Blockchain Framework for Integrated Petrochemical Complexes

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Abstract
With the rapid growth in technology, the world is witnessing a shift towards digital transformation and automation. Oil & Gas sector is often considered as a global economy pillar where data security, decision making, and efficiency are major components. Current practices in the petrochemical industry call for adopting industry 4.0 technologies to minimize operational costs and increase value generation. In conduct, businesses operate by the utilization of information which introduces the blockchain concept. Furthermore, blockchain technology is ideal for timely delivery of information. Additionally, it provides instant, shared, and specific information stored in an immutable ledger to be accessed by authorized network members only. This paper aims to establish a framework leveraging blockchain concepts, to securely integrate petrochemical companies in integrated industrial cities. This blockchain will cover different aspects of operating an integrated petrochemical complex. For example, optimizing the purchases of the feedstocks, raw materials, additives, and packaging from a real-time business model based on the market forecasts, demands, and operational constraints. This blockchain will ensure secure money transactions based on live data from flow and measurement instrumentation.

Keywords:
Blockchain, petrochemical, smart contracts, industrial cities.

1. Introduction

With the increasing demand for energy consumption and the current technological revolution, the development and application of cutting-edge technologies can make a substantial difference in the quality of life. Similarly, the manufacturing industry can rapidly grow through automation and the adoption of industry 4.0 technologies[1]. In the oil and gas field, multiple stakeholders interact with each other to achieve business goals, which call for a shift toward the utilization of dynamic, automated, and efficient solutions. "BP Statistical Review of World Energy" reported that 2019 witnessed a 2.9% increase in the global energy demand and around a 5% increase in natural gas consumption which is the highest growth rate in 30 years[2]. It can be said that the rise of the global economy is highly reliant on petrochemicals and energy resources. At this time, several emerging technologies can be employed in the field such as cloud computing, the Internet of Things (IoT), and blockchain. In literature, multiple attempts to incorporate those technologies exist; yet there's a lack of real-world application. State-of-the-art blockchain technology has a wide range of applications with the assistance of IoT, petrochemical companies have many tasks that can be handled using industry 4.0 technologies [3].

The Oil & Gas and the petrochemical industries can be viewed as three different entities: upstream, midstream, and downstream. Upstream oil & gas companies are involved primarily with oil discovery, extraction, and production either from traditional methods or fracking (shale gas) unconventional methods. Midstream companies are mainly with refining and delivering petroleum and purified natural gasses to the petrochemical (downstream) industries. Processing natural gas is a complex process, involving multiple chemical reactions to create various end-products including ethane, propane, and butane to be transported to the petrochemical sector (downstream) through pipelines most of the time. Finally, the petrochemical industry is further processing the oil & gas feedstocks into useful consumable goods. For example, Agri-nutrients, polymers (plastics, rubbers, and adhesives), and detergents [4].

In the last couple of decades, most energy projects were built in integrated oil and gas companies operating in multiple streams within the same vicinity to maximize product utilization and minimize energy consumption. For example, one area may have drilling operations as well as own refineries and license gas stations to franchisees. Some of the largest and most influential energy companies in the world are integrated companies. The purpose of the downstream

Manuscript received June 5, 2022
Manuscript revised June 20, 2022
https://doi.org/10.22937/IJCSNS.2022.22.6.94

sector is to maximize the value generation [5]. Ernst & Young reported in 2017 that the total transactions in the upstream only was around $344 billion [6]. By incorporating new technologies such as blockchain, the energy sector can be transformed into more efficient, integrated, and robust corporations. This paper aims to establish a framework by utilizing blockchain concepts between upstream, midstream, and downstream in the energy world. The upcoming sections illustrate several real-world scenarios such as addressing the natural volatility of the product prices, demand, and logistic adversities.

This paper is organized as follows. The next section describes the hydrocarbon chain overview. Section 3 discusses the blockchain. In section 4, we surveyed the related literature. Section 5 highlights the proposed framework. Finally, in section 6, we give some concluding remarks.

