Blockchain Technology and Maritime Shipping: An Exploration of Use Cases in the U.S. Maritime Transportation Sector

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Acronyms and Abbreviations

AWS	Amazon Web Services
B/L	Bill of Lading. Also eB/L, electronic Bill of Lading
BIMCO	Baltic and International Maritime Council
BLOC	Blockchain Labs for Open Collaboration
CINS	Cargo Incident Notification System
CO_2	Carbon dioxide, a greenhouse gas
DNA	Deoxyribonucleic acid
EEDI	Energy Efficiency Design Index
EU	European Union
EWF	Energy Web Foundation
GB	Gigabyte
GDPR	General Data Protection Regulation
GHG	Greenhouse Gas
GPS	Global Positioning System
GSBN	Global Shipping Business Network
IBM	International Business Machines, a large technology company
ICO	Initial Coin Offering
ICT	Information and Communication Technology
IEA	International Energy Agency
IMO	International Maritime Organisation
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
ISM	International Safety Management
ISO	International Organization for Standards
MARAD	United States Maritime Administration
MBL	Marine Blockchain Labs
MEPC	Marine Environment Protection Committee
MIT	Massachusetts Institute of Technology
NASA	National Aeronautics and Space Administration
PoA	Proof of Authority, a blockchain validation algorithm
PoW	Proof of Work, a blockchain validation algorithm
PSF	Prime Shipping Foundation
TB	Terabyte
TEU	Twenty-foot Equivalent Unit

1 Introduction

Blockchain technology, which first emerged in 2008, was initially used to facilitate transactions of cybercurrencies such as Bitcoin. Often described as a disruptive technology, blockchain use has since increased dramatically in numerous applications, from the energy sector to real estate to finance. Indeed, some see blockchain as a groundbreaking solution to many of society's problems.

This report explores the potential for blockchain in the maritime sector and sheds light on if and how blockchain might align with—or run counter to—goals and objectives of stakeholders in the maritime sector. The report also provides advice on how stakeholders can best evaluate, and where appropriate support, the use of blockchain to meet their goals and objectives. The challenges discussed here are specific to the maritime sector, but are relevant to any agency from the local, state, and federal level when considering blockchains for energy and transportation issues (Winebrake et al., 2019)[1].

This report is a companion document to a "primer report" entitled, *Blockchain Technology and Maritime Shipping: A Primer* (Winebrake et al., 2020), which includes: (1) an introduction to blockchain technology—including definitions and descriptions of decentralized networks, distributed ledgers, hashing, block creation, consensus mechanisms, smart contracts, and key differences between public and private platforms; (2) strengths and weaknesses of blockchain; (3) the potential role of blockchain in the maritime sector, including key drivers and issues in the maritime sector, and examples of uses of blockchain in the maritime sector; and, (4) barriers, challenges and concerns surrounding the use of blockchain in the maritime sector. The companion primer document also includes an in-depth discussion of the advantages and disadvantages of blockchain systems vis-à-vis existing alternatives such as centralized databases.

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[1] Some of the material in this report draws on research conducted by the authors of this report, in previous work conducted for the New York State Energy Research & Development Authority on a similar topic (Winebrake et al., 2019).

This report presents “use cases” of blockchain technology in the maritime sector and is divided into three main parts. In Part 1 (sections 2.1 through 2.4), we present four use cases of blockchain in the maritime sector: (1) fuel quality traceability and assurance; (2) shipment tracking along a supply chain; (3) smart Bills of Lading; and, (4) smart contracts in shipment delivery validation. For each of these use cases we cover the following, in turn: identifying the problem; articulating the risks or barriers to solving that problem; evaluating the opportunities for blockchain to solve the problem; and, where appropriate and for context, explaining existing blockchain initiatives within the use case. In Part 2 (sections 3.1 and 3.2), we present barriers, challenges, or concerns surrounding the use of blockchain in the maritime sector. This provides context for understanding certain requirements for successful blockchain implementation. Lastly, in Part 3 (sections 4.1 and 5) we present guidance on the use of blockchain for achieving the goals of maritime sector stakeholders and conclude.

2 Blockchain Use Cases

2.1 Use Case 1: Fuel Quality Traceability and Assurance

2.1.1 Identifying the Problem

Pollutant emissions from fuel combustion in the maritime sector, including sulfur oxides, nitrogen oxides, and particulate matter emissions, cause hundreds of thousands of premature deaths annually, due to chronic diseases including cardiopulmonary disease and cancer, as well as millions of cases of asthma and other respiratory ailments (Corbett et al., 2007; Winebrake et al., 2009; Sofiev et al., 2018). Research suggests that reducing the sulfur content of fuel used in oceangoing ships would reduce premature mortalities by 34%-50% and would reduce morbidity by ~54% (Winebrake et al 2009, Sofiev et al 2018). Additional negative impacts of ship emissions include acidification of fresh and saltwater environments; water pollution; damage to marine life, and climate change (with all its concomitant harmful impacts) (IPCC, 2014; NASA, 2020).

International governance organizations are establishing new regulations to address these emissions. In 2020 the International Maritime Organization (IMO) implemented clean fuel standards that limit sulfur content of bunker fuel to 0.5% (5,000 ppm), compared to the previous limit of 3.5% (35,000 ppm). Meeting these standards will require shifts to low-sulfur fuel, alternative fuels (such as LNG), or scrubbers (IMO, 2019; Saul, 2019a).

IMO's Marine Environment Protection Committee (MEPC) has also developed an initial strategy to reduce greenhouse gas emissions (GHGs) from maritime, as shipping accounts for approximately 2.2% of global carbon dioxide (CO_2) emissions. The initial strategy will be updated in 2023 and has a goal of reducing GHG emissions from shipping by 50% from 2008 levels by 2050 (IMO 2018, IMO n.d.). A part of this effort will involve transitioning to "zero-carbon" fuels, an approach currently supported by various interests in the shipping industry (Saul, 2019b). For example, a coalition of sixty commercial groups, including leading shipping companies, have committed to "Getting to Zero," which will involve a transition to zero-carbon fuels and appropriate vessels and infrastructure by 2030, as vessels built in 2030 will be part of the worldwide fleet in 2050.

2.1.2 Barriers to Achieving Goals

These regulations – and the data collection requirements for enforcement – could achieve significant environmental and public health benefits. The IMO 2020 standard, for instance, is estimated to prevent over 570,000 premature deaths between 2020 and 2025, as well as millions of cases of asthma (Sofiev et al., 2018). Implementation, tracking, and enforcement of these requirements present substantial challenges, however, as IMO does not have enforcement authority; authority for monitoring, tracking, and enforcement resides with Flag States and port states (IMO 2019). Enforcement and compliance thus far is inconsistent among nations, even in countries that are committed to ratifying the rules and enforcing fuel standards. Much opportunity exists for noncompliant ships to go undetected—for instance, only a small percentage (e.g. 2-7%) of ships tend to be inspected at port in many countries. Also, the legal penalties for noncompliance vary substantially among states as well (Konotey-Ahulu, 2019).

Even for stakeholders wishing to comply with fuel standards, there are many challenges and limitations in existing data collection and assurance processes related to fuel consumption. Purchasers of fuel, for instance, do not have access to quality assurance data related to upstream information such as fuel production and processing (MacDonald 2018a). The lack of fuel quality documentation also presents a challenge related to insurance claims. For example, if shippers were to receive contaminated fuel, insurers do not have access to data to prove compliance or to demonstrate that contaminated fuel was used (MacDonald, 2018b). The "epidemic" of bad bunker fuel, which began in the U.S Gulf Coast region (in particular Houston) in 2018 and was estimated to effect hundreds of ships, demonstrated the importance of verifying the quality and content of fuel. Many ships using bad bunker fuel lost power en route—presenting considerable safety and security issues, especially when affected ships are located in busy shipping lanes or are in the midst of inclement weather and required towing (Norwegian Hull Club, 2018).

Inability (or lack of commitment) to track and enforce these standards could lead to significant dilution of environmental and health impacts through fraud and misappropriation. Estimates of deliberate non-compliance (cheating) in terms of meeting fuel sulfur requirements, for instance, have ranged from 10% to 30% of total marine fuel consumption (Grimmer, 2018; Konotey-Ahulu, 2019).

2.1.3 The Role of Blockchain for Fuel Quality Traceability and Assurance

Part of the inability to reliably track, trace, and assure fuel origin and quality is due to the existing process of documentation in the bunker industry, which uses paper-based bunker delivery notes. In addition to leaving room for fraud, misleading shipowners, shippers, and charterers on quality and/or quantity of fuel, a paper-based system does not allow interested parties and stakeholders such as insurers and regulators access to data on fuel origins, supply chain, and combustion.

Blockchain-based systems may offer an opportunity for improved tracking and traceability of fuel origins and quality by recording on a distributed ledger information and data collected throughout the bunker fuel supply chain. These data could then be accessed by interested parties in the process of seeking to verify compliance with regulations or insurance contracts. Such a blockchain-based fuel tracking system was initially proposed by Blockchain Labs for Open Collaboration (BLOC)'s Marine Blockchain Labs (MBL) in 2018. After conducting pilot projects, BLOC and partners later adapted and refined the system, and as of late 2019 were operating, with a new partner, under the name of BunkerTrace.

