Blockchain model

*Figure I: Transactional model*

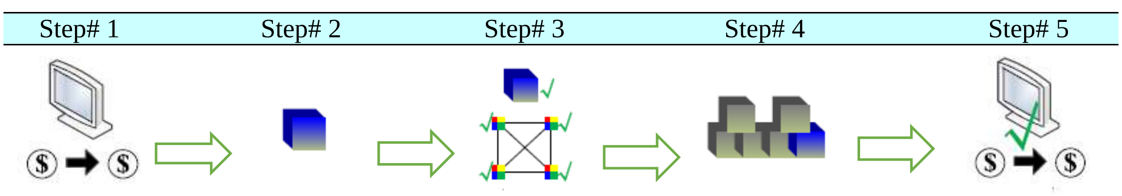



*Figure 2: The blockchain process*

As shown in Figure 2, if a person agrees to complete a transaction with another person (Step 1), they use the transaction related data as a variable and combine with other transactions in the same period to form a new data block (Step 2). Each transaction is encrypted and distributed to multiple computers in a P2P manner. Network members use algorithms to validate transactions stored on individual computers. The algorithm appends a unique hash value to each block. If any information related to the transaction is tampered with, the correct hash value cannot be generated, and an error is reported (Step 3). When this block is successfully verified, it is combined with the block that was previously verified to form a blockchain (Step 4). Finally, both parties confirm the transaction, which means the transaction is successful (Step 5) (PwC global power & utlities, 2016).

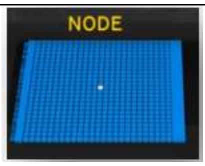
According to Boston Consulting Group (BCG), blockchain technology is built on a foundation of the following four key elements (Ganeriwalla, Casey, Shrikrishna, Bender, & Gstettner, 2018):

- **Distributed ledger and peer-to-peer network:** Blocks of data are chained together, and that blockchain is replicate on different nodes of network ensuring resilience and transparency.
- **Digital signatures and hash functions:** Strong encryption and antitampering measures mean that data can't be retroactively altered and that fosters trust.
- **Consensus algorithms:** A consensus mechanism authenticates the underlying data, eliminating the need for intermediaries (such as banks and brokers) in a transaction.
- **Smart contract:** Under certain circumstances, software code is triggered to execute contractual obligations (such as asset transfer) automatically.

**How does blockchain work?**
A Database: Records are bundled together into blocks and added to the chain one after another. The basic parts:

- The Record: Can be any information, a deal for example.
- The Block: A bundle of records.
- The Chain: All the blocks linked together.

Here is how a deal gets included in a blockchain:



**Step 1**
A trade is recorded. For example, let's say Mr. X is selling two of his coins to Mr. Y for SAR100. The record lists the details, including a digital signature from each party.

**Step 2**
The record is checked by the network. The computers in the network, called 'nodes', check the details of the trade to make sure it is valid.

**Step 3**
The records that the network accepted are added to a block. Each block contains a unique code called a hash. It also contains the hash of the previous block in the chain.

**Step 4**
The block is added to the blockchain. The hash codes connect the blocks together in a specific order.

*Figure 3: Blockchain Technology - How it Works?*

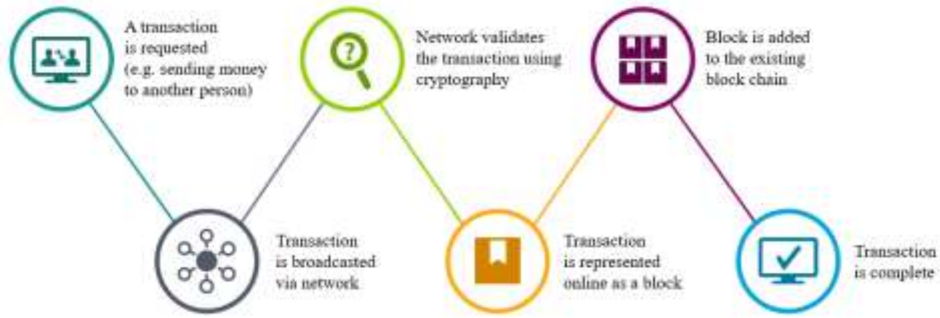



*Figure 4: Blockchain Technology - How it Works Timeline*

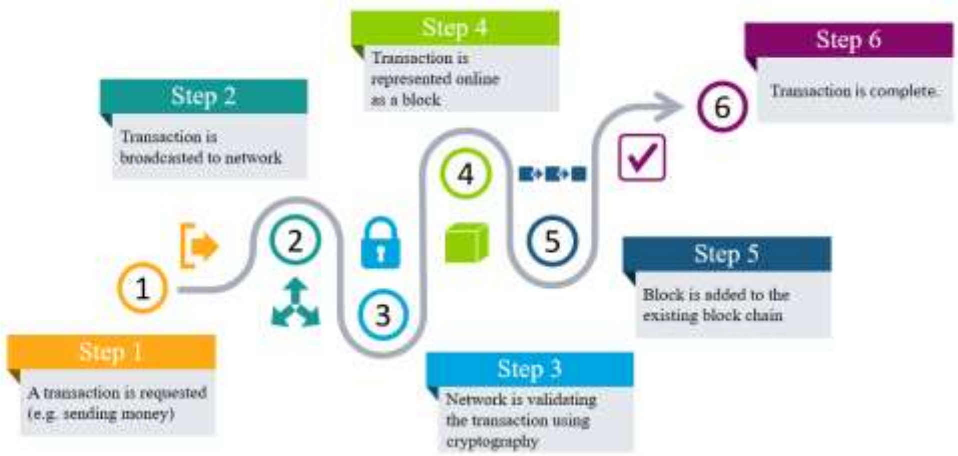



*Figure 5: Blockchain Technology - How it Works Roadmap*

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Blockchain structural features, what does it means for Supply Chain and common characteristics:

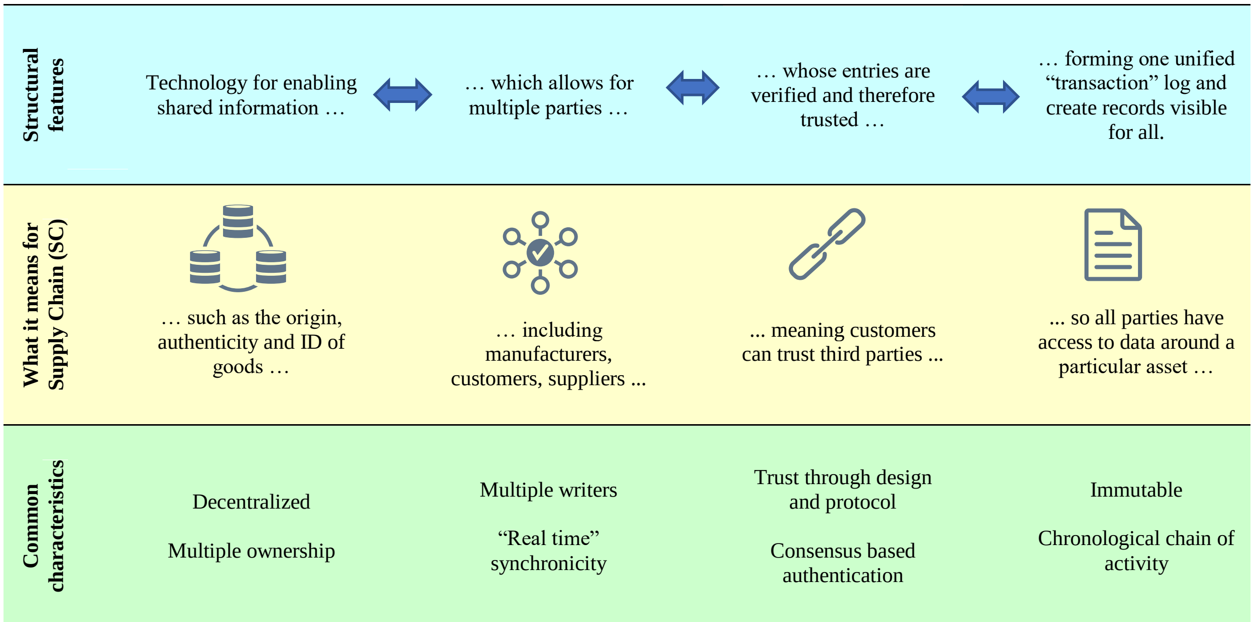


*Figure 6: Blockchain Structural Features and its Meaning for SC & Common Characteristics*

**Table I: Main Types of Blockchains Segmented by Permission Model**

| | | | Read | Write | Commit | Example |
|---|---|---|---|---|---|---|
| Blockchain types | Open | Public permission less | Open to anyone | Anyone | Anyone * | Bitcoin, Ethereum |
| | | Public permissioned | Open to anyone | Authorized participants | All or subset of authorized participants | Sovrin |
| | Closed | Consortium | Restricted to an authorized set of participants | Authorized participants | All or subset of authorized participants | Multiple banks operating a shared ledger |
| | | Private permissioned ("enterprise") | Fully private or restricted to a limited set of authorized nodes | Network operator only | Network operator only | Internal bank ledger shared between parent company and subsidiaries |

** Requires significant investment either in mining hardware (proof-of-work model) or cryptocurrency itself [proof-of-stake (PoS) model].*

## Key Characteristics of Blockchain

Blockchain technology has six main characteristics, including: decentralization, immutability, transparency, efficiency, security and anonymity (Lu, Huang, Azimi, & Guo, 2019).

- **Decentralization:** Decentralization is the most essential feature of the blockchain-based system, which means that the blockchain based system no longer depends on the central processing node, which realizes the distributed recording, storage, and update of data

(Sultan, Ruhi, & Lakhani, 2018). The status of each node is the same, and the data blocks are maintained by the nodes with the maintenance function in the entire system. Stopping any node will not affect the overall operation of the system (Lu, Huang, Azimi, & Guo, 2019).

- **Immutability:** Information cannot be changed after the it is verified and added to the blockchain. For example, in the Bitcoin's blockchain system, unless more than 50% of the nodes in the control system can be simultaneously controlled, the modification is invalid, so the data stability and reliability of the blockchain are extremely high (Sikorskia, Haughtona, & Kraft, 2017).
- **Transparency:** Transparency is the basis for blockchain to be trusted because data record and update are transparent to the nodes of the entire network. Therefore, network-wide nodes with high transparency can be used to review, track data records, and track operations (Jansen, 2018), (Lu, Huang, Azimi, & Guo, 2019).
- **Efficiency:** The blockchain technology makes the system more transparent by distributing database records to users in the system, so it is more efficient in terms of risk, cost, and so on (Hughes, 2018), (Christidis & Devetsikiotis, 2016).
- **Security:** If a centralized network is attacked, it is likely to affect the whole system. However, blockchain-based system has the characteristics of decentralization. If a node is attacked, it will not destroy the security of the entire system. Moreover, blockchains use public key infrastructure to prevent malicious behavior from changing data, thus providing better security (Sultan, Ruhi, & Lakhani, 2018).
- **Anonymity:** In the blockchain systems, both parties can make the transaction anonymous because the program rules in the blockchain can automatically determine whether the exchange activities between nodes are valid (Dorri, Roulin, Jurdak, & Kanhere, 2020).

### Classification of Blockchain Systems

The blockchain-based system can be divided into two categories according to the openness: permissioned blockchain and permissionless blockchain (public blockchain) (PricewaterhouseCoopers (PwC), 2017), (Casino, Dasaklis, & Patsakis, 2019). The permissioned blockchain can be further divided into the private blockchain and consortium blockchain (Lu, Huang, Azimi, & Guo, 2019).

- **Private Blockchain:** The private blockchain refers to a blockchain whose write permission is only controlled by an organization or an individual, and the read permission may be open to the outside. The private blockchain system is the most closed and is limited to use by enterprises, state agencies or individuals. It does not fully solve the trust problem, but it can improve auditability (Zheng, Xie, Dai, Chen, & Wang, 2017).
- **Public Blockchain:** The public blockchain refers to a blockchain that can be read by anyone in the world, can send transactions and can be validated effectively, and anyone can participate in the consensus process. The public blockchain is the ultimate embodiment of decentralization (Samaniego, Jamsrandorj, & Deters, 2017).

- **Consortium Blockchain:** The consortium blockchain refers to a blockchain that is restricted to the participation of the members of the consortium. The read and write permissions on the blockchain and the participation of the accounting rights are determined according to the consortium rules. Each participant in the consortium blockchain does not have to worry about where their data exists. The data they generate can only be seen by themselves or by authorized people. In this way, it will solve data privacy and security issues and decentralize. It is a combination of public and private blockchains (Pilkington, 2015). Table 2 summarizes the characteristics of the three kinds of blockchains (Zheng, Xie, Dai, Chen, & Wang, 2017), (Atlam & Wills, 2018), (Viriyasitavat & Hoonsopon, 2019). When selecting the blockchain type, factors such as database requirements and multi-party writing should be considered. A white paper published in 2018 by China Academy of Information and Communications Technology and Trusted Blockchain Initiatives have a flow chart for choosing blockchain types (China Academy of Information and Communication Technology and Trusted Blockchain Initiatives, 2018), as shown in Figure 7 below.

**Table 2: Comparison of Three Blockchains**

| **Property** | **Private blockchain** | **Public blockchain** | **Consortium blockchain** |
|---|---|---|---|
| Access | Public or restricted | Public | Public or restricted |
| Energy | Low | High | Low |
| Speed | Faster | Slower | Faster |
| Efficiency | High | Low | High |
| Security | Pre-approved participants and voting/multi-party consensus | Proof of work, proof of stake, and other consensus mechanisms | Pre-approved participants and voting/multi-party consensus |
| Immutability | Could tampered | Nearly impossible to temper | Could be tamper |
| Consensus process | Permissioned and known identities | Permissionless and anonymous | Permissioned and known identities |
| Consensus determination | Centralized organization | All miners | Leader node set |
| Network | Centralized | Decentralized | Semi-centralized |
| Asset | Any asset | Native asset | Any asset |
| Transaction approval | Other of milliseconds | Other of minutes | Other of milliseconds |

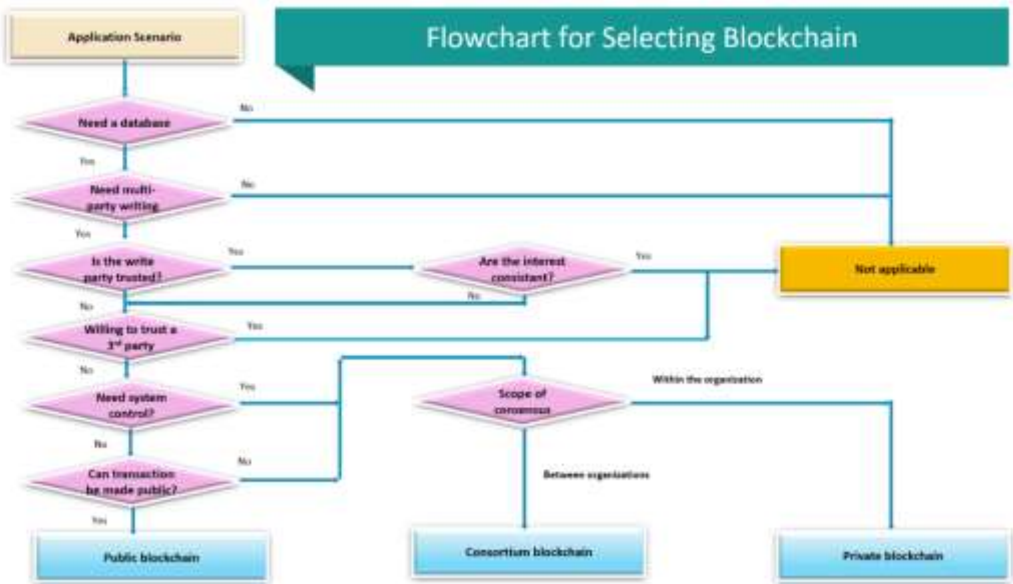


*Figure 7: Flow Chart for Selecting Blockchain*

**Consensus Algorithm**

The verification process is to achieve a consensus on the content of the distributed ledger. It is a process of decentralization and automation. It can be said that the consensus algorithm is one of the most critical technologies in the blockchain. The blockchain consensus algorithm can be classified according to fault tolerance type and consistency degree. In order to facilitate the description of the core mechanism of the consensus algorithm, Yuan and Wang in their article 'Blockchain: The state of the art and future trends' classified it according to the leader election strategy. Their classification and characteristics are shown in Table 3 (Yuan & Wang, 2016).