2. Background

Before the petrochemical feedstocks are produced, the hydrocarbon chain goes through multiple intermediaries from the oil rigs to the final products. The process begins in a gas separation unit, where gases are separated from liquids. Liquids are processed through oil refineries to produce useful products such as petrol, diesel, kerosene, jet fuel, and asphalt. Gases on the other hand are refined in the Gas Purification Units (GPU), separating different intermediate products (Figure.1) such as Methane, Ethane (Figure.2), Propane, ...etc. The next phase is cracking the purified gasses to produce useful products for the end-users. For example, cracking the ethane into ethylene via Pyrolysis reaction, (Fig.1). Subsequently, Ethylene will be fed to the polymerization unit to produce polyethylene, the most common plastic used today (Fig.2). It is very costly to store gasses from GPU as they require high pressure to be transformed into liquid form for storage [7], which demands for optimization methods to increase profitability and minimize loss [8].

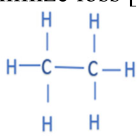

Fig. 1. Ethane

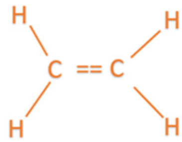

Fig. 2. Ethylene

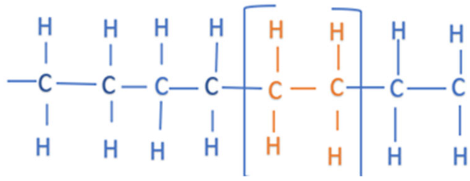

Fig.3. Polyethylene

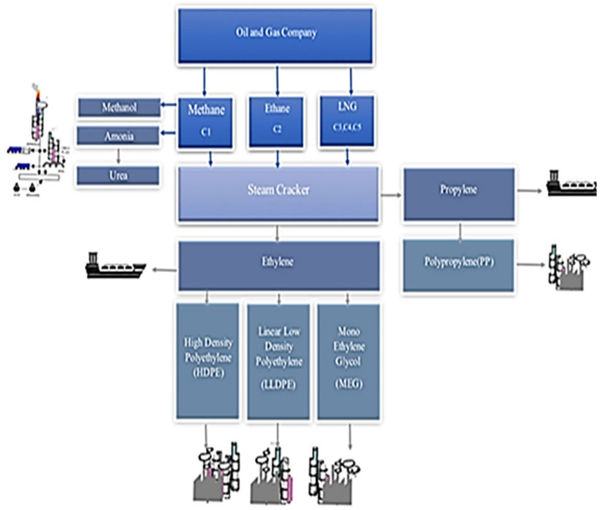

Fig.4. Oil and gas company flow

3. Blockchain Overview

Blockchain is a shared and immutable ledger that facilitates the process of recording transactions and tracking assets in a business network. The asset may be tangible (house, car, cash, land) or intangible (intellectual property rights, patents, copyrights, trademarks). Practically, anything of value can be traced and traded on the blockchain network, reducing risks, and lowering costs for all involved parties. The Blockchain network can keep track of orders, payments, accounts, production rates, and much more. Blockchain members share a unified view of the network, every transaction detail can be seen giving the user greater confidence, as well as new efficiencies and opportunities [9].

3.1 Key Elements of Blockchain Technology

Distributed Ledger Technology
All network participants have access to the distributed storage and its immutable record of transactions. With this shared repository, transactions are recorded only once, eliminating the duplication of effort that characterizes traditional business networks.

Immutable records
No participant can alter or tamper with the transaction after it has been recorded in the shared ledger. If the transaction log contains an error, a new transaction must be added to reverse the error, and both transactions will then be displayed.

Smart Contracts
To speed up transactions, a set of rules, called smart contracts, are stored on the blockchain, and executed automatically. The smart contract can specify the terms of the corporate bond transfer, including the travel insurance terms to be paid and much more.

3.2 Blockchain Benefits

Processes often waste effort in keeping duplicate records and third-party validation checks. Record-keeping systems can be vulnerable to fraud and electronic attacks. Limited transparency can also slow down the data validation process. With the arrival of the IoT, transaction volumes rapidly increased. All of this slows down the business and drains the bottom line - so a better way is needed.

More confidence
When using blockchain, members of the members-only network can be assured that they receive accurate and timely data and that their confidential blockchain records will only be shared with the members of the network to whom are specifically granted access.