The MBL version of a blockchain-based, fuel tracking and origin traceability system—which won the Massachusetts Institute of Technology (MIT) SOLVE Coastal Communities Challenge in 2018—sought to track the quality of fuel through the supply chain, including fuel production, suppliers, transfer of fuel at the terminal, and final combustion. The proposed process to trace fuel purchases involved equipping ports with Mass Flow Meters, using lab testing services and working with fuel suppliers, and automatically capturing data when a ship fuels at port, so that a chain of custody for the fuel could be captured and documented. MBL's proposed system also involved "tagging and securing" data to a given ship, to "link the physical and digital for marine fuel data" (MacDonald 2018a). MBL's fuel quality and origin tracking system is described as "blockchain agnostic", meaning it is not definitively linked to any blockchain platform or system, and it should be compatible with various blockchain platforms or systems (MacDonald 2018a, Maritime Blockchain Labs, n.d.).

In developing the system and conducting initial pilot trials, BLOC/MBL partnered with various stakeholders in the maritime sector, including the International Bunker Industry Association, the logistics firm Bostomar, GoodFuels (producer of sustainable biofuels for shipping), the international shipping association BIMCO, oil tanker managing firm Heidmar, dry-cargo carrier Precious Shipping, and Lloyd's Register fuel testing team—all of whom were involved in simulation testing of the prototype. Lloyd's Register Foundation, which sponsors MBL, shared information related to fuel supply and processes surrounding quality testing for initial phases (MacDonald 2018b).

In February 2019, MBL completed a successful demonstration project, which traced the production, processing, blending, and delivery of a batch of biofuel to the 960-foot vessel Frontier Sky, for a voyage from Rotterdam to eastern Canada. The demonstration project involved partners including the Japanese shipping company NYK, GoodFuels (who supplied biofuel produced from forest residue and cooking oil waste), and Varo Energy, who blended the biofuel with marine gas oil (Gallucci, 2019). MBL made use of the Hyperledger Fabric blockchain-based platform for the demonstration project (Note that Hyperledger Fabric is not considered a "true" blockchain, since it is private and permissioned and lacks certain pure blockchain attributes—such as decentralized consensus) (Bunduchi 2019; Popejoy, 2019a; Popejoy, 2019b).

BunkerTrace, a joint venture between BLOC and Forecast Technology, Ltd (FTL) is the updated and refined version of MBL's blockchain-based fuel origin tracking and traceability system. At one point in their development, BLOC realized digitalization of documentation in fuel assurance (such as recording approvals and signoffs) can only go so far, and rather there is a need for a physical marker in the fuel to determine if fuel has been tampered or altered. BLOC partnered with FTL to incorporate DNA markers into their system (BunkerTrace 2020; Hughes, 2019).

The BunkerTrace system, in addition to the use of blockchain systems for documentation, involves the use of synthetic DNA strand tags, which function as unique (and nearly unlimited) identifiers or "fingerprints" in marine fuel, and which carry information related to fuel quality and origin. BunkerTrace also uses highly sensitive molecules or "flags", which can indicate, in one- to three-minute testing on board, if fuel has been adulterated. Once fuel reaches a vessel, crew can test quickly for the BunkerTrace markers to verify that the fuel being purchased is as described, rather than relying on lab testing or bunkering without being confident of the fuel's quality or origins (BunkerTrace 2020; Hellenic Shipping News 2019; Hughes, 2019).

Stakeholders (such as vessel owners or operators, fuel suppliers, terminal operators, loading operations, or independent surveyors), then upload the relevant data (e.g. fuel test results) to publish to the blockchain. The blockchain platform currently used by BunkerTrace is a private chain of Ethereum, though like the MBL fuel assurance system, BunkerTrace is "blockchain agnostic" (can work with any blockchain platform) and may be tailored to suit the interests of clients.

The BunkerTrace system theoretically possesses the ability to tag and trace fuel from origin (as was the original model proposed by MBL), though pilot/test efforts thus far have taken a simpler approach. BunkerTrace successfully carried out a pilot trial in October 2019 in the Netherlands, in partnership with Minerva, Boskalis, and Cooperative Bebeka. The trial involved tracking and testing fuel in the dredger Prins der Nederlanden, 900 cubic meters of ISO 8217:2010 compliant fuel (0.1% sulfur) supplied by Minerva. The DNA tag was initially added to the fuel using a dosing pump on the fuel line as fuel loaded onto a Minerva bunker barge. After verifying that the fuel line and receiving tanks were empty, and after the fuel was bunkered, Prins der Nederlanden crew sampled the fuel on-board using a kit—a test that reportedly took less than 2 minutes and successfully detected the DNA markers at 2 parts per billion. Samples of the fuel were then collected for later analysis (AJOT, 2019, Hellenic Shipping News, 2019; Wood, 2019).

In late October 2019, after the success of the pilot demonstration, BunkerTrace announced its commercial launch. Then, in late January 2020, BunkerTrace announced a commercial partnership with the Monoco-based firm Marfin Management, which will use BunkerTrace to manage the risk of contaminated fuel being purchased and used on its dry cargo vessels (PortNews 2020). Although BunkerTrace is currently focusing on the commercial market, it is hopeful that the system will be helpful in regulatory compliance as well.

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2.2 Use Case 2: Shipment Tracking

2.2.1 Identifying the Problem

Transactions in the maritime sector are generally slow, time-consuming, and expensive. The shipping industry relies heavily on traditional ways of doing business, including a reliance on hardcopy paperwork and documentation, the use of which involves a number of different parties in the supply chain. Multiple parties not only handle paperwork, but also goods, often redundantly and unnecessarily (Ytterstrom and Lengerg, 2019). The many parties and intermediaries involved in transactions include exporters, importers, port and customs authorities and officials, financiers, surveyors, valuators, agents, etc.; none of these parties have access to data and information on all necessary parts of the supply chain. Transactions involving paper documentation often require physical inspection of documents, resulting in high transaction costs for shipments, and an *estimated 20% of operational budgets are due to poor information management* (Czachorowski et al., 2019). Brokers also increase costs substantially (Botton, 2018; Joseph, 2018).

The paperless exchange of documents has the potential to address some of the challenges surrounding the costs of transactions in the maritime sector. According to IBM, out of a total cost of $2,000 to move a container of avocados from Mombasa to Rotterdam, paperwork costs approximately $300, or 15%. IBM estimates that complete digitalization of the shipping process could save shipping carriers up to $38 billion per year (Ganne, 2018). The desire for faster, more streamlined transactions, and tracking of shipments will likely increase as the shipping industry handles and transports increasing volumes and as customers demand better, more accurate, and timely information (Ytterstrom and Lengerg, 2019).

Another concern with business-as-usual transactions in the maritime sector is one of safety, specifically with regards to carrying, tracking, and declaring hazardous goods. Shipping containers do not often carry indication of their specific contents. Although a product code may be scanned or traced in some data systems, these data systems rarely share or interoperate with other stakeholders' systems. This can present a serious safety issue in the case of hazardous or otherwise dangerous goods (which make up between 5 and 10% of a typical containership's cargo). Misdeclaration of cargo can lead to financial losses, ship damages, injuries, and loss of life. The Cargo Incident Notification System (CINS) estimates that almost one-quarter of serious incidents onboard containerships were due to cargo being mis-declared (Cleaner Seas 2019).

Fraud is a major problem in shipping and incidents and methods of fraud have increased recently. Examples of fraud in the maritime sector include falsification of Bills of Lading, including under-invoicing to avoid taxes; bribes and illicit payments to obtain contracts, influence inspections or enable port operations; and defrauding importers or exporters with illegally purchased letters of credit. Such fraudulent activities are estimated to increase the cost of shipping operations by ~10%, according to the World Economic Forum (DiGregorio & Nustad, 2017). There is little accountability for inefficiency, fraud, or cargo theft (Botton, 2018; Joseph, 2018).

Implementation of International Safety Management (ISM) code and International Organization for Standards (ISO) requirements related to quality management have complicated the reporting and management of documents in the shipping industry. Outside of safety and quality requirements, documentation requirements for exports also commonly include documents related to export, transportation, compliance, and certificates of origin, among others. These regulatory requirements, and associated needs for improved tracking, are expected to become more stringent over time, in response to the breakdown of trade arrangements between major economic powers, further increasing the complexity of transactions and required documentation (DiGregorio & Nustad 2017).

Another development is the increasing use of (and desire to ensure and verify) refrigeration in shipping. Many products, from food to pharmaceuticals, require climate- or temperature-controlled conditions to ensure product safety or efficacy (Sykes, 2018). According to the World Health Organization, 40% of vaccines degrade from temperature variation during transport. The pharmaceutical industry spent $13.4 billion on transporting temperature-sensitive products in 2017 and as of 2018 approximately 20% of pharmaceutical payloads were shipped on ocean-going vessels. This is estimated to increase to roughly 75% of pharmaceutical payloads sent by marine freight within ten years (Muspratt, 2018).

Availability and use of data analytics in the shipping industry is increasing, and development and availability is expected to increase further in the near future (Ytterstrom and Lengerg, 2019). The Internet of Things (IoT), for instance, is predicted to play an increasing role in the maritime sector, potentially allowing for asset tracking, improved route optimization, and reduced maintenance costs (DiGregorio & Nustad, 2017). IoT involves the use of sensors and other devices which are interconnected to networks and allow for monitoring and related management of devices, machines, equipment or other “things”. Current application of IoT in the shipping industry includes GPS tagging of containers to facilitate movement through transit nodes and allowing for real-time tracking of cargo and vessels (Czachorowski et al., 2019). In the case of temperature-controlled shipping, asset tracking with IoT could involve the use of sensors on the containers, a processing unit, and a transmitter which would allow for real-time monitoring of temperature, which in turn could allow for immediate response or management in the case of temperature approaching designated thresholds (DiGregorio & Nustad, 2017).