**Table 3: Consensus Algorithm Type and Characteristics**

| Consensus algorithm type | Characteristics |
|---|---|
| Proof-based | Proof is usually competitive to accomplish a task that is difficult to solve but easy to verify. |
| Voting-based | Minors who first obtain more than half of the votes will receive the accounting rights. |
| Stochastic | Determine each of accounting nodes directly according to a random method. |
| Alliance | A group of representative nodes are elected based on a specific method, and representative nodes obtain the accounting rights in turn by rotation or election. |
| Hybrid | Use a mixture of multiple consensus algorithms to select accounting nodes. |

**Blockchain Technology and Digital Transformation**

Blockchain technology, the heart of digital transformation, is a secured, flexible and encrypted digital shared ledger that not only manages contracts and financial calculations, but also links automation and applications. It allows business processes and data to be shared across the organizations by decentralizing the procedure, thereby promoting overall decentralization. Blockchain applications that first began in the finance industry have now expanded to government, healthcare, manufacturing, supply chain and many others.

Today's blockchain applications can be divided into four broad categories based on their stage of development, namely stages 1.0, 2.0, 3.0, and 4.0. The following table summarizes the four categories along with its main features (Gateway Digital, n.d.).

**Table 4: Blockchain Category and Main Features**

| Category | Main Features |
|---|---|
| Blockchain 1.0 - Bitcoin/Currency | Cryptocurrency is the first implementation of distributed ledger technology (DLT). It allows financial transactions based on DLT through the Internet of Money- Bitcoin. |
| Blockchain 2.0 - Smart Contracts | Ethereum blockchain aims to execute Smart Contracts to reduce the cost of verification, execution and fraud prevention. They are independent computer programs that automatically execute predefined conditions. |
| Blockchain 3.0 - DApps | DApps have decentralized data storage and decentralized communication channels which run on centralized servers. A DApp has the front-end/user interfaces written in any language, running on decentralized storages such as Ethereum Swarm, whereas the back-end runs on a decentralized peer-to-peer network. The front-end can make calls to its back-end like in a traditional app.<br><br>DApp = Frontend (hosted on Ethereum's Swarm) + Smart Contracts (running on Ethereum) |
| Blockchain 4.0 - Blockchain for Industry (4.0) | Blockchain 4.0 is making Blockchain 3.0 usable in real-life commercial usage. Some real-life scenarios are for supply chain and approval workflows, safe and secure IoT data collection, payments and financial transactions, and fitness and health management. |

**Futuristic Initiatives**

Blockchain travelled a rocky road in the last couple of years but is still hotly tipped as a technology with huge potential for transforming business and day-to-day life. The following bullet points shed some light on its main futuristic initiatives (Gateway Digital, n.d.):

- **Automotive:** Track and transfer of ownership, and delivery of goods and services without the need for intervention.
- **Education:** Data Storage around assessments, degrees, transcripts, etc.
- **Supply Chain:** Allows a transparent process for shipment tracking, deliveries, and progress among other suppliers.
- **Government:** Manages personal identity information, criminal backgrounds and e-citizenships authorized by biometrics.
- **Energy:** Decentralized energy transfer and distribution are possible via micro-transactions of data sent to the blockchain.
- **Retail:** Tracing of transactions, bills of lading, etc. on blockchain.
- **Healthcare:** Data warehouse for electronic medical records, accessed and uploaded via biometrics.
- **Travel & Hospitality:** Data storage of authenticated travel-ID on the blockchain.


*Figure 8: Blockchain Applications*

**Where Does It Add Value?**

The perceived value from blockchain-based solutions include but not limited to:

- Enhanced end-to-end flows of processes by building bridges between functions, systems and across various ecosystems.
- Value-added capabilities to dramatically improve level of service, grow previously untapped opportunities to grow one's business and develop new business models previously unimagined.
- Serious players have an opportunity to rewrite business rules and establish themselves as new industry hubs with unparalleled access to markets.


*Figure 9: Blockchain Benefits*

In light of the above, blockchain technology can be defined as shared and distributed data structures or ledgers that can securely store digital transactions without using a central point of authority (Andoni, et al., 2019). Most importantly, blockchain provides the opportunity for the automatic implementation of smart contracts in peer-to-peer (P2P) networks (Swan, 2015). They can alternatively be seen as databases that permit multiple users to make changes in the ledger simultaneously, which can result in multiple chain versions. Instead of managing the ledger by a single trusted center, each individual network member holds a copy of the records' chain and reaches an agreement on the valid state of the ledger with consensus. The exact methodology of how consensus is reached is an ongoing area of research and might differ to suit a wide range of application domains. New transactions are linked to previous transactions by cryptography which makes blockchain networks resilient and secure. Every network user can check for themselves if transactions are valid, which provides transparency and trustable, tamper-proof records (Andoni, et al., 2019).

Blockchain technology is primarily known from cryptocurrency applications that are recently experiencing an unprecedented rise in the past few years. Several key applications have been identified by numerous sources. A report by the UK Government (Mark, 2016) states that blockchains might have the capacity to 'reform our financial markets, supply chains, consumer and business-to-business services, and publicly-held registers. Potential applications spread from asset registries and transfer of ownership of hard assets (Swan, 2015) to secure recording of intangible assets. Swan (2015) envisions these assets as any type of information, reputation or online voting systems. Research works from the financial sector discuss blockchain applications in the banking sector and state that blockchain-enabled platforms can facilitate financial transactions between different financial institutions and make payments faster by speeding up confirmation times (Guo & Liang, 2016). Other applications may improve transparency in supply chain records with certification of manufactured products or diamonds certification (Lomas, 2015). In fact, the variety of applications proposed is such that Tapscott and Tapscott (2016) compare blockchains to the advent of the Internet and state they could prove to be a technological breakthrough, bringing about significant process optimization and novel business models (Tapscott & Tapscott, 2016). The potential lies on the fact that blockchain or distributed ledger technologies (DLT) can redefine digital trust and can remove intermediaries forming a new paradigm of management that can potentially disrupt traditional forms of governance (Konashevych, 2016). The disruptive nature lies on the potential of replacing top-down control with consensus and also in the underlying philosophy of distributed consensus, open source, transparency and community-based decision-making (Mark, 2016). According to the Research Institute of the Finnish Economy (Mattila, 2016), these characteristics could instigate further societal changes and implications.

According to a recent Gartner report (2017), blockchain technologies have already surpassed the peak of inflated expectations in the hype cycle and are predicted to be 2–5 years from mainstream adoption (Gartner, 2017). Along with use cases in various sectors, the potential of blockchains in the energy industry has just started to be realized as shown by the increasing number of startups, pilots, trials and research projects. A survey of the German Energy Agency (2016) on the views of energy decision-makers shows that near 20% believe that blockchain technology is a game-changer for energy suppliers. The survey was based on the views of 70 executives working in the energy sector including utility companies, energy suppliers, network operators, generators and aggregators. More than half of survey participants plan or have already undertaken initiatives for blockchain innovation (Burger, Kuhlman, Weinmann, & Richard, 2016). Several energy utility companies have taken interest in exploring the potential benefits of distributed ledger technologies (DLT), as an enabling technology for low-carbon transition and sustainability (Mattila, et al., 2016). Moreover, according to senior consultancy and commercial reports by Deloitte (2016) and PwC (2016), blockchains have the potential of radically disrupting energy related products and commodities, as they become digital assets that can be traded interoperable (Grewal-Carr & Marchall, 2016).

Early research initiatives and startups indicate that blockchain technology could potentially provide solutions to some of the challenges faced by the energy industry (PwC global power & utlities, 2016). Requirements for future energy systems can be summarized by three key principles: decarburization, decentralization and digitalization, with a shift to empower consumers. However, current structure of energy and electricity markets is inadequate to achieving this vision, as small players' participation in the markets is practically excluded and incentives for active consumer participation have so far proved not sufficient. Early blockchain developers are establishing transactional digital platforms that can be completely decentralized and can enable P2P energy trading. They are developing local energy marketplaces and IoT applications that can play a significant role in the vision of the smart grid (US Department of Energy, 2009) (European Communities, 2006). According to PwC, energy firms are increasingly reporting higher energy costs and lower revenues (PwC global power & utlities, 2016). At the same time utilities face demands for increasing transparency by the regulatory authorities (Competition and Markets Authority, 2016). As a result, any possibility of cost savings and efficiency improvement in the operation of energy systems and markets can prove significant and is worth investigating.

Moreover, potential gains in transparency and competition could benefit other key policy targets related to energy affordability and fuel poverty (HM Government, 2015). A commercial report by Deloitte (2016) states that blockchain-enabled transactional digital platforms could offer operational cost reductions, increased efficiency, fast and automated processes, transparency and the possibility of reducing capital requirements for energy firms. Cost savings potential is not restricted to utilities and can be relevant to energy consumers and prosumers (Andoni, Robu, & Flynn, 2017), who are facing increasing energy prices and removal of Renewable Energy Sources (RES) incentives, respectively. Solutions promised by blockchains, such as P2P trading in local or consumer-centric marketplaces (Pinson, et al., 2018) could potentially lead to cost savings for energy consumers.

On the other hand, blockchain technologies need to address several issues before achieving larger adoption. One key challenge is that of scalability and cost, while maintaining desired properties of decentralization and security. Other emerging issues relate to user anonymity, privacy and the governance of blockchain systems, which often goes against traditional practices adopted by governments and industry.

Development efforts in the blockchains and energy area are ongoing, and have been documented in a number of industrial white papers and reports, produced mainly by established consultancy companies. However, this research paper argues a systematic and technically informed approach, using a neutral, academic standpoint, is still required to evaluate the relevance and applicability of this novel technology to the energy sector.

The following figure sheds light on some of blockchain ongoing initiatives:

| **Institution** | **Initiatives** |
| --- | --- |
| البنك المركزي السعودي SAMA Saudi Central Bank | • Signed an agreement with Ripple.<br>• Cross-border payments initiative. |
| J.P.Morgan | • Developed Quorum.<br>• Open platform for smart contracts and distributed ledger applications. |
| مصرف الراجحي Al Rajhi Bank | • Cross-border payments trial between Rajhi offices in Riyadh and Jordan. |
| Westpac, ANZ | • Bank Guarantee in commercial transactions.<br>• Partnered with IBM for platform development. |
| Shell, bp, Statoil | • Consortium to develop Blockchain platform for energy commodities trading. |

*Figure 10: Examples of Blockchain Ongoing Initiatives*

**Blockchain for Optimal Supply Chain for Oil & Gas Industry**

With the advancement of science and technology, the importance of oil and gas resources in promoting global economic and social progress is increasing. According to the 'U.S. Energy Information Administration, International Energy Outlook 2019, Petroleum and other liquids including biofueled, and natural gas account for more than 54% of total energy consumption (Figure 11). Furthermore, according to "BP Energy Outlook 2019 edition" (BP, 2019), although the world is vigorously promoting the development of new energy, oil and gas will still occupy half of the world's energy by 2040. Besides, the report also pointed out that with the continuous expansion of liquified natural gas (LNG) trade, LNG will account for 15% of total natural gas demand in 2040. Therefore, oil and natural gas will continue to dominate the global energy market in the next 20-30 years (EIA, 2019).

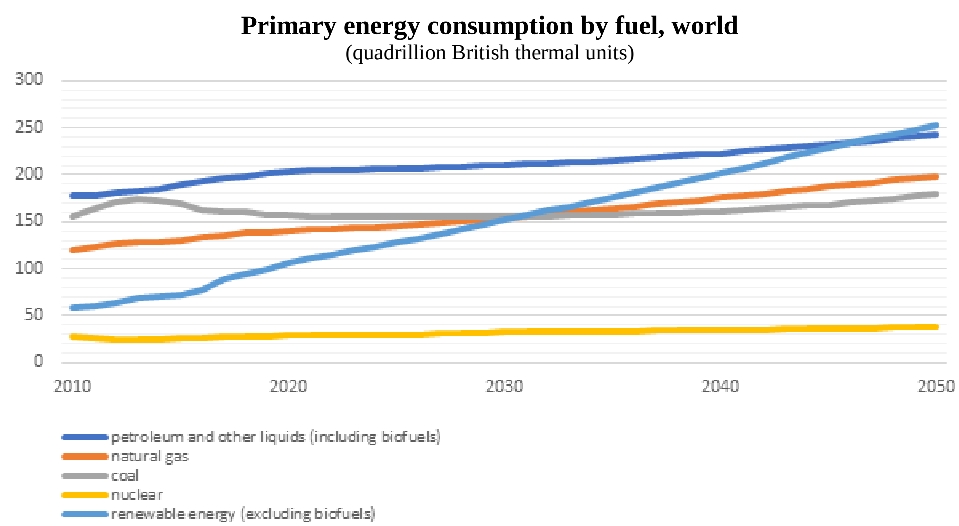


*Figure 11: Worldwide Total Energy Consumption by Fuel (EIA, 2019)*

As oil and gas resources play an essential role in the energy field, the technologies of the oil and gas industry have also developed rapidly over the past years, such as intelligent drilling technology, intelligent oil and gas fields, and marine digital platforms (World Economic Forum, 2017), (Fraser, Anastaselos, & Ravikumar, 2018). It can be seen that the oil and gas industry is gradually developing towards the direction of intellectualization, digitalization, and automation. Oil and gas industry can be divided into three sections according to the market division: upstream, midstream and downstream. The upstream refers to the exploration and development of oil and gas, the midstream refers to the transportation of oil and gas, and the downstream refers to the storage and sales. The value chain of the oil and gas industry is shown in Figure 12. In different markets, there are still many shortcomings in management, which are concluded in Table 5.

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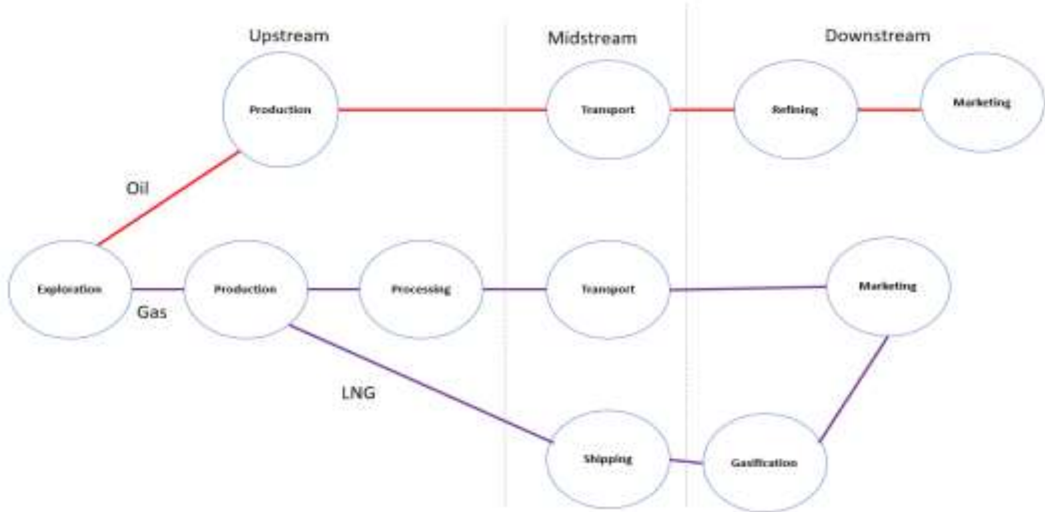


*Figure 12: The Value Chain of Oil and Gas Industry*

**Table 5: Management Issues and Consequence in Different Markets in the Oil and Gas Industry**

| Market | Issue | Cause | Consequence |
|---|---|---|---|
| Upstream | Equipment tracking difficulties | The number of devices is enormous and the management of asset integrity is not perfect | Human error, huge supervision fine |
| | Data leakage | The location where the data is generated is different or data is not well stored and processed | Wrong data leads to wrong decisions |
| Midstream | Data handling and replication | Duplicate third party transactions or duplicate contracts between different parties | Increase operating costs, erroneous transactions, and delayed transactions |
| Downstream | Integrity and security | Close networks are vulnerable to external attacks | Fraud, loss of Trust, increase validation cost |

Except for the various management issues listed in Table 5, there are still other issues to be addressed. For example, since the oil and gas industry is a huge system, it involves multi-party transactions and trade, the paperwork and reconciliations generated in each link are very cumbersome and error-prone. In summary, the management issues of the oil and gas industry mainly involve the following four key aspects:

- A large amount of paperwork and reconciliation work increases the monetary and time costs of the transaction.
- The oil and gas industry has the characteristics of multiparty investment and cooperation, and the risks of fraud, error, and inefficiency in transactions are relatively high.
- The third-party management costs in the oil and gas trade are relatively high, the trade negotiation process is inefficient, and the exchange of critical data is slow.
- Important data is at higher risks from cyber-attacks.