Greater security
Consensus on data accuracy is required of all network members, and all validated transactions are immutable because they are permanently recorded. No one, not even a system administrator, can delete a process.

More competencies
By using a distributed ledger that is shared with network members, time wasting records reconciliation is eliminated. To speed up transactions, a set of rules, called smart contracts, can be stored on the blockchain, and executed automatically.

3.3 How does Blockchain technology works?

When a transaction occurs, it is recorded as a "block" of data These transactions show the movement of an asset which can be tangible (product) or intangible (intellectual). The data block can record information according to the user's choice: identity, timing, location, quantity, and even status, such as the temperature of oil shipment. Each block is connected to the one before and after these blocks form a chain of data when an asset moves from place to place or its ownership changes. The blocks confirm the exact time and sequence of transactions, and the blocks are securely linked to each other to prevent a block from being changed or a block being inserted between two already existing blocks.

Grouping Transactions Together in an Inseparable Chain
Each additional block reinforces the validation of the preceding block and thus enhances the entire Blockchain unit. This makes the blockchain safe from tampering, bringing the core strength of the concept of immutability. This prevents the possibility of malicious actors and supports the creation of a ledger of trusted transactions from members of the entire network [10].

3.4 Blockchain types

There are primarily two types of blockchains: Private and public blockchain. However, there are many differences as well, such as consortiums and hybrid blockchains. Before we get into the details of the different types of blockchains, let's first learn the similarities they share. Each blockchain consists of a group of nodes or units that operate on a peer-to-peer (P2P) peer-to-peer network system. Each node in the network contains a copy of the shared ledger that is updated in time. Each node can verify transactions, initiate, or receive transactions and create blocks. There are four possible types of Blockchain.

Public Blockchain
Public Blockchain is an unrestricted and authorized distributed ledger system. Anyone with internet access

can log on to the blockchain platform to become an authorized node and be part of the blockchain network. A node or user that is part of a public blockchain is authorized to access current and past records, verify transactions, or do Proof of Work for an incoming block, and do mining. The primary use of public blockchains is for mining and exchanging cryptocurrencies. Thus, the most common public blockchains are the Bitcoin and Litecoin blockchains. Public blockchains are mostly secure if users strictly follow security rules and methods. However, it is only risky when participants do not faithfully follow security protocols. Example: Bitcoin, Ethereum, Litecoin

Private Blockchain
A private blockchain is a restrictive blockchain or only operative permission in a closed network. Private blockchains are usually used within an organization or organization where only selected members are involved in the blockchain network. The level of security, permissions, permissions, and accessibility are in the hands of the controlling organization. Thus, private blockchains are similar in use as public blockchains but have a small and restricted network. Private blockchain networks are deployed for voting, supply chain management, digital identity, asset ownership, etc. Examples of private blockchains are Multichain and Hyperledger projects (Fabric, Sawtooth), Corda, etc.

Consortium Blockchain
A blockchain consortium is a semi-decentralized type where more than one organization manages a blockchain network. This contrasts with what we saw in the private blockchain, which is operated by only one organization. More than one organization can act as a node in this type of blockchain and exchange information or do mining. Consortium blockchains are usually used by banks, government institutions, etc. Examples of a blockchain consortium are Power Grid Corporation, R3, etc.

Hybrid Blockchain
Hybrid Blockchain is a mixture of private and public blockchain. It uses the features of both types of blockchains that one can have a private permission-based system as well as a less public permission system. With such a hybrid network, users can control who gets access to the data stored in the blockchain. Only a specific portion of the data or records from the blockchain can be allowed for public announcement while keeping the rest in the private network confidential. The hybrid system of blockchain is flexible so that users can easily join a private blockchain with multiple public blockchains. The transaction is usually verified in a private network of hybrid blockchain within that network. But users can also launch it into the public blockchain to get verified. Public blockchains increase hashing and include more nodes for verification. This enhances the security and transparency of the blockchain network. An example of a hybrid blockchain is Dragon chain [9].