2.2.2 Barriers to Achieving Goals

Digital tracking of shipments from origin to destination has the potential to reduce transaction costs, track hazardous substances or otherwise dangerous goods, reduce opportunities for fraud and theft, and measure and track the conditions of climate-or temperature-sensitive goods. Given shipping industry and stakeholder goals of minimizing negative environmental impacts, and ensuring security, safety, and efficiency of maritime operations, industry stakeholders may have interest in pursuing or supporting efforts to improve efficiency and effectiveness of tracking and tracing of shipments through digitalization of paperwork and tracking of assets and shipments in the maritime sector. However, there are security risks and concerns associated with the shift to digitize information what has traditionally been paper-based.

As described in the companion primer document (Winebrake et al., 2020), cybersecurity is an increasing concern in the maritime sector, given the potential impacts on critical areas of cargo handling and management; passenger servicing and management; welfare of crew and administration; management and control of machinery and power; access control systems; and communication systems, among others. Intentional (e.g. cyber-attacks), or unintentional errors such as loss or corruption of data have the potential to result in operational, safety or security failures, or in failures to protect the marine environment (IMO 2017). Potentially serious security concerns have been identified in several areas of communication technology used in the maritime sector. For instance, demonstrations have shown that vessels can be hacked and navigated remotely by taking over the ship's GPS system; signal jammers can interfere with several onboard systems used for communication and navigation; and, port and cargo systems can be hacked, with data trails erased (DiRenzo et al 2015). The shipping industry increasingly faces cybersecurity threats, such as the NotPetya ransomware attack that affected Maersk in 2017, at a cost of over $200 million to the shipping company (Mathews, 2017; DiGregorio & Nustad, 2017).

There are also many concerns and challenges surrounding the use of IoT specifically. Users of the system must trust that the data received from IoT devices have not been altered. IoT devices have relatively limited computing power with internet (often wi-fi) connectivity, and their firmware is typically not updated frequently, making them vulnerable to cyber-attack. Nineteen distinct categories of security issues associated with IoT were highlighted in a 2018 review article; these included jamming adversaries, Sybil and spoofing attacks, sinkhole and wormhole attacks, privacy violations, and insecure interfaces, software or firmware (Khan & Salah 2018)[2].

2.2.3 The Role of Blockchain in Shipment Tracking

Blockchain presents one way in which paperwork could be digitized in the maritime sector, thereby addressing some of the security concerns surrounding the use of IoT and digitization by assisting in tracking of shipments from origin to destination, and recording relevant data in a transparent, yet secure and trustworthy format, accessible to all relevant parties. Blockchain is complementary with IoT technologies in its potential to improve security and provide for storage of data collected from IoT uses. Blockchain itself does not enable the use of sensors, monitoring or management, or data collection—these are all aspects of the use of IoT and associated data-collection systems. Blockchain can, however, allow for the documentation

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[2] Remaining security issue categories reported in Khan and Salah (2018) include: insecure initialization, insecure physical interface, sleep deprivation attack, replay or duplication attacks due to fragmentation; insecure neighbor discovery, buffer reservation attack, RPL routing attacks, transport level end-to-end security, session establishment and resumption, CoAP security with internet, and middleware security. An in-depth discussion of these security threats is beyond the scope of this report, but the reader is directed to Khan and Salah (2018) for details and elaboration.

and storage of recorded data on a ledger, and also has the potential (in conjunction with oracles[3]) to allow the use of smart contracts in managing devices in real-time (DiGregorio & Nustad 2017). Blockchain could eliminate the need for a centralized broker or authority, serving as an autonomous clearinghouse when appropriately integrated with IoT devices.

In the maritime sector, the application of blockchain (and smart contracts, see below) for shipment tracking could involve a computer program that would engage all involved parties (exporters, export and port authorities and officials, importers, financiers, surveyors, and valuators). For example, various documents or data could be uploaded to a blockchain, allowing parties to directly negotiate on the network without third parties; once documents were approved and signed by parties, a program would then approve and move on to the next phase of the transaction. Finally, the contract would be automatically executed by network consensus, and relevant information would be uploaded information for all interested parties (Joseph, 2018). All relevant information about the shipment could be stored in a "block" and managed by the blockchain, thereby avoiding the need for intermediaries to register, track and certify information (Botton, 2018).

The ability to have all of this information is one place, accessible to all relevant parties, would lower transaction costs, as well as reducing auditing and accounting costs (Botton, 2018). Blockchain has also been envisioned as allowing the tracking of shift in ownership of a shipment automatically within seconds of when it has been sold (Ytterstrom and Lengerg, 2019).

In the case of compliance in documentation and reporting for codes and standards, blockchain has the potential to reduce administrative burdens by allowing the streamlining, digitization and automation of certain documents and reporting requirements through the use of smart contracts by relevant agents in the shipping industry (DiGregorio & Nustad 2017).

Blockchain technology may also facilitate the tracking and documentation of temperature-controlled conditions in shipping. Blockchain-enabled shipping containers that

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[3] Oracles are outside data sources which provide necessary data on real world events and conditions relevant to the contract (such as prices or air temperature or whether a physical barrier has been crossed, etc. Oracles are defined and discussed in more detail in companion primer document..

regulate temperature have been developed and could be useful in tracking the transport of temperature-sensitive goods such as food and pharmaceuticals (Hampstead, 2018). Certain containers used in air freight, for instance, include sensors to monitor temperature and location among other variables. The “blockchain-like” ledger used with these containers records documents such as bills of lading and customs forms (Hampstead, 2018).

As described by Jugovic et al., (2019), the potential benefits to stakeholders of blockchain in tracking and tracing shipments would include, for example:

a) Carriers: reducing wait time and reloading time by allowing exchange of information—such as confirmation of ship arrival—in real time; reducing loss, delays and inefficiencies in the case of inaccurate information, where email is typically used for communications; and, providing a common place for information through the supply chain.

b) Ship Operators: facilitating online communication to reduce costs; allowing exchange of more detailed information surrounding shipments in real time, providing a standardized interface, and allowing buyers to use the system for independently tracking events in their system.

c) Intermediaries: providing a standardized area for collection of data from numerous sources; allowing increased visibility and saving time in correcting paperwork mistakes, developing a secure audit trail linking original documents with customs declarations.

d) Terminals: reducing costs of, and streamlining, communication between shipping lines and ports by providing a standard platform.

e) Insurance firms: ensuring consistency in data, with all stakeholders receiving the same version of key data. Data are permanently available, allowing better intelligence, and analysis of risks and trends, and risk assessment.

f) Regulators: allowing more complete information available sooner, to allow improved targeting and decisions on which containers to check. Reducing paperwork and increasing automation, allowing regulators to shift focus to other key activities.

2.2.4 Existing Initiatives of Blockchain in Shipment Tracking

There are a number of initiatives seeking to use blockchain in shipment tracking along a supply chain, including those in general tracing, tracking of hazardous and dangerous goods, and cold-chain tracking, among others—many of which are introduced and briefly described in the companion primer document (Winebrake et al 2020).

Projects include those initiated by shipowners, supply-chain operators, information and communication (ICT) providers, and dedicated consortia projects. As described by Wagner and Wisnicki (2019), shipowners-initiated projects—such as TradeLens, a Maersk-IBM partnership, and the Global Shipping Business Network (GSBN)— involve a technology vendor, and aim to develop universal tools for global container shipping; more participants and stakeholders are invited to join as the platform develops and expands. Projects initiated by ICT providers—such as CargoX—have the goal of providing a neutral platform which is not controlled by any one entity using the system. Supply chain operators' projects are initiated by stakeholders involved in maritime logistics such as ports and intermodal operators (e.g. Silsal by Abu Dhabi Ports, or Calista tool from the port of Singapore). Dedicated consortia projects are often initiated by government or research institutions, digital technology developers, or other entities (such as BLOC—Blockchain Labs for Open Collaboration), and aim to test solutions in a specific context; shipowners, though not often initiating these efforts, play a key role in proof of concept (Wagner and Wisnicki, 2019).

TradeLens, an IBM and Maersk partnership, is perhaps the best-known initiative involving blockchain-based technology in the maritime sector. This partnership seeks to increase transparency in shipping supply chain by tracking shipments from origin to destination (O-to-D) with status visible to all participants in the network—ideally including stakeholders such as shipowners, brokers, land transportation providers, customs agencies, port regulators, and insurance companies, etc. As of August 2019, over 100 organizations were involved in the TradeLens early adopter program (MI News Network, 2019).

The TradeLens system records transactions and tracks assets such as containers. Documents can be digitized and electronically signed. Over one hundred types of events can be tracked and recorded, including starting consignment tracking; planned loading on vessel; planned, estimated, and actual vessel departure and arrival times; submission of dangerous goods request; packing of container, and whether packed container is selected for or passes inspection. Certain data points are mandatory for all consignments, while others are conditional, depending on the nature of the shipment and the parties involved (TradeLens, 2019a). As of late March 2020, TradeLens had reportedly tracked nearly 1 billion events, published over 8 million documents, and processed over 20 million containers (TradeLens, 2020). As information sharing among firms may raise concerns of antitrust law violations, certain information (such as vessel capacity, contract terms, or service rates) are not authorized to be shared among stakeholders on TradeLens, as per a February 2020 Cooperative Working Agreement (Neuburger, 2020).