Based on the above problems, it is time for the oil and gas industry to change its management mode. Blockchain technology has great potential for use in the oil and gas industry. In 2008, the emergence of Bitcoin triggered a boom in the development of blockchain technology. The development of blockchain technology has been through three stages: the blockchain 1.0 era represented by Bitcoin, the blockchain 2.0 era marked by Ethereum and smart contracts, the blockchain 3.0 era for application in the social field (Mohsin, et al., 2019). Currently, blockchain technology has been applied in many industries. However, in the beginning, the oil and gas industry has been holding a wait-and-see attitude and rarely involved. Until 2017, British Petroleum (BP) began testing the blockchain project, and the oil and gas industry took the first step in applying blockchain technology (Lu, Huang, Azimi, & Guo, 2019).

According to the reports issued by Deloitte in April 2017, the blockchain has great potential in the oil and gas industry mainly in the following four aspects: trading, management and decision making, supervision, and cyber security (Deloitte, 2017), (Koeppen, Shrier, & Bazilian, 2017). In the following subsections, the potential applications of these four aspects will be analyzed.

**Trading**

According to EY's Global oil and gas transactions review 2019, the total annual oil and gas transaction was $387.5 billion (EY, 2019). The report also carried out statistics and analysis based on the transaction volume of upstream, midstream and downstream. The following Figure shows the oil and gas industry from the specific content of the industry chain and participants (Joshi, Haghnegahdar, Anika, & Singh, 2017).

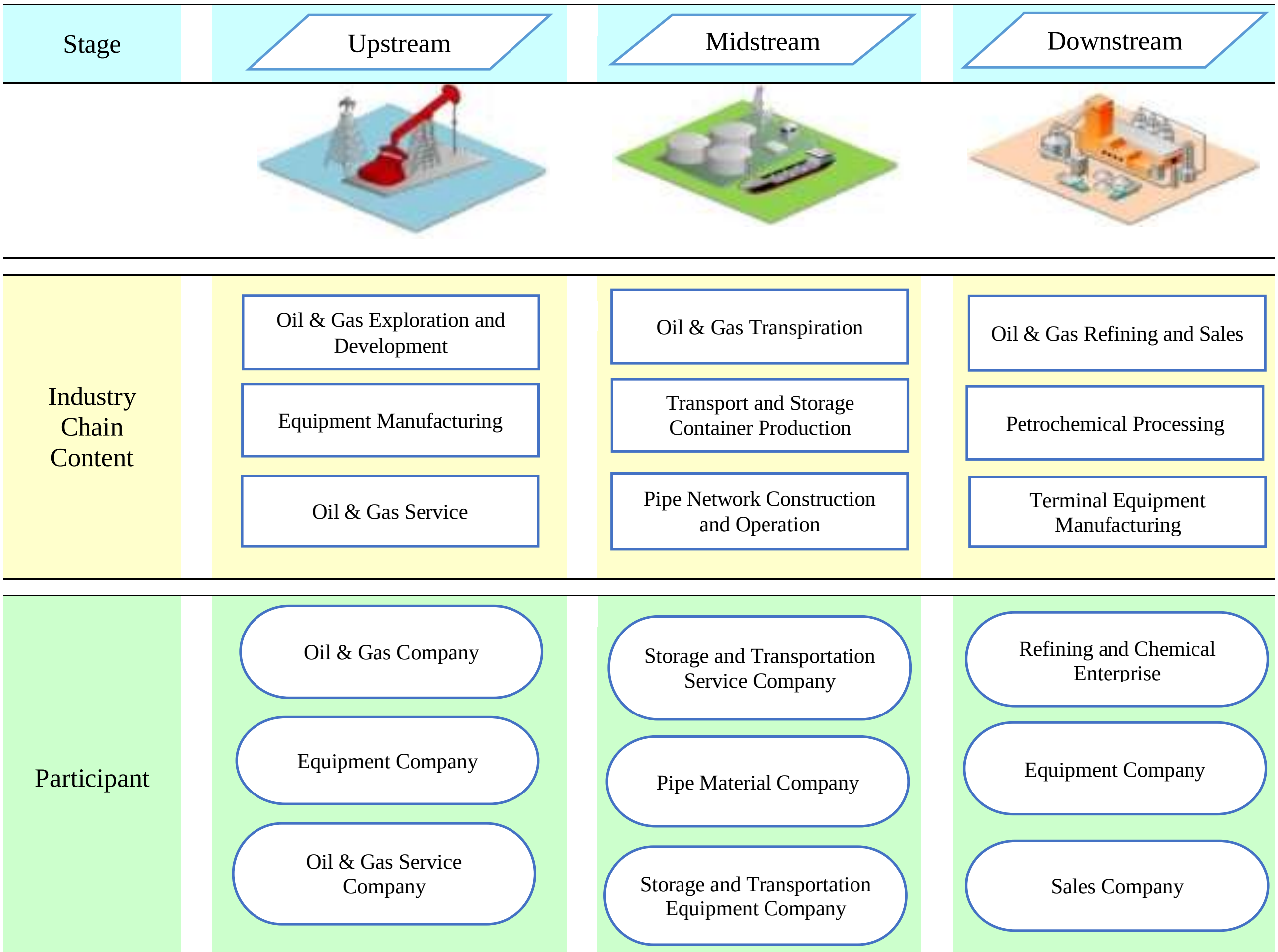


*Figure 13: Oil and Gas Industry Chain*

It can be seen that the oil and gas industry is a multilink industry including exploration, development, and processing, wholesale, retail and so on. A large number of transactions and contracts are involved in these phases, resulting in a large amount of reconciliation work and tracking work. Based on the literature review, the applications of blockchain technology in oil and gas trading are mainly include smart contracts and transactions.

**Smart Contract:** Smart contract is a kind of contract that records terms with computer language instead of legal language, and it is one of the most important concepts in Ethereum (Deloitte, 2016), (Buterin, 2015), (Delmolino & Arnett, 2016), (Gendal, 2015). Ethereum supports the development of smart contracts through turning complete languages (Solidity, Serpent, Viper). As an application running in the Ethereum Virtual Machine, the smart contract can receive transaction requests and events from outside, and generate new transactions and events by triggering the running code logic in advance (Figure 13). The results of the smart contract can be updated for the status of the ledger on the Ethereum network, and these modifications cannot be forged and tampered once confirmed. Also, it has one of the most significant advantages is that no third-party intervention is required. Because of the huge and complex nature of the oil and gas industry, long and complicated contracts may arise in the trade of all parties, and the number of contracts will be considerable. Smart contract can greatly reduce paperwork, simplify the process, improve efficiency, and save costs. However, smart contracts should be audited when using smart contracts and follow smart contract security development principles because the improper design will lead to severe loss. From the statistical data of blockchain security incidents, smart contract security incidents accounted for 6.67%, although accounting for a relatively small proportion, the resulting financial losses accounted for 43.3% (Lu, Huang, Azimi, & Guo, 2019).

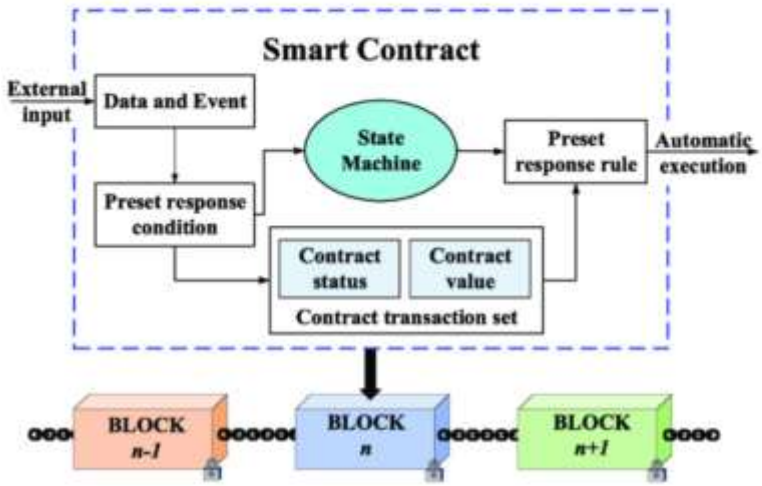


*Figure 14: Smart Contract Model Based on Energy Blockchain (ResearchGate, 2019)*

Blockchain brings a new paradigm to software development and, as such, secure development standards and practices (such as implementing secure coding and security testing) need to be implemented (and updated) to account for smart contract life cycle (creation, testing, deployment, and management). According to Diego Rodriguez Roldan, Director at Deloitte Advisory practice in Spain, "it will be necessary to apply methodologies such as the Secure Software Development Life Cycle (S-SDLC) in order to minimize the threat of a critical bug during the life cycle smart contracts". The attack on the Decentralized Autonomous Organization (DAO), a decentralized organization built on top of Ethereum, is an example where smart contracts was attacked. An attacker managed to exploit a bug in a smart contract that led to the theft of 60M Ether (Piscini, Dalton, & Kehoe, 2017)

**Transaction:** In the environment of oil price fluctuation, many oil and gas enterprises are facing tremendous pressure to reduce costs and improve productivity, to maintain an acceptable profit margin. In the oil and gas trading, the traditional way makes the transaction inevitably produce errors, and the transaction is prone to fraud and compromise. Blockchain technology can solve the problem well (EY, 2017). It can also make the transaction more transparent. Both sides of the transaction can view all the transaction records and evaluations of the other side, thereby can improve the success rate of the transaction. In addition, both sides of the transaction can also see the specific situation of each stage in the transaction process, to be more able to control the overall situation (Lakhanpal & Samuel, 2018), (IHS-Markit, 2018), (Hari & Lakshman, 2016). However, from a more macro point of view, there are currently international crude oil futures such as Brent, market participants include refineries, refined oil consumption enterprises and so on. The purpose of trading can be either hedging or cross-term or cross-variety arbitrage. These commodity futures transactions involve many processes such as account opening certification, clearing and so on, which makes the blockchain more useful. Moreover, another major application of blockchain in transactions is cross-border payments. Oil and gas are usually sold in large quantities, especially between countries, and the frequency of transactions is also high, which is different from the scale of transactions between banks. Cryptographic currency (e.g. Bitcoin and Ether) can significantly reduce the cost of cross-border payments, in addition to instant transfers, they can also reduce the time required for intermediaries, as well as for verification and liquidation of funds.

**Management and Decision Making**

**Decision Making:** Blockchain also has important application potential in decision making. In the exploration and development of oil and gas, many design-related problems are involved, such as three-dimensional data scanning of underground reservoirs, oil and gas development programs, and design and maintenance of oil and gas related devices. In current way, it usually takes months to years from feasibility study to implementation. However, the efficiency will be greatly improved if blockchain technology is used to not only prove the workload, but also calculate the relevant data. Besides, in each stage, the blockchain can also provide a record that cannot be tampered with, greatly helping the design process (Lu, Huang, Azimi, & Guo, 2019). In management decision-making, many decisions need to be made according to the information and data of the whole system. However, it is challenging to obtain data in real time, and a lot of information is stored in an independent system. The structure, protocol and data format of these systems are not necessarily the same or interoperable. Blockchain technology can make data exchange and transmission more efficient, thus improving the correctness of decision-making. Additionally, many decisions in the oil and gas industry require management level to vote, and smart contracts in the blockchain enable automated, transparent voting applications. The voting sponsor can initiate a vote and give voting rights to the voter. The voter can vote or entrust their votes to others, and anyone can publicly check the result (Bee Finance Network, 2018).

**Management:** The blockchain can simplify the management process and make the management method more scientific. As we all know, oil and gas pipeline networks occupy a vital position in oil and gas systems, and the pipeline network is complicated and difficult to manage, especially regarding resource allocation. If the relevant demand data and supply data are uploaded to the blockchain and form a smart contract, the deployment of oil and gas resources can be made more scientific. If the relevant information of the pipe network can form a blockchain, the integrity or reliability management of the pipe network will become more successful.

**Supervision**

**Tracking:** Globally, many oil and gas products are stored, ordered, transported and distributed through various channels such as producers, suppliers, contractors, subcontractors, oil and gas refiners and retailers. Once there are slips, productivity and production level will decline, and serious cases may occur such as loss of goods (Christidis & Devetsikiotis, 2016). The blockchain not only tracks products in the oil and gas supply chain, but also provides audit trails of equipment used throughout the lifecycle, making all aspects of the supply chain more transparent, saving logistics costs and improving operational efficiency, this is also the most essential function of the blockchain to solve the oil and gas industry chain management. In recent years, LNG has become the mainstream of natural gas trade. Due to its low-temperature characteristics, the import and export carriers are mainly shipping. Figure 15 below shows a tracking case of LNG in the supply chain (Lu, Huang, Azimi, & Guo, 2019).


*Figure 15: Example of Using the Blockchain to Track LNG Industry Chain Products*

Natural gas is extracted from the gas field and then transported to the natural gas treatment plant for dehydration or decarbonization. The purified natural gas is transported to the liquefaction plant for LNG production and then to the LNG export station for storage. LNG is loaded at the export station and enters the shipping phase. After arriving at the LNG terminal at the target location, LNG is then gasified into the application phase. This process involves multiple stakeholders, each of whom maintains their own database to track the product. This blockchain not only means that there is a shared database that can track the product, but also means that it is an auditable information tracking system (because it can be encrypted and verified). For example, from the LNG shipping to the LNG terminal stage, when the LNG arrives at the LNG terminal, the shipping personnel will send the signed information to the smart contract, so that everyone in the chain will know that the LNG has arrived at the LNG terminal of the target location. On the other hand, when the transaction is signed, it is sent to the recipient in an encrypted manner to let them verify that the LNG has indeed arrived. At this time, the staff of the LNG terminal issues the same smart contract for confirmation. Similarly, the same method also can be used for tracking related devices. The tracking function of blockchains can be applied not only to the product or asset tracking, but also to intellectual property tracking. Due to advances in technology, the oil and gas industry will involve much content related to intellectual property. However, the legal copyright registration fee is high, and even if the copyright registration is applied, the approval time is long. Blockchain technology can store and track related content, realize the traceability of ownership, and thus achieve the role of intellectual property protection.

**Compliance:** Due to the high degree of transparency of blockchain technology, it can improve compliance in the oil and gas trade (Anjum, Sporny, & Sill, 2017). The data generated by the blockchain is shared within the Trust: Data framework proposed by the Massachusetts Institute of Technology, which significantly reduces compliance costs and increases speed (MIT Connection Science, 2019). Besides, some bidding or management issues during oil and gas exploration and development can also be solved by blockchain. For example, the problem of invalid bidding, the liability of contracting negligence in project bidding, and the civil liability for refusing to sign the contract after winning the bid.