Fig.5. Blockchain features

4. Related Work

Current implementations of blockchain can be summarized in four angles: decision making, cyber security, management, and trading. At this point, Asia and Europe are showing expeditious growth in blockchain technologies. However, little tested frameworks are being employed globally. Due to the existing lack of real-world application, the future of blockchain in the oil and gas field is leaning towards employing different blockchain architectures and integrating multiple technologies [11]. Authors in [12] proposed a framework manifesting the success or failure of smart contract appliances in Iraqi oil and gas companies. A sample of 361 employees was surveyed aiming to measure the effect of individual, environmental and organizational factors that influence the enactment of smart contracts. Structural equation modeling was used to analyze the obtained data. It was discovered that organizations support having a secured application of smart contracts. Also, it would be a sustainable method for companies to achieve long-term goals. While in [13] Possible future opportunities for blockchain implementation in the oil and gas industry were discussed. Blockchain technology can successfully detect pipeline leakage and serve as a unified platform for stakeholders to record monitor, and process pipeline-related data. Billing can be a potential use of this technology as outsourcing is very common in such fields. One of the biggest challenges in incorporating blockchain is related to governance as it's an emerging technology. A study in [14] Utilizes the concept of private blockchain by suggesting a smart contract method that grants reversed traceability.

Moreover, supply-chain-related data will be collected using IoT and then stored in a blockchain that only authorized parties can access. Two smart contract architectures were produced namely, check progress and oil distribution. Some limitations were sustainability, big data processing, and interaction between several devices and technologies.

A study in [15] uses HAZOP approach to assess process safety and suggest operational enhancements in upstream and downstream markets while referring to industry 4.0 technologies. Suggestions include incorporating IoT, blockchain, big data analysis, and cloud computing technologies into existing processes. One promising application of blockchain was in supply chain management by providing real-time data. Also, smart contracting is a great area of development as it would lay out an efficient and robust platform for decision-making. Similarly, the research in [16] investigates blockchain for supply chain industries. A framework that handles complex supply chain networks via SCM practices was proposed. The framework was implemented, and the evaluation results revealed that the integration of blockchain features (real-time information sharing, cyber-security, transparency, secure transactions, reliability, with SCM practices positively influenced the operational performance of the supply chain. Study in [17] focuses on the transportation of crude oil about logistical concerns and political conflicts. Pe Tro Share (PTS) was introduced in compliance with Industry 4.0, PTS was defined as a novel ridesharing platform, focusing primarily on product quality, not the source of origin. The goal was to ensure that crude oil remains a public commodity; the role of the broker was eliminated to achieve that objective. Smart Resource Allocator Module, Logistics Module, and Transfer Module were applied. PTS uses Internet of Things (IoT) networks for location tracking and quality control. Using blockchain transactions were kept anonymous. Simulation results show that system efficiency and cost-effectiveness can be greatly enhanced by enabling anonymous sharing of crude oil products.

The study in [18] provides an overview of blockchain technology by pointing out the blockchain contribution to creating foundations in the economic field. Further, blockchain-based applications including relevant environmental, economic, operational, and social benefits were reviewed. A chain of possibilities for innovative blockchain-based applications extending to the midstream of the Oil and Gas industry can be made. It was Suggested that blockchain should be an integrated platform through a series of different applications, such as measurement, billing, carbon trading, security, supply chain management, and performance-based contracts. An approach was proposed to manage the complex supply chain in the oil and petrochemical industry [19], by identifying the risks facing the enterprise-level supply chain in an Indian oil company. Initially, the various enterprise-wide risks of supply chain management SCM projects were identified, and the company's supply chain risks were defined. then these risks were grouped under the categories of Operations, Finance, Human Resources, and Strategic Business Risk. Subsequently, a heat map was created to locate the various risks of red, yellow, and green areas suitable for developing a risk management plan. Then the risks were prioritized through planning. It was observed that some high-priority risks could be eliminated or managed due to specific characteristics of the blockchain such as transparency, decentralization, and being consensus-driven. The concept of Smart Micro-Gas, a cognitive micro natural gas industrial ecosystem based on mixed blockchain and edge computing, was proposed in this work [20]. Its design and implementation are based on three aspects: multilayer, Multiview, and multi-dimensional. A mixed transaction model for natural gas was then built, based on the most significant smart contract algorithm in the blockchain. Lastly, a case study for data prediction and the suggested smart contract algorithm is executed on a smart natural gas testbed. The system provided in this study provides multi-level liquidity to natural gas data and allows for diversified transactions.