There are a number of additional initiatives involving shipment tracking and tracing in the maritime sector, including efforts to specifically track and trace dangerous and hazardous goods—such as a BLOC, Lloyd's Register Foundation and Rainmaking consortium project to handle the misdeclaration of hazardous goods—and efforts to track, trace and document climate-controlled conditions (e.g. BLOC and ShipChain). These systems, which involve the use of IoT technology, can identify and document, for instance, if a container has been opened, or if a container has dropped below (or exceeded) a certain temperature threshold, and for how long. If a container has been opened, or the temperature has gone out of designated bounds, personnel can be alerted, and the incident can be documented on blockchain (Radocchia, 2017; Hampstead, 2018).

Most blockchain systems used in shipment tracking and tracing in the maritime sector use (or plan to use) a *private, permissioned* blockchain-based system. Certain systems, though, use public, permissionless blockchain—such as ShipChain, which works with actors all along the supply chain (e.g. trucking), and uses Ethereum for certain transactions, and private sidechains of Ethereum for other data and transactions (ShipChain, 2020).

Blockchain is not the only opportunity for digitization of the supply chain and the tracking and tracing of shipments. As recognized by experts in the shipping industry in a recent study, digitalization in general could reduce the need for documentation in shipping and reduce transaction costs accordingly (Ytterstrom and Lengerg, 2019). Similarly, digitalization has the potential to facilitate the tracking of hazardous and dangerous goods, or to reduce opportunities for fraud and theft. Each form of documentation, digitalization, and tracking—including blockchain—is associated with its own challenges and limitations.

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2.3 Use Case 3: Smart Bills of Lading

2.3.1 Identifying the Problem

A Bill of Lading (B/L) is a contract of carriage which serves as a document of ownership and receipt, and is required by Maritime Law. The B/L is one of the most important and extensively used documents in shipping, serving three functions: (1) evidence of a contract between the shipper and the carrier; (2) a receipt of freight services and goods; and, (3) a document of title, or ownership, of goods. Bills of Lading include names of shipper, consignee, and carrier; vessel; port of load and port of discharge; itemized list of goods, including number of packages and packaging type, weight, and/or volume; freight class of goods; payment terms; special handling instructions; and freight rate and amount (Spelic, 2016; Mao, 2017).

Thus, the B/L essentially gives ownership (or title) of the goods to the person holding the B/L. So, it has been argued, the value of the B/L is approximately equal to the goods it describes—or an average of approximately $60,000 per shipment. Bills of Lading are traditionally paper-based documents, and the transfer of goods from one party of another requires the physical possession of the B/L (Spelic, 2016; CargoX, 2018). The B/L must be in physical possession to claim goods at port. However, Bills of Lading are often delayed due to banks and other intermediaries, and can take more than a week to arrive, meaning cargo can arrive at ports ahead of the B/L—adding to system inefficiencies and increased costs as cargo wait at ports (Czachorowski et al 2019; CargoX 2018).

Another reason Bills of Lading may take so long to arrive is that they are transported by courier delivery services (such as FedEx or UPS), and typically travel by courier at least three times—once from the issuer to the shipper, once from the shipper to the consignee or bank, and once from the consignee to a cargo release agent, for a total average shipment time of five to ten days. Transportation of paper B/L documents requires not only time but energy and generates associated pollutant and greenhouse gas emissions. Bills of Lading require resources to produce, with one source estimating that 400,000 trees are cut annually to produce the many millions of Bills of Lading issued each year; one Bill of Lading issuer, which represents 2% of the market share, prints out more than 4 million sheets of paper annually (CargoX 2018).

There are also significant financial resources involved in the issuance and transportation of Bills of Lading, with an estimated cost of up to $100 for courier services alone, or a total cost of up to $180 per B/L. Total annual aggregate expenditures on Bills of Lading transportation and printing are estimated at around $7 billion (CargoX 2018).

Lastly, fraud is also a concern with Bills-of-Lading, including forged signatures inaccurate descriptions of cargo, and use of forged corporate stationary, using corporate logos on falsified documents (Czachorowski et al 2019; CargoX 2018).

In response to the above concerns, efforts have been made to improve upon the traditional B/L system. Sea waybills, for instance, are documents which allow transfer of possession without a physical document being required. Letters of Indemnity can also be presented in exchange for cargo, in the case that cargo arrive at port prior to the Bill of Lading. Efforts are also being made to replace paper Bills of Lading with digital forms of Bills of Lading, such as Telex B/L or electronic Bills of Lading or eB/L. Electronic Bills of Lading are the legal equivalent of a paper B/L, and function as a receipt, evidence of contract of carriage, or document of title.

2.3.2 Barriers to Achieving Goals

Shipping industry stakeholders may have interest in exploring or supporting efforts to improve efficiency and effectiveness of the B/L system through eB/L and other digitalized systems. However, electronic forms of Bills of Lading come with their own challenges, including potentially the ability to easily duplicate forms, challenges in ensuring authenticity, and issues with centralization and trust of the operating/administrating company (CargoX 2018).

And, as with any form of digital or electronic communication, there are security risks. As described in the companion primer document (Winebrake et al., 2020), cybersecurity is an increasing concern in the maritime sector, given the potential impacts on critical areas of the maritime sector, including cargo handling and management, access control systems, and communication systems, among others. Intentional (e.g. cyber-attacks), or unintentional errors such as loss, corruption, or compromising of data have the potential to result in operational, safety or security failures, or in failures to protect the marine environment (IMO 2017). Potentially serious security concerns have been identified in several areas of communication technology used in the maritime sector, for instance demonstrations have shown that port and cargo systems can be hacked, with data trails erased (DiRenzo et al 2015). The shipping industry increasingly faces cybersecurity threats, such as the NotPetya ransomware attack that affected

Maersk in 2017, at a cost of over $200 million to the shipping company (Mathews, 2017; DiGregorio & Nustad, 2017).

2.3.3 The Role of Blockchain for Bills of Lading

Blockchain has been envisioned as a potential solution to address many of the challenges associated with paper or electronic Bills of Lading, by allowing for a decentralized, traceable, and immutable platform to document Bills of Lading, and to make them accessible to relevant parties. Two initiatives in this area—CargoX and TradeLens—highlight the potential configurations of such systems.

CargoX, a crowdfunded project which began in January 2018, has created a blockchain-based platform for sharing smart Bills-of-Lading. CargoX is "blockchain agnostic," meaning the system can be compatible with any blockchain platform, but it is currently based on the public, permissionless platform Ethereum. The system is paperless and is reported to cut transfer time from several days to minutes or seconds. In addition to improving transaction transfer speed, paperless B/L are also anticipated to reduce transportation costs, eliminate emissions from courier services to transport traditional bills of lading, and reduce chances of loss, theft, or damage to the B/L. The first container processed using CargoX's technology was shipped from Shanghai, China and released in Port of Koper, Slovenia in August 2018; the Bill of Lading was issued and transferred electronically "in just minutes instead of days or weeks". The electronic Bill of Lading cost $15, approximately 15% of the estimated typical cost for a document to be delivered such long-distance using courier services (MI News Network 2018a; MI News Network, 2019).

The CargoX system involves the use of Smart B/L tokens. As described in the CargoX 2018 Blue Paper document, CargoX Smart B/L work as follows:

> "At the origin the carrier uses our [application] to create a blockchain-assisted Smart B/L… After exporter pays the shipping costs, the carrier sends the Smart B/L to the exporter's address….After receiving the money for the goods from the importer, the exporter transfers ownership of the Smart B/L to the importer by using our [application]. The importer can claim ownership of the goods at the destination port by presenting the Smart B/L token to the carrier or [other relevant entity] at the destination by using our [application]…At the destination the carrier

> releases the goods to the importer once the importer proves ownership of the
> Smart B/L token” (CargoX, 2018)

Seeking to minimize security concerns, CargoX smart contracts are vetted by external auditors, and interested parties or potential participants may also have the system audited by their team or external auditing professionals. CargoX also uses a “bug bounty” program, where researchers and “white hat hackers” are invited to inspect CargoX code and identify weaknesses (CargoX, 2018).

TradeLens, the IBM-Maersk partnership, uses a blockchain-based system, a beta version of which allows for processing or “actionable doc flows” of Sea Waybills/Bills of Lading. The benefits of actionable doc flows, according to TradeLens, include: simplified transmission of shipping instructions; management of document states and versioning; faster submission of shipping instructions to creation of the Final Bill of Lading; sharing of documents with all permissioned parties (quickly); and, immutability, traceability, and auditability of documents. This system will allow the shipper, carrier, and any other relevant and permissioned parties to view the consignment, transport equipment, and documents, as permissions allow (TradeLens, 2020). TradeLens uses a private, permissioned, blockchain-based system.

2.3.4 References: Use Case 3 - Smart Bills of Lading

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2.4 Use Case 4: Smart Contracts

2.4.1 Identifying the Problem

Transactions in the maritime sector are generally slow, time-consuming, and expensive. An estimated 20% of operational budgets are due to poor information management (Czachorowski et al., 2019). Brokers also increase costs substantially (Botton, 2018; Joseph, 2018). Paperless transactions have the potential to address some of the challenges surrounding the costs of transactions in the maritime sector. According to IBM, out of a total cost of $2,000 to move a container of avocados from Mombasa to Rotterdam, paperwork costs approximately $300, or 15%. IBM estimates that complete digitalization of the shipping process could save shipping carriers up to $38 billion per year (Ganne, 2018).

Existing payment systems are fraught with inefficiencies. In 2017, over 200 million twenty-foot equivalent unit (TEUs) containers were handled in the global maritime sector, requiring the issuance, verification, payment, and reconciliation of over 1.25 billion freight invoices. The system inefficiencies associated with these transactions, including transaction costs and payment terms such as “Cash Against Documents” (where trust of new customers is an issue), are estimated to cost over $34 billion (Drewry, 2018; Hellenic Shipping News, 2018).