**Data Record:** Oil and gas companies need to obtain land use rights before conducting exploration, development and other activities. However, understanding the source of the land can be difficult, and there may be multiple records of ownership conflicts in a separate database. In this environment, land transactions are highly vulnerable to fraud. Blockchain technology can create an invariable audit trail of land mobility, value and ownership. This will reduce the loss or mismatch of ownership, the occurrence of ownership disputes, and provide tax authorities with the transparency of land transactions, real time record of the accurate transfer of value (Liang, et al., 2017).

**Cyber Security**

According to statistics, in 2016, nearly three-quarters of oil and gas companies in the United States experienced at least one cyberattack. For hackers, oil and gas companies have many vulnerable breakthroughs (oil and gas enterprise structure is shown in Figure 16), such as complex operating system and production process, little intersection of information technology (IT) and operation technology (OT), delay of real time system caused by firewall, inconsistency of network standards among departments, irregular updating of system security patches (especially vendor's security system), and historical legacy problems (Mittal, Slaughter, & Zonneveld, 2017). For example, intelligent sensors can provide important information such as the real-time status of offshore oil field operations, but these sensors are currently the most insecure part of the enterprise network because it is possible for industry competitors to obtain such information through espionage activities. If blockchain technology is used to store important data in a distributed manner, the risk of network attacks can be effectively reduced. In order to increase the data security of enterprises, financial technology developers are developing projects in the "Trust:: Data" framework, including OPAL, Digital Personas and Identity, Tradecoin, MIT Enigma, OpenPDS (MIT Connection Science, 2019).

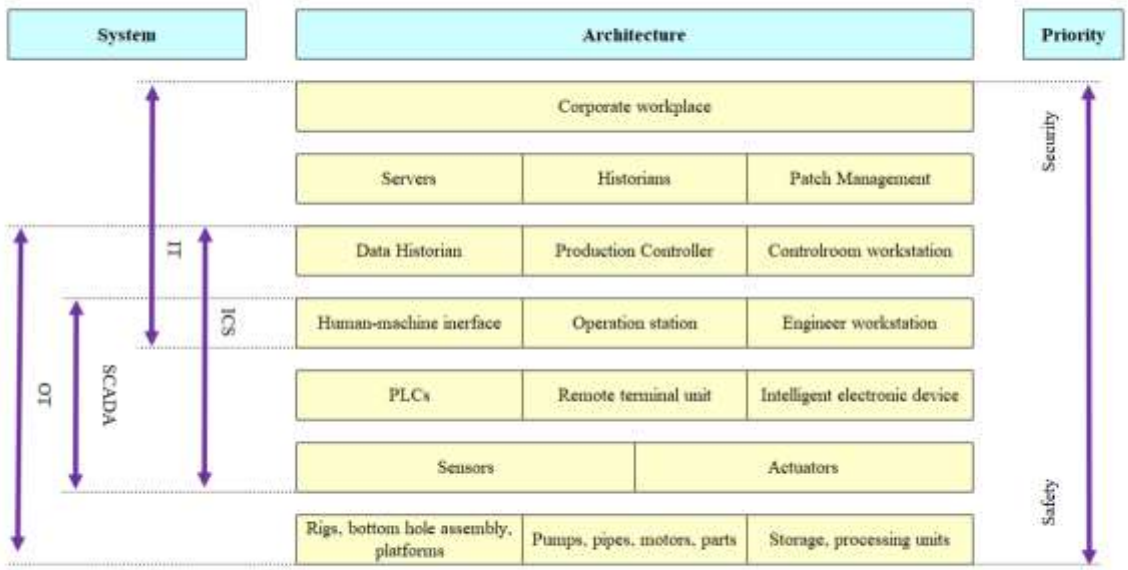


*Figure 16: Oil and Gas Enterprise Structure*

**Examples:**

At present, the application of blockchain technology in the oil and gas industry is in its infancy. Two well-known related blockchain projects are: Vakt, komgo SA (Hoffman, 2018), and Consortium.

**Vakt:** Vakt is a blockchain-based commodity trading postprocessing company. On November 29, 2018, it announced the world's first enterprise-level blockchain platform for the crude oil industry. Its first users include BP, Equinor, Shell, Total, Gunvor, and Mercuria, and it has launched larger products back in January 2019. Their goal is to increase speed and security, which benefits everyone in the supply chain from market participants to customers. Vakt uses J. P. Morgan's Quorum blockchain technology. Quorum is a blockchain platform based on Ethereum, but it has higher privacy and a variety of voting-based consensus mechanisms (Berge, 2018). Vakt post trade processing activities include: deal recap, confirmation, contracting, logistics, and invocing.

**komgo SA:** Another important project, komgo SA, is a blockchain platform for commodity trading that is supported by commodity supply contracts. It is also jointly developed by many companies, and the first operation of komgo SA is crude oil transportation in the North Sea. It is expected that the platform's transactions will expand to new areas: metals and agricultural products. Since then, the scope of the platform will continue to expand (Damien, 2018).

**Consortium:** Established in February 2019, and its members include: ExxonMobil, Hess, Repsol, Chevron, Marathon, Equinor, Texaco, and Pioneer Natural Resources. Its main focus is on asset tracking and traceability, asset valuation, inventory management, hydrocarbon accounting, audit, billing and settlements, land lease and mineral rights management, digital letter of credit, fright bill payment and audit, automated bill of lading validation.

## DISCUSSIONS, RESULTS AND FINDINGS

This section discusses the application status, opportunities, challenges, risks, development trends of blockchain technology, and concludes with a road map along with some models of using blockchain technologies in supply chain management.

### Application Status

Over the past few years, blockchain technology has begun to emerge in the oil and gas industry. Many energy giants have begun to invest in the development of this technology. Among them, BP and Shell are pioneers in blockchain application technology in the oil and gas industry. At the end of 2017, Sinochem Group successfully completed China's first blockchain crude oil import trading pilot project from the Middle East to China (Milano, 2018). There are two major applications in the project, digital bill of lading and smart contracts, which can significantly improve the efficiency of crude oil trading execution and optimize the transaction financing cost by 20% to 30%. In addition, the blockchain platform jointly developed by Abu Dhabi National Oil Company (ADNOC) and IBM will be the first application of blockchain technology in global oil and gas production accounting (World Oil, 2018), (Zaher, 2018). Unlike other projects, it will apply to the entire oil and gas life cycle, not just a critical part of the commodity supply chain. ADNOC expects to automate the transaction process through the platform, and by deploying advanced technology resources. Additionally, ADNOC expects that the deployment of blockchain technology will reduce its drilling time by 30% and achieve savings of up to $1 billion. Table 6 lists 12 major oil and gas industry blockchain projects worldwide (S&P Global Platts, 2018), and Figure 17 summarizes the status of these projects from the region and status. It can be seen that as of mid-2018, most of the blockchain projects in the oil and gas industry are in operation and commissioning, and some are in the testing stage. Europe has the largest number of projects, and Asia and Europe have the fastest development in the application of blockchain in the oil and gas industry. But overall, there are few blockchain projects in the oil and gas industry relative to other industries.

**Table 6: Major Oil and Gas Blockchain Projects**

| Continent | Location | Oil / Gas | Stage | Company Name | Remarks |
|---|---|---|---|---|---|
| Asia | Xiamen, China | Oil | Live | Sinochem Group | Simulated gasoline export from Quanzhou to Singapore |
| Asia | Abu Dhabi | Oil & Gas | Pre-launch | ADNOC and IBM | Oil and gas production automation |
| North America | Houston | Gas | Test | S&P Global Platts | Platform for confirming transactions, reporting prices |
| Europe | London | Oil | Pre-launch | Vakt | Platform to cut post-trade costs |
| Europe | | Gas | Pre-launch | OneOffice (BTL) | Platform to cut post-trade costs |
| Europe | Hamburg | Gas | Pre-launch | Enerchain | Platform for P2P wholesale trading |
| Asia | Fujairah | Oil | Live | FOIZ, S&P Global Platts | Oil terminal stock levels reporting |
| Africa | | Oil | Live | Mecuria, ING, SocGen | Digital documents used for cargo trade three times on way to China |
| South America | Chile | Oil & Gas | Live | Energia Abierta | Regulator tracking national energy data |
| Europe | Britain, Italy, Austria | Oil & Gas | Live | Interbit | Oil and gas trading |
| North America | America | Oil & Gas | Live | PetroBLOQ | Oil and gas supply chain management |
| Europe | Switzerland | Oil & Gas | Live | komgo | Trading platform |

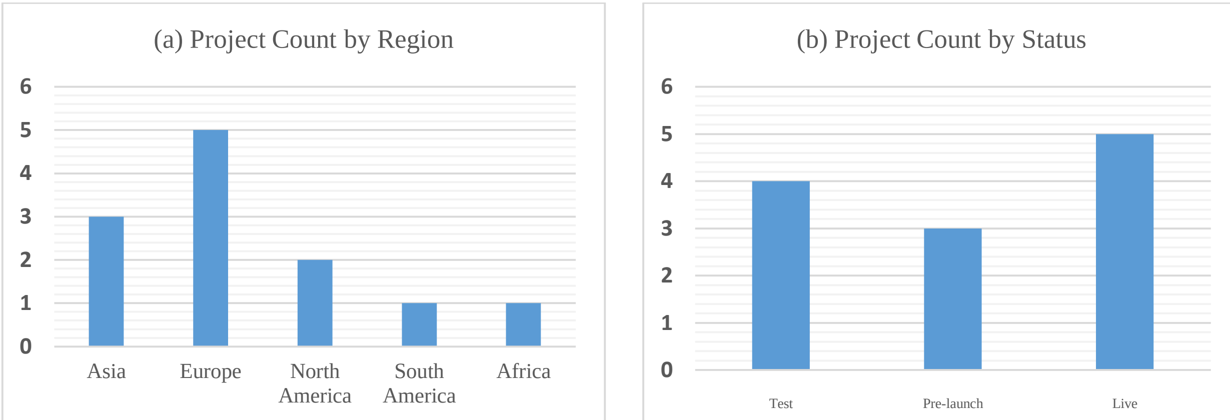


*Figure 17: Statistics on 12 Major Oil and Gas Blockchain Projects*

**Understanding Level**

From the perspective of understanding blockchain in the oil and gas industry, this paper summarizes the following information from the statistical records of 1,053 respondents in Deloitte's 2018 global blockchain survey (Deloitte, 2018):

1. 72% of respondents in the oil and gas industry believe that blockchain technology will have a big impact on the industry;
2. 61% of respondents in the oil and gas industry believe that the blockchain is only a currency database and can only be used in the financial services sector;
3. Regarding the level of understanding, 87% of respondents in the oil and gas industry believe that their understanding of the blockchain is 'Excellent' rather than 'Expert' (only two levels in this survey);
4. In terms of investment in blockchain technology, 72% of respondents in the oil and gas industry invested between $1 million and $10 million, while only 9% invested more than $10 million. In contrast, 38% of respondents in the automation field invested more than $10 million in their organization;
5. Only 15% of the organizations in the oil and gas industry have applied the blockchain to production, while 84% are only in the consciousness or experimental phase.

For another report (World Energy Council, 2018), the World Energy Council interviewed 39 people in the energy field in 2018 and released a report called 'Is blockchain in energy driving an evolution or a revolution?'. They have a maturity model based on the interviewees' responses. It can be concluded from the two survey reports that the understanding of the blockchain by the oil and gas industry is not comprehensive enough. Table 7 summarizes some common misconceptions about blockchain, and the application of the blockchain is still in the experimental stage. In addition, the oil and gas industry's investment in the blockchain is still not strong enough.

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**Table 7: Common Misunderstanding about Blockchain**

| Misunderstanding | Reality |
|---|---|
| Blockchain is distributed ledger technology | Blockchain is a form of distributed ledger technology, and not all distributed ledger technologies use blockchain technology |
| Blockchain is bitcoin | Bitcoin is a type of cryptocurrency and an application of blockchain |
| Blockchain is absolutely impossible to tamper with | The blockchain is not absolutely unalterable, but cost of tampering is very high |
| Smart contracts are legally binding | Without a separate contractual agreement, smart contracts are not legally binding |
| Blockchain is currently the best database | Blockchains are not necessarily better than traditional databases |
| Blockchain is absolutely safe | Although the blockchain is based on encryption standards, the method of ensuring privacy is completely outside of any blockchain standards and implementation |

## Opportunity and Challenge

Due to the decentralization and transparency of the blockchain, it can bring many opportunities to the oil and gas industry (Accenture, 2018). However, a new technology will inevitably encounter many challenges when it is first applied, as shown in Table 8.

.

**Table 8: Opportunities and Challenges of Blockchain in the Oil and Gas Industry**

| Opportunity / Challenge | Item | Cause |
|---|---|---|
| Opportunity | • Low transaction costs | Eliminate the involvement of third parties. |
| | • Commodity price decline | Reduced transaction costs. |
| | • Resource transfer is more convenient | Customer will more convenient to become suppliers and sell excess resources |
| | • Convenient transaction | A large number of documents, contracts and payments are simplified. |
| | • High transparency | Decentralized data storage and blockchain tracking. |
| | • Standardized language | Data sharing is fast and convenient. It can provide standardized language, exchange information in a secure way, and facilitate the sharing of infrastructure. |
| | • Asset integrity management | Data cannot be tampered with and traceable. It can be used to tract assets such as oil and gas production equipment and pipelines. |
| Challenge | • Way of thinking | People in the oil and gas industry do not have a thorough understanding of blockchain and hold a wait-and-see attitude. |
| | • Adapt to new market model | The introduction of blockchain will change the mode of operation of the oil and gas industry, and even change the mode of other related industries, it will take some time to adapt and coordinate. |
| | • Supervision | As the current management mode of the oil and gas industry is still relatively old. Blockchain technology is currently difficult to adapt to the current management environment. |
| | • Technology and security | As the application of blockchain technology in the oil and gas industry is still in its infancy, there will be many technical problems and data security issues. Specific performance: high-frequency business needs are difficult to meet; consensual algorithms consume massive energy; lack of relevant development, integration and maintenance systems; privacy protection, smart contract loopholes, and other security issues. |
| | • Trust | There is no legal o regulatory framework yet. |
| | • Data quality | Blockchain cannot guarantee the quality of data, but can only guarantee the accuracy of data. |
| | • Cost | If blockchain technology is adopted, it will involve many management systems and database that have been maturely applied in the oil and gas industry. The replacement requires much costs, and the development of technology also requires numerous money. |
| | • Professional | In the overall environment, there are not many professionals in the blockchain applications, especially for the oil and gas industry. |

## Risk

Although the blockchain technology has many advantages, the current operating system is still not perfect, and there are many risks. Risks can be divided into operational risks, cyber risks, and legal risks (Surujnath, 2017), (Lindman, Tuunainen, & Rossi, 2017).

Operational risk means that if the blockchain is applied to the oil and gas industry, technical or social problems may produce bad results. It may be reflected in:

- Loss of data and identity.
- The transaction costs of the public blockchain are high.
- Lack of recipients and users.
- Lack of long-term experience leads to imperfect management.
- Initial applications may have technical problems.
- Lack of a standardized mode of operation, function and security deficiencies.

Cyber risk refers to bad behavior such as fraud due to insufficient security or design flaws, it is reflected in:

- There may be fraud in the interface between the real world and the blockchain world.
- The exchange may be attacked by hackers, and the user's password may be hacked and funds transferred.
- The hard fork of the block will cause the trust of the entire network system to be questioned.

Legal risk refers to some illegal acts that may occur in the operation of blockchains, it is reflected in:

- Tax evasion may be triggered.
- Illegal use of information.
- Blockchains are used for illegal transactions.

**Development Trends**

The blockchain has been in development for a decade, from the earliest application to bitcoin to the present application in various industries. However, blockchain technology is continually improving and is striving to find a better application experience. This paper summarizes the future development trends of blockchain technology in the oil and gas industry from five aspects.

**Hybrid Blockchain Architecture**

(Fu & Fang, 2016): Consortium blockchain is currently the main implementation of the blockchain project, but it does not have the scalability and anonymity of the public blockchain. However, with the development of blockchain technology, the oil and gas industry will not be satisfied in the future by applying blockchain only between enterprises, and a hybrid architecture of public blockchain for the masses and consortium blockchain for enterprises can be formed.