The work in [21] proposes Electro Blocks, a blockchain-based smart energy trading scheme that enables efficient mechanisms for secure energy transactions between customers and service providers, because of these facts. In Electro Blocks, nodes in the network validate transactions using two cost-aware and store-aware algorithms. The cost-aware algorithm finds the closest node that can supply energy, while the store aware algorithm ensures that energy demands are sent to the node with the least amount of storage space. It used performance parameters including mining latency, network exchanges, and storage energy to assess the Electro Blocks' performance. Simulation results show that Electro Blocks maintains a secure trade-off between users and service providers.

Using a secure hash algorithm-based blockchain, the research in [22] provides a new secured decentralized ledger in a database that controls petroleum product distribution records. Also offered was a telematics approach for geolocation tracking and monitoring of petroleum volume level, which is linked to a remote database and dynamically updated with real-time data. The use of SHA-1 computation techniques to implement this permission blockchain technique ensures hashing of every transaction generated based on the previous transaction and has proven efficiency, as it is not vulnerable to individual tampering of the record, but it only allows access to any changes or updates when participants in the chain have over 75% agreement; otherwise, permission is denied. The research in [23] highlights, through the presentation and discussion of two case studies as possible blockchain applications—(i) the UK Energy Company Obligation scheme and (ii) the Italian White Certificate Scheme— This paper explores the key benefits and implications of using blockchain in the energy efficiency sector. Moreover, it was shown how a blockchain-based smart contract system can handle the fundamental difficulties around trading energy efficiencies savings, such as correctly predicting savings, data openness among players, and expensive administrative processes. It has further shown how a blockchain-based smart contract system can handle the fundamental difficulties around trading energy efficient savings, such as correctly predicting savings, data openness among players, and expensive administrative processes. Finally, this paper shows how a smart contract for selling energy-saving certificates was implemented on the Ethereum blockchain using smart contract transactions. Several other studies have been proposed to equip the blockchain security and integrity [24-40].

5. Proposed Framework

This proposal intends to create a blockchain network that acts as an overall master optimizer in petrochemical integrated areas.

System Stakeholders

Exploration Rights: This will enable the company to search for fossil oil. Typically, the rights are given by the government entities. If discoveries are found with a sizeable amount of crude or shale gas, the rest chain will expand based on the available amount from the extraction.

Drilling & Extraction

This is the first actor in the oil & gas chain. A drilling company starts when a potential reservoir is located deep beneath the earth's surface. To gain access and extract oil or gas, a hole must be drilled through the various rocks, materials, and layers to reach the ultimate target mineral.

Refineries and Gas Purification Units

The crude oil goes into several chemical processes such as distillation and liquid extraction to transform the natural mixed oil into useful products, such as gasoline, diesel, kerosene, asphalt, liquefied petroleum gas (LPG), and petroleum naphtha. Similarly, the GPU separates and purifies the gasses into methane (C1), ethane (C2), propane (C3), butane (C4), … etc.

Olefin Cracking

The first block in the petrochemical industry where hydrocarbons are broken down into smaller alkenes (olefins). The feedstocks can be ethane, propane, LNG, naphtha, or a mix of it. The main two olefins are ethylene (C2=) and propylene (C3=) because of their useful precursors in many products such as polymers and chemicals.