There are several areas where the existing payment process in the maritime sector is relatively inefficient, compared to payments in other areas. The first is the comparative lack of automation, for small and medium shippers and forwarders in particular, where manual work is involved in invoicing, and payments typically involve bank transfers and checks. Processing of invoices by shippers requires an estimated 2 to 15 minutes of manual labor per (correct) invoice, and much more if invoices are incorrect. The impacts and costs of these inefficiencies tend to be borne by smaller companies and entities (shippers and forwarders), while larger companies tend to make use of long-term contracts and IT solutions for freight invoicing and settlement (Drewry, 2018; Hellenic Shipping News, 2018).

The process of using ‘Cash Against Documents’ payment terms is another recognized source of system inefficiency and costs but is used to protect shippers and freight forwarders in the case of working with a new unknown consignee (i.e. in the case where trust is absent). In a ‘Cash Against Documents’ arrangement, the shipping line will not release a Bill of Lading until after origin charges have been paid and will not release cargo until destination charges have been paid. These arrangements are time- and resource-intensive and associated with high transaction costs (Drewry, 2018; Hellenic Shipping News, 2018).

Letters of Credit, contractual agreements on behalf of a customer of the bank authorizing one bank to make payments to another bank and beneficiary, have been used for centuries in international trade. Letters of credit require the use of banks as intermediaries, and as such are associated with high transaction costs—up to hundreds of dollars per letter of credit (CRF, 1999; PSF, 2018).

Several additional challenges or limitations of the payment process in the maritime sector include: transfers of funds may not reach the intended recipient; delays in crediting funds to accounts may take up to three weeks or more; losses due to currency conversions (even in absence of exchange rate fluctuations); and, high costs of transactions through partner banks (Prime Shipping Foundation, 2018). Stakeholders also face risks of nonpayment on various levels, including political, financial or social situations in certain countries, commercial risk due to potential insolvency by the importer or exporter, and risk of loss of amount collected due to exchange rate fluctuations (Marinelli, 2019).

Though automated payment schemes exist in the United States domestic freight market, they are relatively absent from the maritime sector. Various methods to address or improve upon the challenges and inefficiencies in shipping payments have been proposed and/or developed—mostly involving platforms which allow customers to apply for credit, and/or allow for digitalization and automation of payment processes—and include PayCargo.com, CargoSprint, Veem, US Bank/Elavon, Cass, and a partnership between MasterCard, Stargo and BlueJay to allow digital payments in freight shipping (Hellenic Shipping News, 2018).

2.4.2 Barriers to Achieving Goals

Digitalization of delivery validation and payment processing in shipping has the potential to reduce inefficiencies, reduce transaction costs, and save time and resources. Given industry stakeholder goals and objectives., stakeholders in the maritime sector may have interest in pursuing or supporting such efforts. However, there are security concerns associated with this shift, as conversion of payments to digitalized, centralized, platforms may place participants' data at risk, presenting participants with potential security and/or financial risks.

As noted in the companion primer document (Winebrake et al., 2020) and above use cases, cybersecurity is an increasing concern in the maritime sector, given the potential impacts on, and implications for critical areas of the maritime sector, including cargo handling and management, and communication systems, among others. Intentional (e.g. cyber-attacks), or unintentional errors such as loss, corruption, or compromising of data have the potential to result in operational, safety or security failures (IMO 2017). The shipping industry increasingly faces cybersecurity threats, such as the NotPetya ransomware attack that affected Maersk in 2017, at a cost of over $200 million to the shipping company (Mathews, 2017; DiGregorio & Nustad, 2017).

2.4.3 Role of Blockchain in Smart Contracts

Blockchain has been envisioned as a potential avenue to improve upon the efficiency of delivery validations and/or payments in the maritime sector, by allowing for a decentralized and immutable platform which could improve the speed and reliability of remittances and remove unnecessary intermediaries through the use of a transparent and secure system to handle transactions (PSF, 2018).

Smart contracts on blockchain have been suggested as one way to minimize or eliminate the current challenges and limitations to streamlined, efficient and effective transactions in the maritime sector, while also allowing for accessible records for all relevant parties. As envisioned, such smart contracts could offer an opportunity to streamline, and improve the efficiency and transparency of shipping transactions and contractual agreements, while reducing costs.

In the case of shipment validation and payments, smart contracts could allow for participants to enter into agreements on the blockchain platform where, for instance, payments would be held in escrow until a shipment delivery is validated, cargo is released, a certain inspection is passed, or any given set of conditions is met. Payments on blockchain could involve the use of tokens or a cybercurrency on blockchain in place of current legacy systems. Tokens or cybercurrencies specific to the maritime sector could be used to facilitate shipment delivery validation and/or payments. This approach, it is argued, could allow instant payments as well as instant conversion of currencies, and simplify the number and complexity of transactions between companies. The use of smart contracts and tokens in delivery validation and payments has been proposed and/or is in development by several entities (including 300Cubits, Prime

Shipping Foundation, and ShipChain), albeit—as described in the following section—unsuccessfully thus far.

2.4.4 Existing Initiatives

300Cubits proposed making use of smart contracts on the Ethereum platform and allowing for its “TEU” tokens to be used as booking deposits on shipments. A trial shipment consisting of two 40-foot containers shipped from Malaysia to Brazil was completed in early 2018; the TEU tokens were returned to users upon receiving a port EDI message confirming receipt of the shipment. The system went live in July 2018—with 300Cubits in discussions with major shippers (MI News Network 2019; Meyer, 2019). However, by October of 2019, 300Cubits had suspended blockchain operations, citing a lack of business. The majority of TEU tokens were “burned” and are now defunct (Meyer, 2019).

ShipChain, based on the Ethereum platform, is a blockchain-enabled end-to-end shipping logistics company with the goal of tracking shipments from the production facility through final delivery to a customer. ShipChain developed the SHIP coin/token, with one stated intended use being to allow customers to use SHIP coins to pay for shipment tracking or other real-world services (Monarch and Bailey, 2019); its initial coin offering (ICO) in 2018 (essentially an opportunity to invest in the company) was met with a great deal of public scrutiny, as after raising over $30 million, the value of SHIP coins plummeted to about 1% of the initial value, and the price now stands at a fraction of a penny. Though the SHIP coin does not appear to be being used in any applications, ShipChain is still involved in shipment tracking and tracing, using the Ethereum main platform and sidechains in various modes and industries (trucks, rail, air, maritime shipping) (ShipChain, 2020).

The Prime Shipping Foundation (PSF) began as an open-source project with the goal of allowing for payments in the maritime sector using their PRIME token/cryptocurrency. As with 300Cubits and ShipChain, the proposed PSF system was intended to use the Ethereum platform. The Prime Shipping Foundation, in its White Paper, suggested that the system would allow users to track shipments through the entire supply chain, and would facilitate—and allow instantaneous—payments and currency conversions. The proposed system would also incorporate smart contracts to facilitate negotiations and allow payments between participants given that certain agreed-upon conditions were met; payments, which would be made with

PRIME tokens, would be held in escrow until these conditions were met (Sok, 2018; PSF, 2018). An initial coin offering (ICO) was scheduled for late 2018, but there has been no reported activity by PSF, the CEO reportedly left the project unexpectedly, and the PSF website is no longer functional (TokenMarket 2018).

The failures and/or cancellations of these projects indicate that there are significant barriers and challenges to the use of blockchain and smart contracts in validating shipments and payments in the maritime sector; these barriers and challenges are presented in Part II, Section 1 of this document, and in general are relevant to all use cases, though they differ in level of significance and relevance by use case, and depend upon the nature and type of system (i.e. private, permissioned or public, permissionless).

2.4.5 References: Use Case 4 - Smart Contracts

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3 Barriers, Challenges, and Concerns Surrounding Blockchain in the Maritime Sector

3.1 Blockchain Challenges in the Maritime Sector

There are many existing initiatives involving blockchain technology in the maritime sector, as the previously discussed use cases illustrate. However, for the most part these initiatives are at a pilot or preliminary phase and involve the use of a private, permissioned platform among a select or limited group of participants. Before large-scale implementation of blockchain is feasible there are a number of barriers and challenges that need to be addressed. Several of these barriers and challenges were introduced in the companion primer document (Winebrake et al., 2020), but we include them here in the context of these use cases, in particular when they may present significant concerns or may counteract shipping industry stakeholders' goals and objectives.

3.1.1 Challenge 1: Shipping Industry Culture

The shipping industry is generally risk averse, tending not to be early adopters of new, potentially risky technologies (Gausdal et al., 2018; Ytterstrom and Lengerg, 2019). Before implementing new technologies, the shipping industry expects a technology to have a proven track record and supporting infrastructure and systems in place. Thus, the move to blockchain technology may require a significant shift in perspective.

3.1.2 Challenge 2: Privacy, Security, and Safety

Privacy is a potential concern in all cases involving blockchain, as ledger records are intended to be permanent, and what might be considered private or proprietary data can be viewed and shared by all participants (Andoni et al., 2018). Privacy and security concerns are of particular concern in the maritime sector, depending upon the information and data shared, and depending upon which (if any) proprietary information may be visible to others. In recent research which involved interviews of stakeholders in shipping, participants noted that data protection is desired, and sharing of data and transparency are avoided, as "competition is fierce" and "a lot of industry actors are basically competing with the same service," and also due to a desire to keep trade secrets, etc. (Ytterstrom and Lengerg 2019). Privacy could be considered of particular concern when participants might be sharing data on a platform owned or administered by a competitor (e.g. IBM-Maersk's TradeLens). Others have noted that in addition to the desire to keep trade secrets, some parties in shipping may view the transparency into their supply chain as undesirable, due to the desire to avoid criticism (e.g. the ability to view, on blockchain ledgers, details of specific factories where clothing is sourced may place firms under public scrutiny) (Botton, 2018).