**Cooperate with other Technologies**

(Fry, 2018): In recent years, not only blockchain technology is rapidly developing, but other technologies such as artificial intelligence, big data, and cloud computing are also advancing rapidly. However, these techniques can aid in the development of blockchains. For example, artificial intelligence based on blockchain uses smart contracts in terms of user equipment registration, authorization, authentication, and value exchange to improve security. The combination of blockchain and cloud computing will effectively reduce the cost of blockchain deployment. In addition, the blockchain will promote the development of other technologies. For example, various artificial intelligence modules can implement links through blockchains and can learn on the chain to promote the evolution of artificial intelligence. In a practical case, the blockchain as a service (BaaS) system developed by the combination of blockchain and cloud computing aims to provide users with better blockchain services. Therefore, BaaS service providers pay more attention to the vertical industry connection, to provide reasonable smart contract templates, good account system management, good resource management tools, and customized data analysis and reporting systems.

**Cross-chain and High-Performance Blockchain**

(Back, et al., 2014): At present, each blockchain network is a relatively independent network, and data information cannot be interconnected. Cross-chain technology makes blockchain suitable for industries with complex scenarios. Current mainstream cross-chain technologies include Notary schemes, Sidechains/relays, Hash-locking, and Distributed private key control. Due to the complexity of the oil and gas system, multiple blockchains can be established according to different scenarios. Cross-chain technology can realize digital asset transfer between multiple blockchains, thereby improving efficiency. In addition, in order to improve the throughput of the blockchain system, many scholars and experts are developing high-performance blockchain solutions. There are currently three ideas for improving performance. The first is to change the blockchain topology to a transaction-based Directed Acyclic Graph (DAG). The second idea is to change the consensus strategy to increase throughput by reducing the number of nodes participating in the consensus. The third way is to improve the overall throughput of the system by increasing the horizontal scalability of the system.

**Hybrid Consensus Mechanism**

(Jagati, 2018): Due to the critical position of the consensus mechanism in the blockchain, it will continue to develop. There are many consensus mechanisms, each with its own advantages and disadvantages. The application of a single consensus mechanism has other flaws. In order to improve efficiency and security, the consensus mechanism will be developed towards a hybrid consensus mechanism and will be dynamically configured according to different situations in different application scenarios or running processes.

**More Interdisciplinary Professionals**

(Vilner, 2018): The global demand for blockchain talents has grown since 2015 and experienced explosive growth in 2016-2017, but for now, its share of global talent market demand is still meager. Blockchain technology is a multi-disciplinary and cross-disciplinary technology. Compared with the talents of R&D technology, the blockchain underlying system architecture design talents need to master several interdisciplinary professional skills and understand the underlying design principles of blockchains, which means that the oil and gas market needs professionals who have both the experience of system architecture design and know the specific business of application scenarios. Therefore, more professionals in the future will be more inclined to implement the blockchain, and more inclined to interdisciplinary.

**A Road Map for Using Blockchain Technology to Improve Supply Chain Performance**

Blockchain has been hailed as the biggest breakthrough since the internet. Its potential benefits span industries, and many companies today are actively considering adopting it to explore its transformative potential. The subsequent paragraphs address the question: How should firms approach such a promising but risky new technology?

Blockchain can pave the way to a reconfigured world in which banks, insurers, utilities, retail firms, media companies, hospitals, and law firms all communicate with one another effortlessly. In a world with widespread blockchain adoption, business models would change drastically: Utility firms would arrive on maintenance calls because customers' smart home systems had triggered service delivery and already contacted the insurer and bank for payments. Retailers shipping products from remote villages across continents would clear border security and customs checkpoints in seconds, tracking the process every step of the way. Pharmaceutical companies would more easily trace drug ingredients to their source, vastly reducing the incidence of the counterfeit medicines that plague today's supply chain.

Using blockchain, media streaming firms could track content usage with precision. Even little-known artists would receive royalties accurately and instantly. Copyrights of all types of art could be traced and intellectual property rights enforced globally. Software service firms would have access to customers' digital identities, enabling a holistic view of their service needs. Hospitals, too, would have a secure and comprehensive view of patients' health, medication, and lifestyle, just as banks would of customers' financial affairs. Each firm, regardless of its size, would be able to capture a holistic picture of customer needs and customize its services at an individual level. Hospitals could deliver precision treatments since smart wearables would monitor patient health and communicate necessary stats to doctors. Pharmaceutical companies could develop more drugs for orphan diseases because they would have access to sufficient patient samples from across the world upon which to perform research. Banks would not only make payments across international borders in seconds, but also automatically file taxes and manage customers' wealth. They would communicate with foreign banks and provide visibility into necessary documentation and sources of funds, making financial transactions globally accessible. Energy distribution would change with peer-to-peer energy exchanges and smart grids that widen revenue streams. Governments could make financial inclusion a reality and manage welfare programs effectively with tamper-proof digital identities. Increased transparency in government services, welfare payments, and voting could substantially decrease opportunities for corruption.

Despite these exciting possibilities, it is not always obvious whether a particular company should adopt blockchain, or when and how it should go about it. Technology-driven companies do often succeed at outpacing competitors, but the right firm capabilities and market timing are critical for success (Sadowski & Roth, 2016). Therefore, managers should exercise caution before committing. It is crucial to carefully analyze the firm's need for blockchain, its anticipated value, and the firm's capabilities before investing in the technology. To cut through the noise surrounding blockchain, the Mack Institute has studied firms, spoken to leading practitioners, and laid out the following road map to help companies make informed decisions. This paper examines four key questions that managers should consider as they work through whether their firm should adopt blockchain, how it might impact their business, and the strategic choices for implementation.

The Power of Blockchain Blockchain's properties can make existing processes more efficient while providing new solutions to pressing problems (Deloitte LLP, 2016). At its core, blockchain is a shared ledger that is transparent to all parties and is almost unalterable. This kind of visibility creates trust among participants, paving the way to business model transformation. On a blockchain, transactions take place over a peer-to-peer computer network. Each transaction's data is recorded in a hash-coded 'block.' Every subsequent transaction is sent to the network, validated, then encoded in a new block along with all the previous hash codes. The blocks of data provide a continuous record (the chain of blocks for which the technology is named), so a user can trace previous transactions all the way back to the first one. Since all the data-blocks are linked, data become nearly impossible to change and all parties on the network can trust the data's authenticity. The ability to create extensive, tamper-proof data records opens up powerful opportunities. Crédit Mutuel Arkéa Bank of France, for example, has created an internally-shared Know-Your-Customer (KYC) platform which allows employees at every function of the bank to access the entire history of a customer's KYC documentation (Palmer, 2017).

Six banks in Canada are attempting an industry-level solution to decentralize and share digital identities externally across banks, insurers, utility providers, etc. This move would provide stakeholders with access to authentic real-time data on customers, delivering a holistic picture of customer finances. Apart from providing process and cost efficiencies, blockchain can transform automatic triggering and delivery of financial services. Blockchain allows the terms of a contract to be encoded on the application so that only transactions in compliance with those terms can be recorded. These smart contracts encapsulate all the rules of interaction among participants in the blockchain network. Information such as terms of operations between participants, their rights, consensus requirements, product and pricing information, and so forth are written into the code, allowing transactions to be executed automatically without the need of a verifying body. When smart contracts are paired with shared proofs of identity, then verification and authentication of transactions can become fully automated. For example, ST Aerospace has piloted a blockchain-based 3D-printing solution that verifies design purchases from the U.S. as genuine and from the right source (Chia, 2017).

Digital rights management makes the design file tamper-proof. Smart contracts identify the right materials and printing techniques, then immediately trigger printing on a 3D printer in ST's Singapore facilities using its laser metal process. Similarly, the Federal Aviation Administration and other aviation agencies have a critical need to establish the provenance of aircraft parts. By digitizing this tracing process in a tamper-proof way, these agencies can save cost and time while ensuring better quality. Nasdaq has launched its own payment platform that verifies and executes trading transactions based on smart contracts. The platform also automates streamlined payments, liquidity readjustments, and reconciliations based on real-time data and embedded trading rules (Nasdaq, Inc., 2017). Such payment platforms can eliminate financial intermediaries like clearinghouses and money transfer firms that charge high transaction fees (especially for international transactions).

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The disintermediation that blockchain provides can render transactions in the insurance sector more transparent, reduce moral hazard, verify claims, and reduce transaction disputes (Barlyn, 2017). Similarly, verification of the authenticity and validity of government records, land titles, and notary services can be automated so that their accessibility is improved and their management is made vastly more efficient (Endemann & Tejblum, 2018). Every transaction record on a blockchain is time-stamped. When time-stamping is combined with hash functions and smart contracts that build consensus mechanisms for recording data, supply chain controls change dramatically (Brunekreef & Prounader, 2018). Danish shipping firm Maersk is creating a global shipping container platform (Morris, 2017). When a shipment container arrives at the U.S. border, the Department of Homeland Security can view the shipment's entire history. Inspectors can see who has handled it, in what condition, at what time, and whether customs has verified the container's regularity. If all checks are satisfied, Homeland Security can immediately record its acceptance. Hash functions and time-stamps establish the reliability of data, and hence the provenance of goods, while obviating the need for third-party verification. Walmart is tracking perishables such as pork and mangoes to leverage these gains; Provenance Ltd. is tracking seafood; Pfizer, medicines; and De Beers, diamonds.

The following end to end product traceability use case demonstrates the potential use and value of blockchain technologies in supply chain:

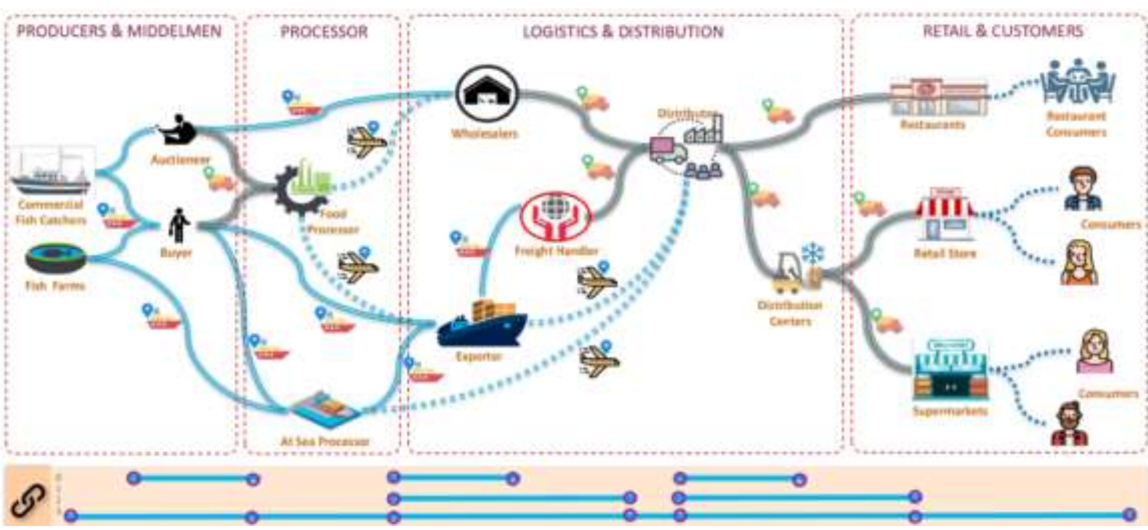


*Figure 18: End to End Product Traceability Blockchain (Liu, Kadiyala, & Cannistraci, 2019)*

Great potential often comes with great challenges, and managers must clear many hurdles before they can begin to realize blockchain's promise. Business challenges such as cost of entry, financial implications, infrastructure, talent, risk appetite, and privacy make its adoption difficult.

To help businesses make sound decisions as they navigate this unfamiliar and risky path, the author elected to use the Mack Institute model, which is a step-by-step road map that demonstrates how to take a structured approach when implementing a blockchain strategy for the supply chain.

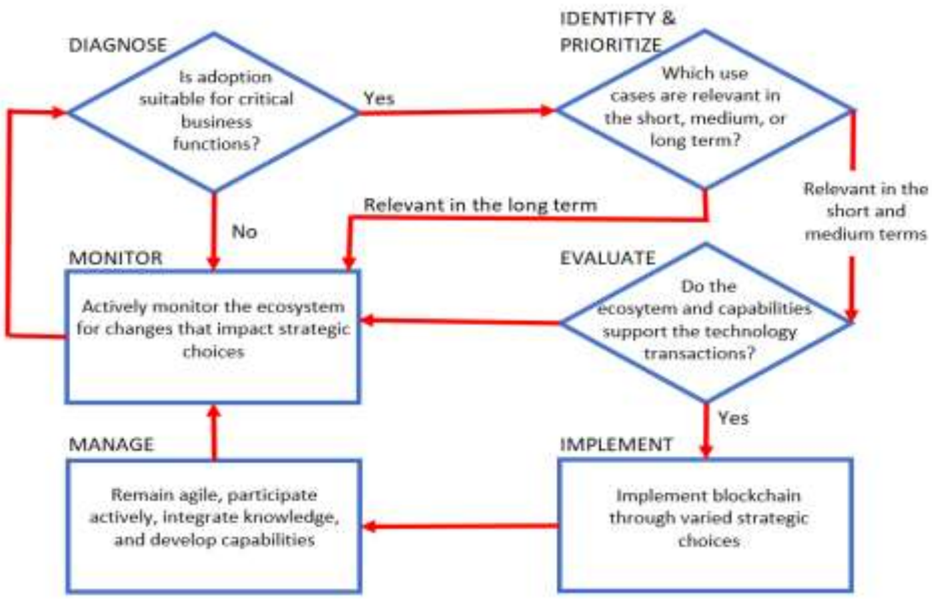


*Figure 19: Systematic Road Map for Developing Blockchain Strategy (Kolli, Jain, Prateek, Rush, & Chaudhuri, 2018)*

During each step of the way, it's important that organizations not get caught up in the hype surrounding blockchain but evaluate its merits independently. Moreover, since every step is crucial in today's fast-paced and highly competitive markets, Kolli et al. (2018) introduced four key questions for firms to ask themselves as they navigate this road map (Kolli, Jain, Prateek, Rush, & Chaudhuri, 2018).

**Diagnose: Do the Organization Really Need Blockchain Now?**

Technology shifts can prove disruptive, even fatal. Before changing technology strategies and committing resources, firms should evaluate whether the shifts are actually relevant to them at a given point in time. They should ask the fundamental question of whether they currently need blockchain at all. To help answer this question, refer to the diagnostic matrix below. It overlays a firm's transaction measure with the technology's infrastructure measure to evaluate both the need for blockchain and the risk of adoption.

**Interparty Transactions Index (ITI):** The ITI of a company is high if it performs a high number of transactions involving several parties with a high counterparty probability of non-compliance with the terms of the contract. For example, intra-firm transactions involve a high degree of confidence and a low risk of non-compliance, whereas transactions involving multiple external vendors are at higher risk of non-compliance with the contract.

**Infrastructure Readiness Index (IRI):** A newly implemented blockchain solution would need a robust network infrastructure to function to its full potential. The firm will assess its infrastructural readiness to deal with mission-critical projects by two key parameters: scalability and privacy.

An effective blockchain solution would involve a large network of stakeholders on a shared platform. The computing infrastructure can help the addition and collaboration of players without overtaxing the network as an adoption scale. Decentralized data poses a higher risk of theft, especially of sensitive information such as financial or medical records. The firm should test the impenetrability of its infrastructure and resolve privacy and security issues before a blockchain solution can be implemented. High scalability and low safety risk translate into high infrastructure readiness.