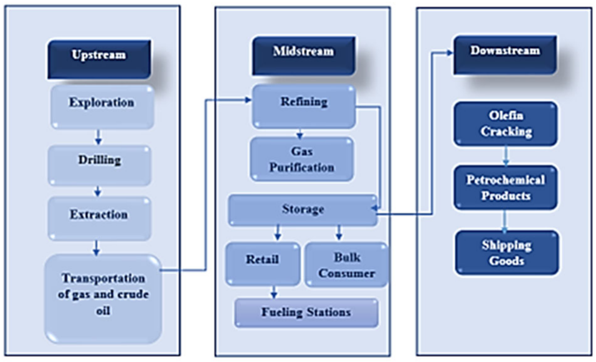

Fig.6. Oil & Gas Block Flow Diagram

This framework utilizes a multi-leveled blockchain network. The highest level in the hierarchy is to maximize the net profit gain based on the overall global inputs. This can be achieved by calculating the gain delta between the available extracted crude oil, refinery capacities, local refined product demand, local power generation demand, GPU capacities, and cost of logistics versus crude oil export. As of Eq. 1.

$$\text{Exportation Excess} = \text{Extracted} - \text{local demand} \quad (1)$$

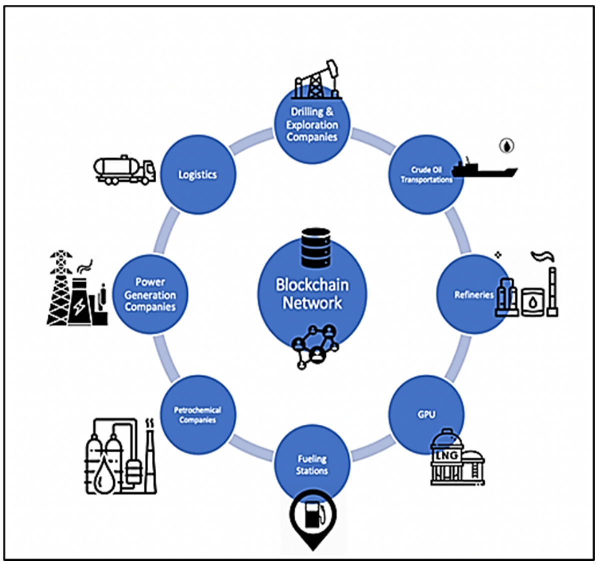

Fig.7 Blockchain Network Entities

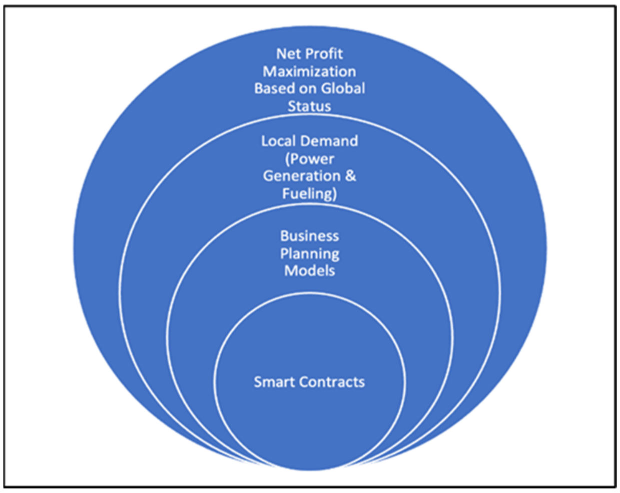

Fig.8. Blockchain Hierarchy

5.1 Network Value Generation

The blockchain network will expand the value generation and increase the sector efficiency by adjusting the plants' throughputs according to product prices and production net profit as shown in the below-mentioned function. Typically, when crude oil prices increase to three digits US dollars per barrel, the net profit margin of the petrochemical downstream products decreases. On the other hand, when crude oil prices decrease below \$60 per barrel, the net profit margin of the petrochemical products increases. Furthermore, when the crude oil prices are between \$60 to \$100, the net profit will be merely a function of the global supply and demand [2]. As shown in Eq.2.

$$NetProfit = f(Production).\text{cost}(\$) \quad (2)$$

Currently, oil and gas companies are adopting linear programming (LP) arrays to solve optimization problems and increase profitability by calculating the best attainable output. For example, warehouse management, logistics, optimal resource allocation, asset utilization, and profit maximization can be integrated with LP [3]. Linear programming is a mathematical technique that has been used for more than half a century to help businesses and organizations determine the optimum method to increase productivity. However, the proposed framework will utilize the LP output as an input to the blockchain network by reading several IoT devices between the operating entities [4].