Safety and security issues are similarly a concern for these use cases, as depending upon data shared, information on specific goods moved may be viewable to those outside the shipping network. Positional data might be used to track vessels by identifying port locations, fueling locations and patterns and/or routes—this has been recognized as a concern with electric vehicle charging patterns, for instance (Knirsch et al., 2018). Unauthorized access to, or processing of, this data could present serious safety or security risks, and could have serious ramifications for safety and public health. This is particularly the case with tracking dangerous and hazardous goods, or potentially sensitive goods such as pharmaceuticals or food. These security and safety risks may also be of particular concern to shippers in light of recent issues with "bad bunker fuel," and ships being left without power, effectively stranded and vulnerable until towed.

As described in greater detail in the accompanying primer document, unfortunately even public or permissionless blockchain unfortunately is not as immutable or "unhackable" as typically assumed or described, and blockchains are being hacked at an increasing rate (Orcutt 2019). Over $1 billion, for instance, was stolen from various blockchain cryptocurrencies in the first 9 months of 2018 (Khatri, 2018). Certain privacy or security concerns may be reduced with private or permissioned networks, but (as noted in the companion primer document [Winebrake et al., 2020]), these come at the expense of decentralization and immutability. Private, permissioned networks may come with their own concerns regarding privacy and proprietary information, as in certain cases shipping industry actors (e.g. Maersk in the case of TradeLens) are the initiators, owners and operators of the platform, and competitors may be hesitant to join in response to concerns as to how competitors' data are being used.

Privacy and security risks of blockchain are of potential concern in terms of ensuring the safety, security, and efficiency of maritime capabilities. An accurate understanding of the privacy and security risks of blockchain—and the efforts to address or minimize these risks—will be important for stakeholders prior to moving forward with widespread implementation. In order to move forward with confidence, many stakeholders in the shipping industry may need assurances regarding privacy and security, so that private or proprietary information may not be accessible to those who might use the information for purposes that do not align with the interests of the participating stakeholders.

These assurances will likely involve system design, including which data and information will be shared (and how), and who will be participants and/or administrators. In the case of private or permissioned blockchain systems, in order for shipment tracking and tracing to move forward on a widespread basis—and specifically if data are to be used in regulatory compliance—it will be important to understand and carefully select who will be the entities and individuals with administrator privileges in the system. The importance of ownership and/or facilitation by neutral parties, as opposed to single companies, for instance, has been mentioned in interviews of stakeholders in the shipping industry (Ytterstrom and Lengerg 2019). If data and information are to be used in regulatory compliance in any way, efforts will need to be made to ensure that disinterested or unbiased parties, and/or those involved in oversight are involved in the network to observe activity and changes made, so that participants in the network, and those relying on the information for regulatory compliance will have checks and balances to assure that information is accurate and has not been altered.

3.1.3 Challenge 3: Data Tampering

An important limitation of blockchain-based systems is the potential to tamper with data prior to publishing to blockchain. The use of blockchain does not guarantee that the information recorded in ledgers is correct and does not prevent tampering with data prior to entering it into a blockchain ledger (Clift-Jennings, 2019). The more distant a party (such as a regulator) is from the data source (e.g. documenting the contents of a container, or fuel production, testing or combustion), the more opportunity there is for data alterations, whether manipulated maliciously or misreported accidentally (Clift-Jennings, 2019). This could have serious implications if relying upon data recorded in a blockchain for verifying compliance with safety or environmental regulations. In the case of IMO 2020, for instance, significant financial incentive may exist to use noncompliant fuel, depending on the price differential between compliant and noncompliant fuel.

There are efforts being made to address these concerns. The company Filament has developed a system combining hardware and software which can be used to indicate when a device has been tampered with, and if so, it will no longer "sign"[4] or "attest to" the accuracy of data or allow it to be published to the blockchain (Clift-Jennings, 2019). The Filament system, which also allows for aggregating and publishing of data to a blockchain, has been developed and used in pilot projects in the energy sector (e.g. solar energy production and for use with smart meters), and has developed products in the automotive sector (e.g. tracking vehicle usage and facilitating payments).

Filament's approach demonstrates the importance of acknowledging the potential for tampering, and the need to minimize the risk of tampering to the extent possible, if relying on data to verify compliance—while also demonstrating that efforts are being made and will likely continue to be made to address this concern. Though no such technology for maritime applications has been identified (in this work), efforts are being made in the maritime sector to develop and implement the use of technologies which will, for instance, verify documentation, and verify and validate data prior to being published to blockchain.

3.1.4 Challenge 4: Energy Consumption

Another concern with blockchain is the energy consumption of certain blockchain platforms—public, permissionless blockchain platforms, in particular. As described in greater detail in the accompanying primer document, the Ethereum platform, which is used in many applications in the maritime sector, consumes vast amounts of energy—more than the daily energy consumption of a typical U.S. household per Ethereum transaction, with the total network consuming over 7.5 TWh (the approximate electricity consumption of Luxemburg or Zimbabwe) (DeVries, 2020).

Given the potentially extensive use of blockchain in the above examined use cases, and the potentially enormous number of transactions (per hour and day, and potentially millions, or even hundreds of millions transactions annually depending on scale and extent of use), the use of

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[4] In this way, Filament functions as an "oracle", as described in greater detail in the companion primer report, and section 3.1.6 of this report.

public blockchain systems such as Ethereum could consume vast amounts of energy, which would in turn be associated with increased emissions of pollutants and greenhouse gases (on a lifecycle basis). These negative environmental impacts run counter to many maritime sector stakeholders' goals of minimizing adverse environmental impacts and maximizing the public benefits of water transportation on communities. The potential energy and environmental impacts also counteract efforts such as IMO's Energy Efficiency Design Index (EEDI), and the Marine Environment Protection Committee's roadmap strategy to reduce greenhouse gas emissions from ships 50% by 2050 (MEPC 62/24/Add.1 Annex 19, page 12; IMO 2018; IMO n.d.).

High electricity consumption of blockchain may be of particular significance in the maritime sector due to the potential sources of electricity powering the blockchain system nodes (computers), and the location of these emissions, and affected populations. If (energy inefficient) blockchain systems were used for the shipment tracking use case, electricity might be produced in areas of concern for coastal air pollution, such as China, which in early 2020 was second only to the United States in Ethereum nodes, and which also relies upon coal for the majority of electricity generation (Etherscan 2020a, IEA, 2020). Additionally, as the majority of Ethereum nodes are located in the United States, the majority of upstream electricity production would be expected to take place in the United States, where associated increases in emissions and health effects would be expected.

Certain blockchain platforms are more energy efficient per transaction—particularly private, permissioned blockchains, or "blockchain-based" systems such Hyperledger Fabric (on which Marine Blockchain Lab's original fuel origin and quality tracing system was based), IBM and Maersk's TradeLens, or other proprietary systems. These systems, however, lack key attributes of blockchain such as distributed consensus and immutability. In the energy sector, the Energy Web Foundation has developed a platform which is similar to Ethereum in several respects, but for which certain aspects of the architecture and consensus mechanism have been modified, to allow for improved transaction speed, throughput and energy efficiency. The Energy Web Foundation format reportedly reduces energy consumption by an order of magnitude (or even 2 or 3 orders of magnitude, depending upon source); energy consumption savings are mainly achieved through a shift from Proof-of-Work (PoW) to Proof-of-Authority

(PoA) consensus mechanism[5], where selected participants administrators have authority to approve, validate or make changes to entries (EWF, 2018). The ledger is publicly accessible for viewing, but not for write permission or validating, meaning the Energy Web Foundation system sacrifices decentralization, and participants must have trust in the selected validators.

Given maritime sector regulatory and stakeholder goals of minimizing adverse environmental impacts and maximizing the public benefits of water transportation on communities, the energy consumption and associated emissions of any blockchain platform used extensively in the maritime sector are important to consider.

3.1.5 Challenge 5: Legal and Regulatory Concerns

Regulatory oversight (or lack thereof) presents a challenge in the maritime sector, both due to the potential legal implications and also in that it presents barriers to the adoption of blockchain. Parties justifiably perceive the use of blockchain as risky in the absence of regulatory oversight, and regulatory bodies see little impetus to engage or develop guidelines or standards, etc. when there is so little use of blockchain in the maritime sector (Botton, 2018).

Shipping industry stakeholders have expressed concerns regarding the need to regulate blockchain technology in terms of ownership and use of data, among other concerns. Stakeholders also have concerns related to EU’s General Data Protection Regulation (GDPR) and how the industry can manage data and/or own customer’s data (Ytterstrom and Lengerg, 2019). Stakeholders in the shipping industry have also expressed concerns surrounding jurisdiction, and not knowing how disputes, if they were to arise, would be settled (Wagner and Wisnicki, 2019).

There are also challenges and limitations with regulatory bodies using blockchain in enforcement. For a public, permissionless platform, these include questions as to which transactions are enforceable if a public blockchain were to experience a “hard fork” (split), thereby creating two forks with unique data and transactions (Abadi and Brunnermeier, 2019).

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[5] Blockchain consensus mechanisms are described in the companion primer report, *Blockchain Technology and Maritime Shipping: An Exploration of Potential Impacts in the U.S. Maritime Transportation Sector* (Winebrake et al., 2020).