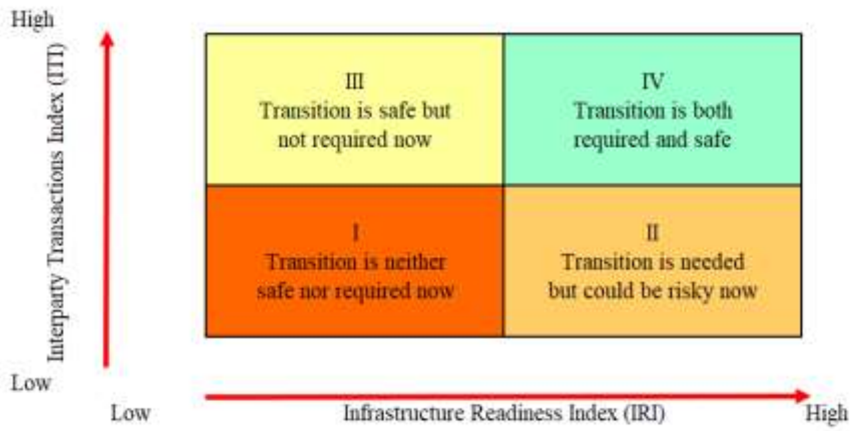


*Figure 20: Diagnostic Matrix for Blockchain Adaptation (Kolli, Jain, Prateek, Rush, & Chaudhuri, 2018)*

**Table 9: Diagnostic Matrix for Blockchain Adaptation**

*The higher the IRI is, the smaller the risk of adopting blockchain is.*
*The higher the ITI is, the greater the need for blockchain is.*

| | ITI Low | ITI High |
|---|---|---|
| **IRI High** | III: Transition Is Safe but not Required Now | IV: Transition Is Both Required and Safe |
| | • Large tech firms (non-supply chain functions)<br>- IBM, Microsoft, Wipro, Google, etc.<br>• Small tech startups providing single or limited product solutions on shared infrastructure (blockchain-as-a-service) or on platforms provided by large tech firms<br>- Everledger, Axoni, ShipChain, etc. | • Large tech firms (supply chain functions that need involve tracking multiple vendors)<br>- Intel, IBM, Microsoft, AWS, Wipro, Google, Cisco, etc.<br>• Non-tech firms that are building their tech competencies through internal resources or leasing shared infrastructure<br>- Verizon, Comcast, GE, BNY Mellon, Citi, Goldman Sachs, etc. |
| **IRI Low** | I: Transition Is Neither Safe nor Required Now | II: Transition Is Needed but Could Be Risky Now |
| | • Small and medium enterprises that have limited vendors, transactions, and resources<br>- Startups, small manufacturers, cottage industries, one-shop retailers, local restaurants and service providers, SME brokers and money transfer services, etc.<br>• Firms dealing in public transactions, publicly consumable goods, and shared resources that don't need scalability or privacy<br>- Non-profit firms, charity organizations, religious institutions, government bodies, research, and educational institutions, Airbnb, Uber, etc. | • Firms dealing in health, medical records, and medical research data<br>- Hospitals, healthcare service providers<br>• Financial settlements, trading transactions, cross-border transactions, insurance and claims<br>- Vanguard, BNY Mellon, Nasdaq, Australian Securities Exchange, JP Morgan<br>• Automobile telematics tracking<br>- Volkswagen, Renault, Toyota, Daimler<br>• Supply chain, Retailers, CPG<br>- Bosch, Walmart, Alibaba, De Beers<br>• Telecommunication<br>- Verizon, Comcast, AT&T<br>• Aerospace<br>- Airbus, Boeing, GE, Air France, Lufthansa<br>• Shipping<br>- Maersk<br>• Government land registry and other document management functions |

## Identify & Prioritize: What's the Impact on Firm Existing Business?

Once a firm establishes its need and risk appetite for blockchain, it can evaluate the business value of investing in a solution. The firm should next identify appropriate use cases and evaluate blockchain's impact on its balance sheet.

To identify use cases, the firm can conduct a scenario planning exercise based on future state, efficiency gains, competitor moves, customer adoption, and uncertainties (Schoemaker & Mavaddat, 2000).

The identified use cases can then be stress-tested to see whether they make business sense. Firms need to focus on two key factors: quantifiable efficiency gains and operational inconveniences during adoption. A cost-benefit analysis should reflect efficiency gains such as revenue increase through improved customer relationships and reduced capital expenditure and operational expenses over time. The firm can avoid disruptions to existing operations through open and candid conversations with technology providers on shared responsibilities. Conducting thorough analyses of the resources required will prevent cost overruns.

As stated earlier, it will be difficult to gauge the exact impact of blockchain implementation. However, firms can make a reasonably accurate estimate using a combination of quantitative and qualitative measures. The sample chart below provides an example of how to prioritize use cases after a scenario analysis (Schoemaker & Mavaddat, 2000). The circles represent relevant use cases, the circle sizes represent quantitative gains, and the axes represent qualitative factors. The expected impact on customer and supplier relationships determines each scenario's importance, and the likelihood and speed of adoption by customers and competitors determines its probability. For instance, smart contracts can eliminate the need for humans to verify financial documents; service firms should therefore treat their adoption as highly probable and highly important.

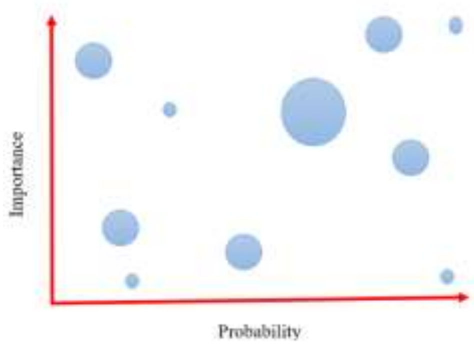


*Figure 21: Prioritizing Use Cases*

**Evaluate & Implement: What are Firm Choices for Implementation?**

Implementing new technologies involves considerable risk, but firms can mitigate many of these risks and accelerate their learning by augmenting internal investments with open and external capabilities. By making strategic choices of internal investments, alliances, and acquisitions, firms can achieve varied levels of market exploration and risk mitigation along with varied controls over resources (Capron & Mitchell, 2012).

Since each of these strategies presents its own merits and constraints, incumbents that succeed in technologically advancing markets will typically take a multi-pronged approach toward exploring new technologies. Pursuing a variety of paths into the future also helps incumbents reduce the probability of shock when unexpected market changes happen (Brown & Eisenhardt, 1997). Ignoring market readiness and investing in new technologies at the wrong time can be fatal, as Sears and Nokia demonstrated (Doz, 2017). Managers would do well to maneuver strategies to keep up with the advancing blockchain ecosystem. This will require staying close to developments in their industry, remaining engaged, and iterating their strategic choices over time. As competitors and other stakeholders develop more robust use cases and tighten the loose ends, strategic engagements with other players can help firms stay on top of their game.

**Manage & Monitor: How do Firm Prepare for Long-Term Sustainability?**

The below S-curve chart indicates that a new technology advances by cumulative engineering effort. Empirical evidence shows that technology substitution is characterized by the surrounding ecosystem evolution (Adner & Kapoor, 2015). Accordingly, blockchain's progress and long-term success will largely depend on how well its surrounding ecosystem develops. For instance, Maersk's success at tracking its shipment supply chain will hinge on the readiness of all stakeholders end-to-end in the supply chain. If all parties in the ecosystem are not infrastructurally ready, familiar with, or comfortable with handling the technology, the solution cannot run smoothly. Each player needs to recognize problems in its own processes and resolve them. The cumulative effort will catalyze the technology's advancement and improve the solution's performance.

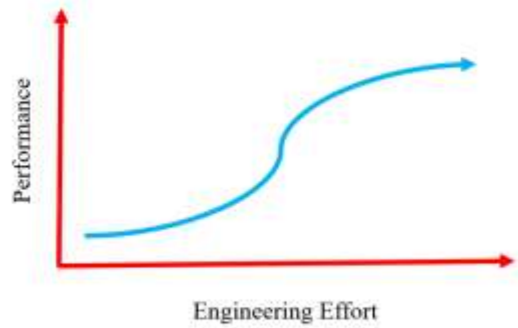


*Figure 22: Technology S-Curve*

A firm's active participation in ecosystem development is the foremost factor in ensuring long-term sustainability. Along with co-developing solutions with other stakeholders, managers can actively lobby regulators to share their knowledge and help create a sensibly regulated environment while also enhancing their firm's credibility.

The second key factor for sustainability is knowledge integration. Emerging technologies almost always develop in networks. As the network expands, capabilities grow and the complexity of knowledge increases. Knowledge management becomes critical and has to be redirected to the firm's advantage (Klein & Poulymenakou, 2006). Mitsubishi, for instance, is well-known for growing its market share by strengthening its active network position through alliances and enhancing its technological capabilities (Stuart & Podolny, 1996). Firms that are exploring blockchain through a variety of internal and external innovations can utilize consortiums to gain and share knowledge.

The third factor for sustainability is establishing processes to transfer knowledge quickly and effectively across the organization. To build unique competencies and supplement human skill sets, organizations need to support environmental scanning, experimentation, and integration of knowledge into actionable tasks (Singh, Chan, & McKeen, 2006). Boeing, for example, commissioned a formal group to study difficulties in the development of its 737 and 747 planes and compare the process with that of its most profitable planes, the 707 and 727. Boeing then formalized the lessons in writing to guide the team building its next set of aircraft. Similarly, British Petroleum established a project appraisal unit to review investments regularly, deduce lessons, and incorporate the insights into future plans. Given that blockchain is still in its early stages, agile learning processes that integrate learning into day-to-day activities can help the technology progress faster. Such processes can minimize the incidence of failures and also diminish internal resistance to new technology adoption (Iansiti & MacCormack, 1997).

Active participation in ecosystem development, knowledge integration and rapid transfer of knowledge across the organization depends on the sustained development and commitment of human capital. A firm's innovation success hinge on on managerial capabilities to connect the dots appropriately, especially when it comes to integrating lessons from pilot blockchain projects into the firm (Henderson & Clark, 1990). Like GE and Ford, which partnered with technology firms to access talent, incumbents can close talent gaps through partnerships (Mankins, 2017). Partnerships with educational institutions and consulting firms can further supplement skill development programs. Addressing the blockchain talent crunch is possible, but will require firms to reassess skills, reorganize resources, and invest in training and development, all of which will challenge incumbents to shake off their inertia.

**Blockchain Potentials in Improving Supply Chain Performance**

Nowadays there are many products being manufactured and distributed every day through supply chains that extend around the world. Goods in supply chain industries travel through a vast network of manufacturers, distributors, and retailers, yet in many cases, complete information related to the product that flows along the supply chain is not available (Galvez, Mejuto, & Simal-Gandara, 2018); (Xia & Yongjun, 2017).

Supply chain visibility is still an important business challenge, with most companies having little or no information on their own second and third tier suppliers (Chen E. , 2017). Supply chain transparency can assist model the flow of products, from raw materials to processing and finishing products, that enable a new kind of analysis in the supply chain (Agrawal, Sharma, & Kumar, 2018).

Besides transparency, traceability is also important to improve supply chain performance. Currently, traceability is becoming an urgent requirement and an important feature to differentiate many supply chain industries including food sector, pharmaceutical and medical products, and high-value goods (Galvez, Mejuto, & Simal-Gandara, 2018).

Blockchain technology application is believed to have great potentials to improving supply chain performance (Pearson, et al., 2019). Blockchain can be applied for creating contracts, tracking goods and payment. Blockchain records every transaction on a block across multiple copies of the ledger that are shared with every party, and the record is transparent. Anyone can add data to the block by doing transaction in the network, see these data, but no one can hack or modify them. As a result, blockchain is immutable data of network activities, which are shared among all parties in the shared network.

This is why blockchain technology innovation is regarded as a game changer on global scale by all actors. Several potential benefits of blockchain technology application are identified from the literature (Ko, Lee, & Ryu, 2018), such as reduction of transaction costs, exclusion of intermediaries which diminishes the risk of human error, and generation of a highly secured platform for communication and trade globally.

Previous researches exploring the potentials of blockchain application in the supply chain have shed some light into the relation between blockchain and traceability systems of supply chain (Petersen & Jansson, 2017), traceability and transparency (Jeppsson & Olsson, 2017), and trust and transparency (Chiou, Huang, & Chuang, 2005).

**How Blockchain Technology Could Improve Supply Chain Performance?**

This section aims at offering a comprehensive map of how blockchain technology applications could improve supply chain performance.

A supply chain is defined as the entire process of making and selling commercial goods, including every stage from the supply of materials and the manufacture of the goods through to their distribution and sale (https://www.supplychaindigital.com). In commerce, a supply chain is a system of organizations, people, activities, information, and resources involved in supplying a product or service to a consumer. Supply chain activities involve the transformation of natural resources, raw materials, and components into a finished product that is delivered to the end customer (https://en.wikipedia.org).

Supply chain consists of various stages and locations. This causes tracking of an event to be difficult along the supply chain. Due to lack of transparency, buyers and consumers cannot ensure the true value of the goods or service offered (Dickson, 2016).

In the supply chain network, it is hard to investigate who is responsible for illegal events that occur. This could be the reason why the world is still facing problems of counterfeiting, forced labor, and bad conditions in factories. With regard to this issue, blockchain technology offers a solution to fix supply chain problems. Even basic implementation of blockchain technology can bring huge benefits to the supply chain. Dickson (2016) in his article 'Blockchain has the potential to revolutionize the supply chain' highlights the main function of the blockchain that is considered very useful in the supply chain:

1. The availability of information to the public. They can access and provide an opportunity to track goods from their origin to the final consumer.
2. A decentralized-based structure allows participation of each party in the network.
3. Basic cryptographic and basic structures that cannot be changed provide security and trust.

Blockchain technology is basically a "digital transcript" created to avoid fraud and improve efficiency and performance but simultaneously allows access for third parties as needed. In addition, blockchain technology is also experiencing developments in usage in various sectors. Blockchain technology is inevitably becoming an important technology in almost every sector including supply chain.

**Blockchain Applications in Supply Chain**

**Blockchain Technology Application for Improving Supply Chain Transparency**

Blockchain can greatly improve the transparency issues within supply chain industries through the use of immutable record of data, distributed storage, and controlled user accesses (Abeyratne & Monfared, 2016). A decentralized distributed system that blockchain technology uses will collect, store, and manage key product information of each individual product throughout its life (Abeyratne & Monfared, 2016).

Tracking products by using blockchain provides the ability to directly validate an item's provenance and authenticity, allowing the customers to obtain the relevant information needed to make the choices to buy the product or not (Lützenburg, 2017). Blockchain technology transparency offers the ability to record and tract the product journey from their origin until the point they get delivered to the customer. Thus, the information is visible for everyone involved in the supply chain. Transparency of information then could improve trust among various parties in the supply chain network (Awwad, et al., 2018); (Wood, et al., 2015).

Blockchain immutability provides assurance to all parties that all activities recorded in the network are free from the hands of malicious actors (Liu, Kadiyala, & Cannistraci, 2019); (Mao, Wang, Hao, & Li, 2018). Such strong security is achieved by applying cryptography algorithm. Supply chain transparency could also be a way to eliminate potential scandals such as the discovery of dangerous chemicals in toy products (Badzar, 2016). It is made possible by the recording and auditing functions of blockchain technology and the near-real-time tracking of the transaction. As a result, the need for external auditors can be minimized, hence could reduce audit cost (Awwad, et al., 2018).

The use of smart contracts over blockchain in supply chain can reduce additional cost and delay, which in turn will create a more efficient supply chain. The smart contracts are the contracts written in the digital form on top of blockchain technology (Francisco & Swanson, 2018); (Sander, Semeijn, & Mahr, 2018); (Yiannas, 2018). Dynamic demand chain produced by the smart contract is more efficient than the existing rigid supply chain in maintaining the online transactions on track (Badzar, 2016); (Notland & Hua, 2017); (Jeppsson & Olsson, 2017). The history of the products from the manufacturer, along with transaction data could be documented as the products pass from one node to another node in supply chain network. This makes the supply chain process more efficient and trustworthy by reducing time delays, added costs, and human errors (Awwad, et al., 2018).

The success of the system depends on the coordination between parties in the supply chain network. The manufacturer firstly embeds the product with a code, which would be hashed and placed on the blockchain to ensure its existence and originality. The product movement through the supply chain would be recorded on the ledger by scanning or registering the code (Badzar, 2016). Supply chain transparency will certainly improve supply chain performance. The retailers are being able to share information and prove to consumers that their products originate from safe and sustainable producers. This, in turn, could increase customer loyalty and trust.