5.2 Local Demand

Local demand for hydrocarbons will be one of the constraints which govern any possible scenario. As it can be derived from Fig 8 , the second layer in the hierarchy will prioritize the local demand, regardless of the blockchain potential value generation. The country's demand must be covered first; after local supply, other tasks can proceed. Many countries are enforcing some types of regulation to mandate the export rates outside of its boundary, this framework keeps this fact into consideration.

5.3 Business Planning Model

The business planning model is an integral part of the underlying blockchain network. It specifies a concrete production plan for each section of the chain (upstream, midstream, and downstream). It starts from a production plan for the drilling and extraction companies, along with refineries, and then, the petrochemical business production plan. Moreover, providing outputs that mandate each entity to produce a fixed-predetermined production rate via the blockchain network.

5.4 Smart Contract Framework

Smart contracts are digitally generated agreements between two or more parties and are securely kept on a blockchain. Typically, the smart contract is triggered when terms and conditions are satisfied [3]. This model covers different noteworthy smart contract scenarios. For instance, but not limited to, electricity generation, crude oil transportation, customer order and fulfillment. The algorithms for Crude oil transportation, and customer order fulfillment, Crude Oil Transportation and Requesting refined products are given in Table 1, 2 and 3, respectively.

Table 1. Crude oil transportation, and customer order fulfillment.

Algorithm 1: Local Power Generation
Output: Electricity demand (Gwatt)
Input: IoT hydrocarbon flow, Demand

```
If (Power value ≥ Demand)
        return "No adjustment required"
Else if (Power value < Demand)
        Call IncreaseHydrocarbonFlow ()
Else if (Power value > Demand threshold)
        Call ReduceHydrocarbonFlow ()
```

Table 2. Crude Oil Transportation Algorithm

```
Algorithm 2: Crude Oil Transportation
Output: Customer order fulfilment
Input: IoT volume, Crude oil grade Specification
If (Volume == Order) && (Quality == Order)
   Call Dispatch Shipment ()
   Call TrackShipment ()
Else if (Volume < Order)
   Call IncreaseCrudeOilFlow ()
Else if (Volume > Order threshold)
   Call VioilationOcuurs()
```

Table 3. Requesting refined products

```
Algorithm 3: Requesting refined products
Output: Requested refined product
Input: IoT volume, Product type, Composition, Quality, Request
If (Volume == Request) && (Product type == Request) && (Composition ≥ Quality)
   Call StoreRefinedProduct()
Else if (Volume < Request)
   Call ChangeDistillationColumnTempreatureProfile()
Else if (Product type != Request)
   Return "Please recycle"
```

5.5 Limitations

Cost

Maintaining a functioning blockchain needs several human and technological assets. Companies still fear investing in new technologies as they impose additional costs.

Security

Incorporating multiple levels of security can influence the system's availability there's a lack of real-world implementation and best practices when it comes to such technologies specifically in terms of security.

Macroeconomy reward: usually, legislative bodies govern the blockchain and enforce outputs according to their key performance indicator (KPI). Therefore, some companies don't see the internal value of implementing blockchain technology.

Technical expertise

As blockchain is an emerging field, access to technical expertise is a concern; especially when there are not sufficient resources available to learn from.

6. Conclusion

The global economy rise is heavily reliant on petrochemicals and energy resources. Most energy projects constructed in the last few decades were functioned by integrated oil and gas companies operating in multiple streams to maximize product utilization and minimize energy consumption. Some of the world's largest and most influential energy companies are working as integrated units. The common between all companies is to maximize value generation. At present, several solutions were introduced, such as cloud computing, the Internet of Things (IoT), and blockchain, which can be utilized to serve critical fields. There are several efforts to include those technologies in the real-world environment still, there is a lack of efficient application due to some security, reliability, and maintainability constraints. By involving emerging technologies such as blockchain, the energy sector can be improved to become an efficient, integrated, and robust corporation. This paper presents a framework for utilizing blockchain concepts and smart contracts between upstream, midstream, and downstream in the energy world. For future work, the framework can be enhanced by considering security aspects and simulated application platforms. In future, various other mobile computing components like cloud computing in contrast to machine learning and deep learning models can be investigated for further feasibility study of the blockchain in smart supply-chain environment [41-55].

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