In the case of private platforms or “blockchain-based” systems, which lack key elements such as decentralized consensus mechanisms and immutability (or inability to alter records after the fact), regulatory bodies would not necessarily have confidence that the ledger entries had not been altered. This would be of particular concern if data from blockchain systems were used in regulatory compliance, and the users and administrators of the platform were the same agents who might be faced with fees or other penalties or consequences of noncompliance.

3.1.6 Challenge 6: Limitations of Smart Contracts

The practical application of smart contracts in blockchain systems is not as simple as it may appear. Several of the limitations of smart contracts, and related legal or regulatory concerns may explain hesitancy of shipping industry stakeholders to engage in using blockchain and smart contracts in certain use cases, such as shipment tracking and payments.

First, a blockchain cannot enforce smart contracts or any transactions involving resources outside of the blockchain (Reyna et al 2018); enforcement, if any, would require legal or regulatory intervention, or intervention by another such third-party authority. That is, while blockchains can show transfers or *obligations* of ownership or transactions, some sort of enforcement is required to ensure transfers of *possession*: “Blockchains can record obligations. Punishing those who default on their obligations is another matter” (Abadi and Brunnermeier, 2019).

For a smart contract to be executed in response to blockchain transactions, the necessary funds (e.g. currency, credits or tokens) must be stored on the blockchain. That is, a payment involving a cryptocurrency or credit (e.g. Bitcoin or tokens—e.g. SHIP, TEU, PRIME) can be executed if that currency or credit is native to that blockchain, and the blockchain can verify that the quantity of currency or credits are in the account; otherwise a blockchain can neither guarantee nor enforce payment. Blockchain cannot execute terms of financial transactions involving fiat currency or other such payments— though blockchain can report and record that a transaction reportedly took place (Greenspan, 2016).

Smart contracts and payments involving fiat currency, then, are not possible on blockchain, unless stakeholders are willing to take the risk of nonpayment with nonenforcement. While transactions involving native currency (tokens and cybercurrency) have been used in test shipments—such as that conducted by 300Cubits—it may be difficult for shipping industry stakeholders to see the value of using a token or cybercurrency in larger operations in lieu of actual legal fiat currency—the use of which is not limited to the platform, and the value of which is not as uncertain and potentially unstable (e.g. ShipChain SHIP token extreme decline in value; 300Cubits cancellation of blockchain operations).

Additionally, traditional legal contracts (e.g. on paper, outside of code) often include clauses and conditions that aren't readily quantifiable, and thus cannot be executed by smart contracts (Reyna et al., 2018). This is particularly the case in the maritime sector, where contracts tend to be unique and specific to the shipment or transaction, special contractual terms are often used, and certain aspects of transactions are typically handled commercially; maritime norms and features would need to be recognized and accounted for in blockchain (Joseph 2018). Currently no government or jurisdiction has implemented the use of blockchain for legal contracts in the maritime sector (Joseph, 2018). If and when governments decide to enforce blockchain contracts, a potential legal issue could arise: if a given blockchain splits through a hard fork (such as the hard fork of Ethereum that resulted in Ethereum and Ethereum Classic) and the forks disagree on the validity of contracts and transactions, then which contracts and transactions are enforceable? (Abadi and Brunnermeier, 2019). Given some of the complexities of, and challenges with smart contracts, many proposed use cases of blockchain (e.g. in the energy and maritime sector) have been found to be infeasible in the near-to-mid-term.

Finally, blockchains cannot pull real world data from outside their network, so data must be provided by entities referred to as "oracles." Oracles are third-party services that feed required information onto the network. Types of oracles include: software oracles which provide information from an online source such as a website (e.g. weather conditions); hardware oracles which provide readouts from the physical world (e.g. when a vessel or container crosses a barrier); inbound oracles which introduce data from the external world (e.g. prices); outbound oracles, which have the ability to send data to the outside world (e.g. to unlock a smart lock once a payment has been received); and consensus oracles, where to improve security, a combination of a majority of oracles (e.g. 3 out of 5) are used (Blockchainhub 2019).

Oracles must "sign" smart contracts in order for them to be executed/validated. To trust the validity of the smart contract, the oracle itself must be trusted, and so must be authenticated; the channel for data communication must also be secure. In order to manage the feeds by oracles and other interactions between the outside world and the blockchain, a trusted third-party entity is required; the addition of third-party oversight, however, diminishes decentralization (Reyna et al 2018).

3.1.7 Challenge 7: Technology Integration and Interoperability

Industry stakeholders believe there is a need for standardization across and interoperability between platforms and applications. This is considered one of the most significant obstacles to the use of blockchain tools in the shipping industry (Ytterstrom and Lengerg, 2019; Wagner and Wisnicki, 2019). Efforts are being made to address this problem. For example, the Digital Container Shipping Association, which was established in the spring of 2019 by major industry actors (e.g. A.P. Moller-Maersk, Hapag Lloyd), is working to promote common industry standards in the container shipping industry for all IT solutions, not only for blockchain. Additional efforts include the Blockchain in Transport Alliance, and the World Economic Forum's initiative to ensure that blockchain is used in an "interoperable, responsible, and inclusive way," and which includes participants such as A.P. Moller-Maersk, Port of Los Angeles, and Port of Rotterdam (Wagner and Wisnicki, 2019).

Technical infrastructure available to support the use of blockchain systems also differs by geographic region (Ytterstrom and Lengerg, 2019). Additional barriers related to the integration of blockchain technology into shipping operations include concerns regarding high costs of implementation, and the low level of use by other industry actors—where stakeholders believe that once certain leaders take initiative, or critical mass is reached, then others will follow (Gausdal et al 2018; Ytterstrom and Lengerg, 2019; Wagner and Wisnicki, 2019).

3.1.8 Challenge 8: Level of Competence and Knowledge

Finally, the level of competence and knowledge by stakeholders in the maritime sector with regards to blockchain systems is generally a concern. Interviews of various stakeholders in the shipping industry identified competence and organizational capabilities regarding implementation of new technologies as a concern in general, and for blockchain specifically; "hype" and surrounding misconceptions of blockchain were also identified as a concern (Ytterstrom and Lengerg, 2019). Bunduchi (2019) conducted interviews with stakeholders in the shipping industry, and found that there are various misconceptions and misinterpretations surrounding blockchain, including a general lack of understanding of what blockchain actually is (and is not); also, there is a lack of understanding of the key differences between public and private blockchain, and the tradeoffs associated with the use of each. Several of those in the maritime sector who are using “blockchain,” Bunduchi notes, are actually using private “blockchain-based” systems which lack key attributes of true blockchain systems. Additionally, several interviewed stakeholders do not seem to understand the rationale behind using blockchain, or the attributes or characteristics it offers compared to existing systems, databases or other alternatives —and this is among stakeholders who are actually (or who are claiming to be) using blockchain systems. Bunduchi’s findings indicate that education and capacity-building of stakeholders in the maritime sector regarding blockchain will be important, if widespread use of blockchain in shipment tracking were desired.

3.1.9 References: Blockchain Challenges in the Maritime Sector

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3.2 Technical Limitations of Blockchain

3.2.1 Speed, Scalability, and Storage

Another concern in terms of logistics with regards to the use of blockchain in shipping is the issue of speed of transaction speeds, storage limitations and scalability. Blockchain processing speed is much slower than traditional databases. Public, permissionless blockchains currently process a small number of transactions per second, compared to thousands of transactions processed per second by centralized databases. Ethereum processes an estimated ~15 transactions per second, with more complex transactions such as smart contracts processed at ~7 per second (Kasireddy, 2017). Queues also develop in response to a high number of pending transactions (MacManus, 2018), with Ethereum's pending transactions queue averaging several thousand transactions at an estimated wait time of 5 to 43 minutes, depending on transaction complexity (Etherscan, 2019); by late March 2020, the number of pending transactions averaged 30,000 to 70,000 (Etherscan, 2020b). Wait time per transaction for Bitcoin ranges from 10 minutes to several days (MacManus, 2018). Since transactions in blockchain are not necessarily processed in order, delays and queues of this nature could be of potential concern in the case of relying on time-stamped entries in a sequential basis, especially if one transaction in the supply chain had not yet been processed, yet the data were required for the next step in the process.

Additionally, blockchain is not designed to store large amounts of data; yet, tracking shipments along the supply chain will likely produce vast amounts of data, and will require processing and storing that data on a continual basis, and over the long term. This will require a great deal of processing speed and storage space, yet these are areas where blockchain technology (and public, permission-less blockchain in particular) is lacking. While IoT devices can generate GB of data in real-time, in 2018 an Ethereum full node (the entire copy of the ledger containing the history of transactions) was 46 GB in size (Reyna et al., 2018). Interviews with stakeholders in the shipping industry have confirmed that scalability is a major concern, while acknowledging that initiatives thus far have been smaller scale and involve relatively few participants; there is a lack of consensus as to solutions in the area of scalability (Ytterstrom and Lengerg, 2019). Scalability of blockchain systems in general has been noted as a concern by agents in the maritime shipping industry (Ytterstrom and Lengerg, 2019). And, although private blockchains are much faster and can handle many more transactions per second, these come with the tradeoffs of loss of decentralization and immutability.

3.2.2 Relatability or Reporting of Data

A challenge with respect to using blockchain for regulatory compliance or reporting (such as in fuel quality assurance or dangerous goods protocols) is the nature and structure of blockchain ledgers, which do not allow the ability to compile, organize, or analyze data in a meaningful way, or allow for relatability of data. Transactions and data can be searched and viewed for verification, but they are not easily accessed or relatable in a form to be used for reporting, analysis, or regulatory compliance, etc. The data, that is, remain data, as opposed to information which would lend understanding or insights, and do not facilitate analysis or understanding of trends, patterns, outliers, or other issues that may be of interest in identifying noncompliance or suspect behavior, etc. In order to collect, store, access, analyze and data in this way, alternative or redundant systems (e.g. centralized databases) would be required, potentially increasing complexity and cost of systems.