**Blockchain Technology Application for Improving Supply Chain Traceability**

The application of blockchain technology can greatly improve supply chain industries particularly in traceability department. By implementing blockchain technology, every actor can remotely trace all information along the supply chain, such as raw material quality, the timestamps of material journey through the supply chain, various actors involved in manufacturing and distribution (Agrawal, Sharma, & Kumar, 2018). Traceability can improve product safety and public confidence. Should any defect product reach a consumer, the system can pinpoint which product should be discarded without jeopardizing an entire product line. This holistic traceability model has the capability to cut costs of product recalls, reduce process inefficiencies, and enable retailers to track individual products in seconds (Kamath, 2018). Blockchain technology is appropriate for establishing a higher traceability level to end user by printing the relevant data directly on the packaging (Creydt & Fischer, 2019). One or two-dimensional Quick Response (QR) codes or Radio Frequency Identification (RFID) tags are usually used because the codes and tags are compact and cheap, especially RFID which is re-usable. These codes can be read out by the consumers using their own smartphones. Each transaction in the blockchain is recorded in the form of hash code showing which parties were involved, transaction detail and timestamp with a digital signature of authentic party or vendor. In the supply chain, each product or good is represented in the form of unique serial number, barcode or tag represented in physical form (Visser & Hanich, 2017). Then, blockchain encrypts data and delivers them to all peers for verification. Once the other peers accept the changes, the transaction block is added to the digital ledger. This consensus serves as an audit trail for each transaction in the network so that if there is any unauthorized change in any block, other peers will either validate the change as valid or reject the change based upon written smart contracts.

One of the many companies that has implemented blockchain technology to improve its supply chain traceability is Provenance. Provenance has demonstrated how mobile technology, such as blockchain and smart tagging, can trace tuna caught by fishermen with a verifiable social sustainability claim. Provenance demonstrates the capabilities of a blockchain-based system in tracking yellowfin and skipjack tuna fish from catching to consumer.

**Blockchain Technology Application for Improving Supply Chain Sustainability**

Supply chain like other industries experiences higher pressure from the society to implement sustainable business practices (Ahlstrand, 2018). Supply chain industry is accused of being contributive to global warming by producing extensive amount of carbon emissions along the process of product distribution from the manufacturer to the consumer (Saberi, Kouhizadeh, & Sarkis, 2018). Therefore, there is an increasing need to green the supply chain.

Blockchain technology offers great potentials to improving supply chain sustainability. Blockchain technology application allows dangerous products and materials to be traced effectively, environmental compliance along the supply chain can also be well monitored (Saberi, Kouhizadeh, & Sarkis, 2018). Other benefits of blockchain technology application to greening supply chain are: First, blockchain technology application is able to trace defected goods precisely, so that it could decrease the need of products rework and recall, which in turn will decrease resource consumption and waste; Second, blockchain technology application can decrease the need to transmit electricity over long distances and subsequently save a big portion of energy wasted over long-distance transmission. It would also remove the necessity for energy storage which saves its resources (Saberi, Kouhizadeh, & Sarkis, 2018).

Given that information in blockchain cannot be altered without the permission of concerned actors, blockchain can help prevent corrupt individuals, or organizations from seizing the assets of people unjustly, thus improving social justice. A blockchain-based supply chain can provide better assurance of human rights and fair work practices. For example, a transparent record of product information assures buyers that the product being purchased is supplied and manufactured from a verified ethical source.

**Blockchain Technology Application in Improving Supply Chain Trust**

Expansion of size and complexity of supply chains has led to trust concerns among various partners in supply chains. The level of trust and willingness to share information rarely exists in large and multi-tiered supply chains (Creydt & Fischer, 2019). As supply chains are getting more global right now, trust is considered an integral asset to develop long-term partnerships (Badzar, 2016). A trust-based supply chain partnership could result in reduced uncertainty and information asymmetry (Mao, Wang, Hao, & Li, 2018). This makes credible information sharing become critical for supply chain industries (Wu, et al., 2017).

The distributed nature and immutable data promised by blockchain make actors with established relationships of trust do a transaction with high confidence based on the information that is available from the blockchain (Abeyratne & Monfared, 2016). This transparency, which cannot be separated from all actors, becomes the evidence of truth because all activities are recorded and produce an audit trail that can settle disputes quickly (Pearson, et al., 2019). Due to the transparency of information under the blockchain environment, the evaluation of trust between actors can be carried out based on the actual transaction information. Blockchain application allows all transactions to be saved in the same account and transparent to all participants in the supply chain network (Xia & Yongjun, 2017). Thus, it is possible to evaluate all parties' credibility within the blockchain environment.

Blockchain relies on cryptography-based, decentralized, and distributed ledgers to provide all participants with trust (Mao, Wang, Hao, & Li, 2018). The validated transactions that are shared to all participants create a decentralized ledger, every participant has the same version of ledger (Saberi, Kouhizadeh, & Sarkis, 2018). There is no conflict regarding transactions because all participants have the same ledger, and therefore, an agreement is reached.

Blockchain's ability to track products can also improve trust between participants. For instance, if a customer receives a defected product, blockchain application could trace the history of the product from the retailer up to the manufacturer and even to the origins of its raw material and the material used which is probably causing defected product (Awwad, et al., 2018).

**Blockchain Technology Application for Improving Supply Chain Cost-Efficiency**

Blockchain technology application could improve supply chain cost-efficiency in several ways, such as by decreasing the need for third-party intermediaries, lowering transaction cost, and minimizing human error (Laaper, Fritzgerald, Quasney, Yeh, & Basir, 2017). Blockchain application allows real-time transparency, thus removes the need for trusted intermediaries to mediate a transaction in supply chain. For instance, in a supply chain without blockchain, if A exports goods to B, an intermediary is needed to ensure that A holds sufficient goods or B has enough money. This practice occurs because these kinds of transactions generally take place sequentially; either A sends the goods prior to payments or B pays before the goods are sent. However, if B's financial affairs utilize blockchain technology, A can check B's account, allowing A to send the goods with confidence. Conversely, B can pay first with confidence if B is provided with the A's updated inventory information in the blockchain system. Therefore, blockchain application could minimize the need for intermediary. The elimination of this intermediary can reduce the risk of fraud and human error in supply chain and also reduce cost (Notland & Hua, 2017).

Real-time financial transparency in blockchain technology also allows supply chain industries to reduce verification and surveillance costs (Ko, Lee, & Ryu, 2018). Supply chain with blockchain technology can develop confident relationships among the parties involved, thereby eliminating the cost of trust and reducing verification costs (Francisco & Swanson, 2018). Verification costs are incurred due to lack of trust between parties. With blockchain, actors involved in the supply chain can provide their true financial status or real-time accounting to the other actors, causing rendering verification by an accounting firm to be unnecessary. Therefore, supply chain industries can save a significant amount of verification costs.

Blockchain technology can also reduce cost by implementing smart contract (Ko, Lee, & Ryu, 2018). Smart contract is defined by a code, and automatically enforced and executed when the term on the contract is fulfilled. A tamper-proof smart contract can be enacted when the exporter's goods successfully clear the requirement. Thus, as the exporter's goods clear the requirement in the smart contract, the exporter is automatically paid a certain amount from the counterparty's cryptocurrency account uploaded to the smart contract. Consequently, a trusted intermediary is less necessary, and intermediary costs fall.

In a nutshell, blockchain technology application has significant potentials for improving supply chain performance, specifically in these five issues: transparency, traceability, trust, sustainability, and cost-efficiency. Blockchain can greatly improve the transparency and traceability issues within supply chain industries using immutable record of data, distributed storage, and controlled user accesses. Every actor can remotely trace all information along the supply chain because each transaction in the blockchain is recorded in the form of hash code showing which parties were involved, transaction detail, and the timestamp. This distributed nature makes blockchain become a trustable system which leads actors within the network can do the transaction with high confidence based on information available from the blockchain.

Additionally, blockchain technology can also promote green supply chain management to improve the sustainability by tracing products and materials effectively as well as monitoring environmental compliance along the supply chain. It can trace defected goods precisely, which will decrease resource consumption and waste as well as save a big portion of energy wasted over the long-distance transmission.

Finally, blockchain technology can reduce the transaction and enforcement costs in the supply chain by implementing smart contract to comply with self-enforcing contractual conditions without the need for an existing trusted third party. This contract possesses many advantages, such as transparency, accuracy, speed, security, efficiency, and trust.

**Blockchain Global Adoption Indicators**

Several global indicators show that blockchain technology is at an accelerated rate of adoption by both governments and industry. In a study recently published by the World Economic Forum (WEF), it is indicated that 10% of global Gross Domestic Product (GDP) will be stored in blockchain by 2027. Gartner, a leading global research and advisory firm, predicts that the value added by adopting blockchain will reach $176 billion by 2025, increasing to $3.1 trillion by 2030. International Data Corporation (IDC), another leading IT advisory firm, reported that global spending on blockchain technology projects will reach $11.7 billion by 2022. Due to this accelerated rate of adoption, the importance of blockchain is being equated to the importance of the internet, where blockchain is described as "the internet of value" as opposed to the "internet of information". Within the Oil and Gas industry, the use of blockchain technology is being explored by industry peers for use cases such as commodity trading, critical equipment traceability and, joint venture collaboration.

**Blockchain Adoption Road Map in Saudi Aramco**

The Information Technology Blockchain Initiative team has been engaging with Saudi Aramco internal stakeholders from admin areas across the company to identify the right use cases for blockchain deployment. To realize a business value out of blockchain deployment, a candidate use case needs to hold certain characteristics such as being executed across-organization boundaries, administered by an intermediary, and require higher levels of transparency. Once a suitable use case is identified, external business partners such as government entities, banks, customers, or suppliers need to be approached with a governance model for the proposed business network. The Governance Model needs to highlight business value for participating partners and to state how the proposed blockchain network is to be managed? how new partners can be enrolled? and how the agreed business rules may be updated? Blockchain adoption best practice calls for a holistic approach to map selected use cases to an appropriate adoption stream. Figure III-7 below outlines the technology adoption streams being currently pursued. The Build Solution stream is best suited for use cases where Saudi Aramco can lead blockchain network development efforts and influence business partners to join. In this stream, a blockchain platform will serve as a foundation for implementing targeted use cases.

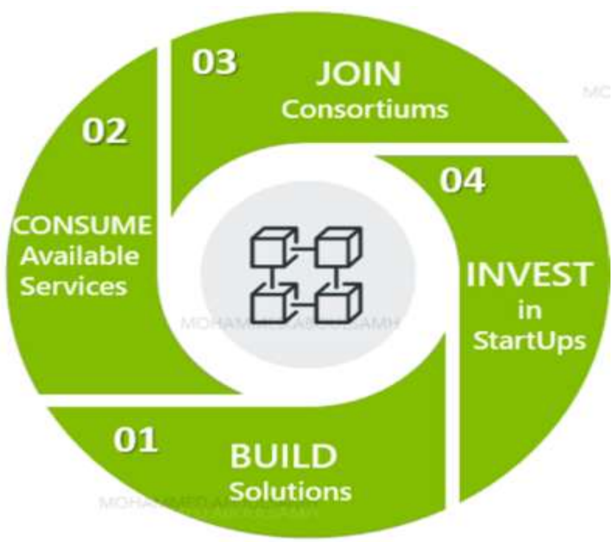


*Figure 23: Blockchain Adoption Streams*

The team has recently completed a procurement action to procure and deploy a corporate platform. In Consume Available Services Stream, the Information Technology Blockchain Initiative team leverages publicly available Blockchain as a Service (BaaS) solutions and integrates them into applicable corporate applications, in collaboration with business proponents. An example of this adoption stream is the utilization of a publically available degree authentication blockchain service to verify candidate's academic qualifications.

The Join Consortium stream focuses on identifying relevant and value-adding international blockchain consortiums that are being formed to leverage blockchain technology in addressing common industry problems. The Blockchain Initiative Team has led the efforts for Saudi Aramco to become a co-founder of the Trust Your Supplier (TYS) Blockchain Consortium, enlisting the Procurement & Supply Chain Management (P&SCM) organization as a primary member of the TYS network. TYS aims to streamline supplier on-boarding and verification processes. Finally, following the Invest Stream, the team eyes the latest and innovative industry solutions and collaborate with Saudi Aramco Energy Ventures (SAEV) and appropriate business proponents to invest in promising blockchain startup companies to benefit from their technological innovations. Investing in Data Gumbo, a promising US-based startup, focusing on oil and gas blockchain solutions is an example of Blockchain Team and SAEV collaboration in this stream.

The blockchain use cases can be grouped in three primordial fields as follows:

**Table 10: Blockchain Use Cases (Three Primordial Fields)**

| Counter-party visibility and facilitation of payments | Material traceability | Data management |
|---|---|---|
| • Visibility into local supplier-managed capacity and service offerings | • Visibility into local supplier managed inventory | • Through integration with other technologies such as IoT, the ability to track and control immutable, secure and provisioned access to distributed but universal master data records |
| • Visibility into spend with 3rd parties | • Visibility and traceability in material supply chain | |
| • Manage local value added | | |
| • Facilitate indirect tax | • Visibility and traceability to prevent sub-standard goods and fraud | • Visibility into auditable log of data access and modification |
| • Requisition to Pay and Order to Cash | • Support of shared or distributed ownership of asset, inventory, technologies | • Introduction of enhanced cybersecurity |

**Blockchain Applications in Saudi Aramco - Use Cases**

**Blockchain Certificate Verifier:** On June 2020, Saudi Aramco deployed the first version of a Blockchain Certificate Verifier to eliminate the risk of middleman fraud and the falsification of certificates. The Verifier is one of several blockchain-based solutions the company has developed as part of recent efforts to explore the technology.

This new application covers the technical certificates verification related to operating machinery and heavy equipment. The Verifier solution offers an easy and quick channel to address certificate fraud by securing genuine professional certificates on blockchain. This approach makes credentials immutable and instantly verifiable. In addition, the solution enables real-time updates on expired or revoked certificates while maintaining the highest standard of security and privacy.


*Figure 24: World Economic Forum, Blockchain Certificate Verifier*

The Certificate Verifier architecture works on the process of the issuer, training institute, academia, or any accreditation body, creating a digital certificate and sending an invitation to the student to receive a blockchain credential of the original digital certificate. Once the student acceptance is confirmed, the issuer applies a cryptographic hash function to store the certificate onto the blockchain. Consequently, the student will receive a certificate identifier which can be shared with a third party, prospective employer, to easily verify the certificate authenticity in the Certificate Verifier ledger.

Since its deployment, the Blockchain Certificate Verifier has introduced an efficient and secure verification environment and cut verification time by more than 90% for heavy equipment operator certificates. In the legacy environment, the certificate verification process was manual, prone to human errors, and could take up to two weeks for a single certificate. In the new solution, certificates are verified nearly instantly in less than 5 seconds.

**Blockchain in Custody Transfer Application:** Saudi Aramco as global hydrocarbon supplier, is responsible for managing the supply chain associated with the Hydrocarbon movements to and from the Company's customers and partners locally and globally. This process includes the physical transfer of the product, the allocation, scheduling, measurement, sales, ticketing, billing, and invoicing. The industry refers to such process as a Custody Transfer application. Each Custody Transfer transaction requires a multitude of necessary financial, auditing, validation, and governance services executed by various internal and external organizations. Considering the nature of the process, Saudi Aramco considers Enterprise Blockchain as a candidate platform to optimize the transactional services securely and efficiently for custody transfer applications. Currently, there is ongoing collaboration between Information Technology and the Process & Control Systems Department (P&CSD) to deploy the custody transfer as a use case in collaboration with other stakeholders in Saudi Aramco. Figure 25 below demonstrates a blockchain network for a Custody Transfer application.

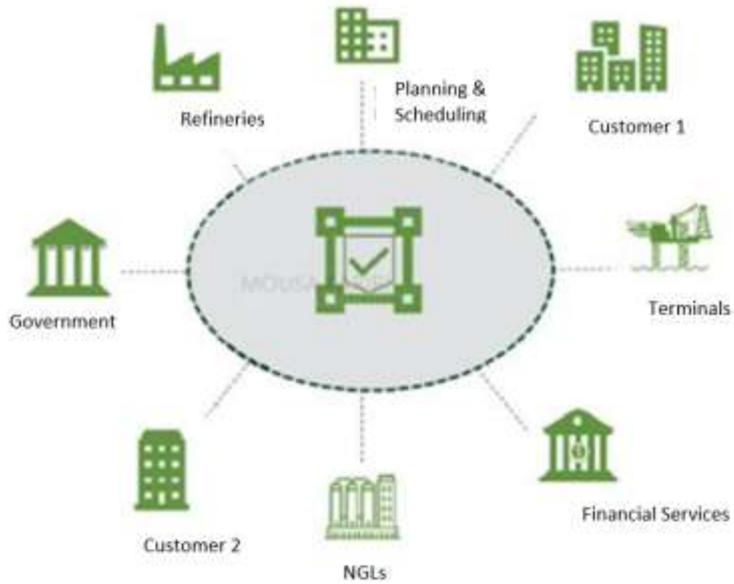


*Figure 25: Blockchain Network for a Custody Transfer Application*

**Bank Guarantee Use Case Model:** Bank Guarantee (BG) is an independent responsibility by a bank, on behalf of its customer, to pay a named beneficiary (Company XYZ) in the event the customer fails to fulfil their contractual obligations.

The following figures demonstrate Current Process, Blockchain & DLT Approach, and Blockchain Technical Architecture for the BG Process Mode.

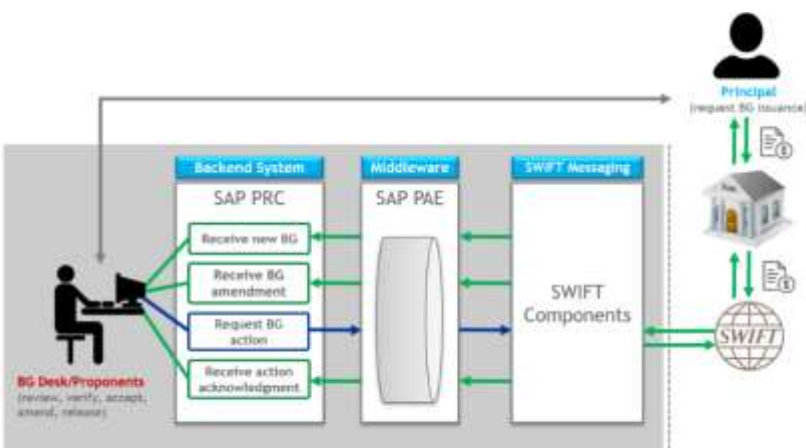


*Figure 26: Bank Guarantee Current Process*

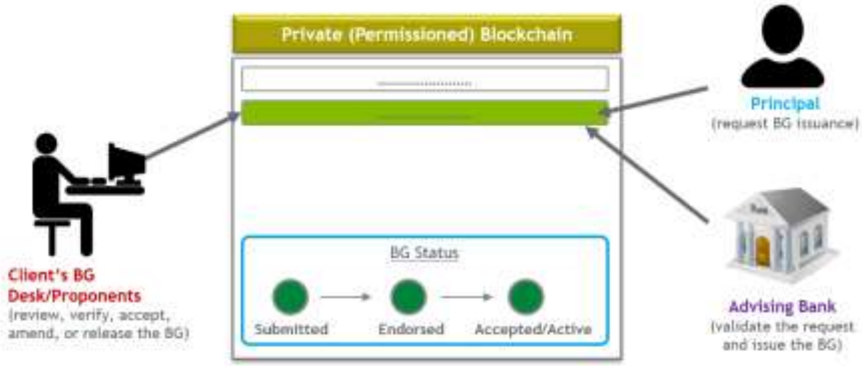


*Figure 27: Blockchain & DLT Approach*

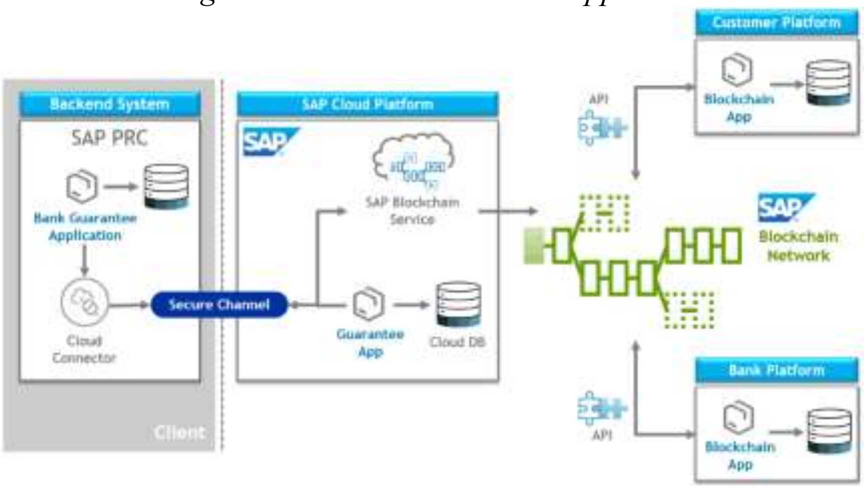


*Figure 28: Blockchain Technical Architecture*

**Supply Chain Key Use Cases**

Early investment in blockchain technology can provide innovative organizations with competitive advantage. Fast movers will likely realize the value of addressing these challenges more quickly and comprehensively than their competition. To accomplish these results, organizations need to understand blockchain capabilities, choose the appropriate starting point for their industry, and prove out the value with an applicable and functional use case. Following are the five (5) core use case categories for executives to consider as they decide where to apply blockchain technology. These use cases are applicable across the supply chain with benefits that differ by industry and organization based on the level of focus and compliance required to complete the cycle. During each stage of the end-to-end supply chain there is opportunity to weave in blockchain capability.

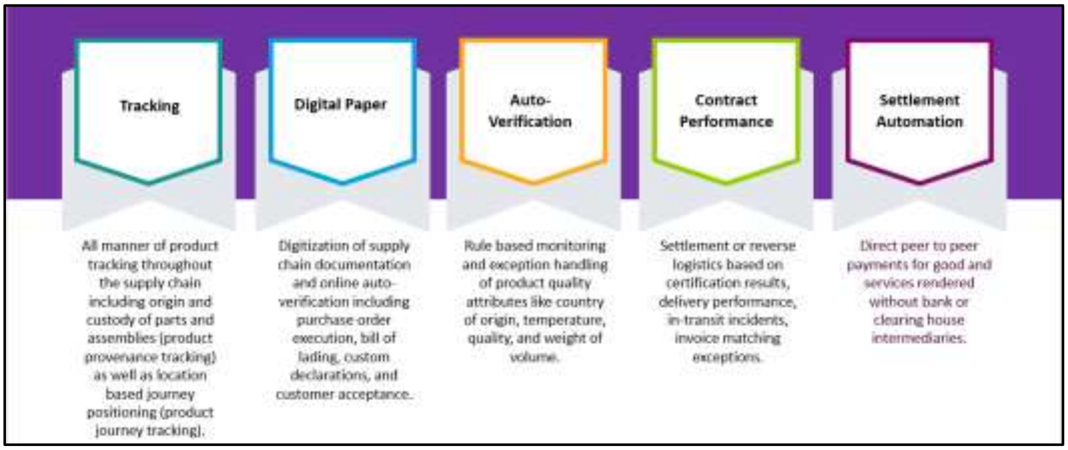


*Figure 29: Blockchain Five Core Use Case Categories in Supply Chain*

## CONCLUSIONS, IMPLICATIONS, AND RECOMMENDATIONS

The blockchain projects and research initiatives reviewed in this work show that blockchain technology is a promising technology for a wide range of services and use cases in the energy sector. The large number of established energy companies and utilities that are currently involved in DLT projects, as well as the investor interest in this area, clearly shows the potential value of this emerging technology for the energy industry. The real, long-term value is, however, yet to be proven, especially as most initiatives have trialed the technology in relatively small-scale projects that are still in an early development phase. As a result, several questions will need to be answered before mainstream adoption of the blockchains in the energy industry.

First and foremost, blockchain technology needs to prove they can offer the scalability, speed and security required for the proposed use cases. Research efforts on distributed consensus algorithms, which are crucial to achieving these objectives, are still ongoing, however a solution that combines all desired characteristics cannot yet be achieved without significant trade-offs.

PoW algorithms are more mature and secure, but on the other hand are also slow and very energy intensive. As a result, blockchain developers are increasingly moving towards PoS schemes that are energy efficient, faster and more scalable. Other promising solutions include techniques such as sharding that enable parallel processing. Often these solutions may come, however, to the expense of security and decentralization. Early adopters of blockchain technologies face the challenge of selecting the right consensus mechanism and system architecture, without having a clear long-term picture of the advantages and downsides that each approach has to offer.

Hence, it is clear that blockchain technology has already passed the proof of concept stage for several use cases but require further development to achieve desired operational and performance objectives. Several recent developments, such as the Energy Web blockchain, can be scaled up to thousands of transactions per second. Similar future developments will significantly determine blockchain adoption in several applications, such as for IoT platforms and services that require very fast confirmation and large numbers of transactions.

Resilience to security risks stemming from unintentionally bad system design or malicious attacks are highly likely. Blockchain faces additional risks such as possible malfunctions at early stages of development due to lack of experience with large-scale applications. Blockchain ecosystems rely heavily on coding new algorithms, a procedure that can be prone to errors. Security breaches are still highly likely before the technology becomes mature, which could result in bad publicity and delays in acceptance from consumers. With respect to cyber-attacks, Bitcoin, the oldest blockchain implementation, has proved to be relatively resilient, but other platforms such as Ethereum, have been the target of serious attacks in the past. Crucially, vulnerabilities in terms of cybersecurity often come from peripheral applications, such as digital wallets or smart contracts. Resilience to such attacks is of great importance, especially for applications in critical infrastructure, such as energy systems.

Another important challenge is that blockchain systems have currently high development costs (Makhdoom, Abolhasan, Abbas, & Ni, 2019). Blockchains may realize significant cost savings by circumventing intermediaries, however for several use cases, they might not have the competitive advantage against already existing solutions in well-established markets. For example, energy transactions can be recorded in conventional databases, such as relational databases that are designed to recognize relations between stored items of information (Damien, 2018). These solutions are already largely available and currently faster and less costly to operate (Alexander, 2018), even though they cannot offer immutability of records or transparency. Blockchain systems may require costly new infrastructure, such as custom Information & Communication Technologies (ICT) equipment and software, the costs of which need to be outweighed by benefits achieved by data integrity, enhanced security and elimination of the need for a trusted intermediary.

At present, information in blockchain systems can be transferred for very low costs, but validation and verification of data comes with high hardware and energy costs (Alexander, 2018). Proof of stake or proof of authority algorithms may significantly improve this in the future.

Significant barriers in the adoption of the technology are relevant both to the regulatory and legal sphere. In addition, several policy makers have established supportive measures for local or community energy systems that aim to reduce costs for consumers, promote low-carbon technologies and tackle fuel poverty. Blockchain technology can support or accelerate such objectives, therefore coordinate well with current regulatory priorities, however regulatory frameworks would need to be amended to allow larger adoption of DLT.

P2P trading platforms are in early stages of development; therefore, the scale of their adoption is currently limited. However, they have the potential to radically change established roles of incumbent energy companies, such as energy suppliers or grid operators, who are in most countries are regulated monopolies and own the physical infrastructure.

In addition, regulatory authorities are responsible for setting the rules of consumer data protection. Blockchain system users should be identified to account for their liabilities but at the same time, consumer or commercial sensitive information need to remain confidential, such as the prices agreed between an energy supplier and consumer within a smart contract recorded in a ledger. When information from multiple participants are recorded in shared ledgers, solutions need to be found for data privacy, confidentiality and identity management. Moreover, smart contracts need to be integrated into legal code to ensure compliance with the law and protection of consumers. In a distributed system architecture, it is not always clear who has the legal and technical responsibility for the negative consequences of the actions of different parties. For instance, if a major attack is successfully deployed because of a software or a hardware bug in the system, there is no central authority to which a consumer may address their complaints to, as in current practice. With blockchain systems, trust is put to the technology itself rather than in a known authority.

Finally, another significant factor that might slow blockchain adoption is the lack of standardization and flexibility. Standards for blockchain architectures need to be developed to allow interoperability between technology solutions. An additional challenge is that once a blockchain system is deployed, any changes in the ruling protocols or code needs to be approved by the system nodes. In blockchain ecosystems, this has historically led to disagreements between developers and multiple system forks. If blockchain is largely adopted in energy systems, these issues may lead to mistrust and fragmentation (Makhdoom, Abolhasan, Abbas, & Ni, 2019). Moreover, blockchain adoption might, in some cases, be inhibited by the bad reputation stemming from the early days of Bitcoin and its association with illegal activities although as blockchain mature, this aspect may become less relevant over time.

To conclude, blockchain or distributed ledger technologies can clearly benefit energy system operations, markets and consumers. They offer disintermediation, transparency and tamper-proof transactions. Blockchain technology has enabled applications of sharing-economy in the energy sector, which has prompted several authors to speak about novel market models and energy democratization (Mittal, Slaughter, & Zonneveld, 2017). Many research and commercial parties are currently pursuing blockchain innovation in the energy sector. Blockchain is a fast-moving area of research and development, therefore a review on this emergent technology is required to improve understanding, inform the body of knowledge on blockchain and realize its potential.

This paper does a systematic review to discuss the application prospects of blockchain technology in the oil and gas industry, and the main purpose of this paper is to expand the influence of blockchain technology in creating a more resilient supply chain for oil and gas industry. The need to process transactions rapidly and verify the creation, transmission and receipt of a specific exchange of value is increasingly crucial to business success. To make the supply chain robust and resilient, there must be transparency, integrity, accountability and credibility across domains that can be strengthened by implementing blockchain technology.
Trust and the ability to validate information will be necessary to rebuild disrupted networks. Blockchain technology provides building blocks to ensure the transparency of trustworthy and protected data for trading partners and customers, and to synchronize processes across a mutually agreed set of rules. With blockchain, the physical (product/goods flow) and digital (information flow) supply chain are better linked to the financial side of the transaction. Blockchain also has the ability to lead to a more fair-trading environment for both producers and consumers.

In summary, blockchain technology has excellent potential in the oil and gas industry, but since it has just been started in the last few years, there are many opportunities, challenges, and risks.

Specifically, this paper first introduces the core theory of blockchain technology in Section I, including the consensus algorithm of the blockchain, data record model and distributed storage system. Secondly, this paper demonstrates the possible application modes and scenarios of blockchain in the oil and gas industry from four aspects in Section II, trading, management and decision making, supervision and cyber security. Finally, this paper discusses the application status, opportunities, challenges and risks of blockchain technology in the oil and gas industry, and also analyzes the future development trends in Section III.

The following conclusions were drawn:

- Europe and Asia are the most powerful in promoting the blockchain in the oil and gas industry, and BP and Shell are pioneers in this field.
- At present, the application of blockchain in the oil and gas industry is still in the experimental stage, and many people in the oil and gas industry do not understand enough.
- Blockchain technology can bring many opportunities to supply chain function of the oil and gas industry, such as reducing transaction costs and increasing transparency. However, it also faces many challenges and needs to address many technical and regulatory issues.
- Blockchain technology may have operational, legal, and cyber risks in the oil and gas industry.
- In order to meet market and management needs, the blockchain will move toward the hybrid blockchain architecture, cross-chain, and hybrid consensus mechanism in the oil and gas industry.

In a nutshell, blockchain is a promising breakthrough technology and is highly applicable to vast businesses. However, it is still hard to find empirical evidence to show the comparison between blockchain approaches and traditional approaches. In view of this, businesses should realize that blockchain technology has not yet reached an optimal level of maturity, and therefore thorough feasibility studies should be conducted before using this technology.

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