3.2.3 System Costs

Shipping industry stakeholders, including MARAD, have goals of increasing efficiency of maritime operations while minimizing operational costs. Blockchains have the potential to reduce or avoid transaction costs in the form of intermediary fees, time and processes, or other transactions costs associated with the status quo. But blockchains—and the equipment, devices, and other system elements required to use blockchain—come with their own costs. These costs are highly variable, and in some cases quite significant. Blockchains themselves are currently expensive to develop. It is unclear whether the savings in transaction costs promised by blockchain will not be mostly offset—if not exceeded by—the cost of blockchain in practice (Andoni et al., 2019).

Blockchain system costs include hardware, software, devices and equipment, training, and services and fees (such as smart contracts fees, the fee for the given application/service, blockchain platform transaction fees, or blockchain-as-a-service—where members may for the use of blockchain nodes, writing data, storage, and which charge by the hour on an ongoing basis). Upfront costs and ongoing fees can reach hundreds to thousands of dollars per month for a relatively modest number of contracts and small amounts of data storage (e.g. $500/month for

25 users and 900 smart contracts annually; cost to store 1 kb of text on blockchain, \$2.88; cost of blockchain network membership with 500 GB storage \$1.93 per hour, indefinitely) (AWS, 2019; Monax, 2019; BitInfoCharts, 2019; Skvorc, 2018). In the TradeLens model (the IBM-Maersk partnership described in Use Case 2), participants are charged on a pay-per-use or subscription basis (TradeLens, 2018); the fee schedule, however, is not published.

These costs, which do not include the costs of establishing a blockchain platform, or the devices and equipment necessary to do so, may be prohibitive in many applications, especially those involving large amounts of data. This was recently the case with a group of several organizations who were involved in funding and verifying carbon credit activities, and realized that the data storage requirements would be too expensive using blockchain; the groups opted to use blockchain for storage of key data elements only (which needed to be immutable), and used databases and other tools for other data. These costs may be particularly prohibitive for smaller companies and developing countries who may not have access to infrastructure or financial capital necessary to make these investments; yet, these are the very parties that blockchain is foreseen to help through reducing traditional transaction costs.

Then there is the issue of increased scale, which is typically assumed to lead to per-unit cost reductions with technological and computing advancements. This may not apply with the use of blockchain technology, however. Though certain devices or equipment may decline in cost, the overall costs of the system (and cost per transaction, etc.) may continue to increase, given that computing requirements, bandwidth, and energy requirements increase as the blockchain network size and processing requirements expand (Reyna et al 2018; Andoni e al. 2019). So, the more that the network is used, the more expensive it could be.

The costs of establishing, using and maintaining a blockchain-based system are highly variable and depend upon the type of platform, the data and storage needs, the number of participants, and a number of other factors that would depend upon the application and use. Though they cannot be estimated on a broad, general, basis, these costs are important to consider in context, for each use case and application.

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4 Guidance on the Use of Blockchain in Maritime Applications

4.1 Recommendations for Maritime Sector Stakeholders

4.1.1 Recommendation 1: Build a Regulatory Framework

As described in the preceding section, there are concerns related to enforcement, jurisdiction, and regulatory implications for participants. A regulatory framework will need to be in place for many stakeholders in the shipping industry to participate in systems using blockchain. Stakeholders in the maritime sector may wish to initiate or support efforts to establish such a framework, or to explore the feasibility of such a framework, which would explore questions such as which data are permitted to be shared, and for which data is sharing prohibited—under anti-trust rules, for instance. If data are to be used in legal transactions or in meeting compliance requirements, issues to consider would include which entities have authority or jurisdiction, or should play a role in the development, use and/or administration of such a system. For legal transactions or compliance, issues to consider would also include rules as to which, if any, data or transactions are enforceable, or will serve to meet compliance requirements, and the criteria which need to be met for data, transactions or contracts to be considered validated or accepted. Actors and agents, and regulatory entities who would need to be involved in the system and processes—including data entry, verification and validation, publishing to blockchain, and data retrieval and/or compilation and their respective roles, responsibilities and checks and balances would also need to be established. Stakeholders, including public sector entities, may wish to join or otherwise become involved in consortiums and/or conversations in this area moving forward.

4.1.2 Recommendation 2: Minimize Security and Safety Risks

Security issues of blockchain (and integrated systems) will continue to be an issue and will likely become more of an issue as use expands and system vulnerabilities are identified, presenting security and potential safety risks in the maritime sector. As noted above, an accurate understanding of the privacy and security risks of blockchain—and the efforts to address or minimize these risks—will be important for stakeholders, including public sector entities, prior to moving forward with widespread implementation of blockchain.

Stakeholders may wish to initiate or increase involvement in consortiums or international bodies involved in the area of blockchain or establish partnerships with neutral parties to better understand the risks and to play a role in developing and evaluating appropriate measures to minimize safety and security risks to the maritime sector. In particular, if data/transactions from blockchain might be used in regulatory compliance, stakeholders may seek to establish partnerships/relationships or otherwise engage neutral parties to better understand security risks associated with different blockchain platforms, and how these risk compare to those of existing or alternative systems—as well as what opportunities may exist for altering data prior to or after data are published to blockchain. Stakeholders may also seek to be involved in, or encourage, oversight and assurances in this area. As many stakeholders may be concerned about sharing data with competitors, stakeholders may wish to invest in, or otherwise encourage development of, blockchain systems and platforms administered by neutral parties, or parties involved in oversight.

4.1.3 Recommendation 3: Evaluate Energy Impacts

Depending on the platform type, and usage (such as transaction type and frequency), the energy consumption and related emissions and environmental impacts of certain blockchain systems may run counter to maritime sector stakeholders' goals of minimizing adverse environmental impacts of shipping. The energy consumption and emissions profile of a given blockchain platform or type of platform, therefore, is important to understand. Stakeholders, including those in the public sector, may consider (individually or as a consortium) conducting or supporting lifecycle analysis of energy use and emissions associated with proposed blockchain platforms and applications in the maritime sector. Ideally, an in-depth and thorough analysis of any blockchain platform or system (by a neutral party/parties) would be conducted prior to stakeholders supporting or encouraging its use at a large scale—as would the energy consumption and emissions generation of alternative or legacy systems. Further exploration and assessment of platforms such as that developed by the Energy Web Foundation (described above) is also advised.

4.1.4 Recommendation 4: Assess Costs

One of the main goals of blockchain systems is to reduce transaction costs in the form of agreements, the necessity for intermediaries and brokers, and keeping, sharing and storing data and records. Blockchain use cases in the maritime sector indicate the potential to reduce transaction costs in a number of areas, including reducing the need for intermediaries such as brokers and courier services, and to reduce related financial expenses and energy costs. However, without an understanding of the comparable costs of the overall investment and expenses associated with blockchain systems, the extent of actual cost savings (if any) are uncertain. As described in greater detail in the companion primer document (Winebrake et al., 2020), though blockchain technology may reduce transaction costs in certain respects compared to existing alternatives, blockchain systems are associated with their own costs, including required equipment and devices and system upgrades and/or replacement, as well as any energy costs, transaction fees, service fees, subscription fees, and storage fees, etc. Most of these costs vary widely or are highly uncertain or dependent upon the system type and configuration, number and complexity of transactions, number of participants, client needs, and a number of other context-dependent factors.

As of now, the financial and economic costs of blockchain technology are highly variable, and highly uncertain. When asked about blockchain system costs, companies involved in blockchain in the maritime sector (and energy sector) tend to avoid answering the question definitively (and even neglect to supply a range of costs) but instead note that the costs are specific to the configuration and client, are currently unknown, or will change over time as the application (or blockchain in general) reaches scale. Current costs, of course, do not necessarily indicate the extent of expected future costs. Technologies typically go through several stages in terms of costs and relative scale of adoption, known as the technology adoption curve. For most use cases (outside of cybercurrencies), blockchain is in the stage of innovators or early adopters, where costs tend to be higher, but costs are also not as much of a consideration (early adopters are interested in testing and exercising the technology to see how it performs, and understand that costs will come down over time, but are not as cost-sensitive). The actual extent of costs will be important for potential later adopters to understand—as will any projections in terms of changes in costs over time, as the technology develops and increases in scale.

As noted in section 3.2.3., however, whereas technologies and systems typically see a reduction in costs in response to increases in scale, systems using blockchain may actually see an increase in costs with greater use, given that computing requirements, bandwidth, and energy requirements increase as the blockchain network expands. Costs may also increase with scale in the case of subscription- or service-based systems, where costs are based on transactions and system storage.

An unbiased and thorough analysis and assessment of the financial and economic costs and benefits of blockchain systems, therefore, is recommended prior to stakeholders making use of a particular blockchain application or platform on a large scale. A cost assessment should also include examination of alternatives, including both technological and policy or strategic alternatives. Technological alternatives might include examining alternative (or existing) ways of collecting, compiling and storing data and/or documents, and comparing these to blockchain on a systems or lifecycle basis. For instance, centralized databases might meet the needs for data and document access, organization and storage, and might do so at a lesser overall cost in terms of time and financial expenditures. Each system comes with its own unavoidable advantages and tradeoffs. As noted by Abadi and Brunnermeier (2019), the ideal qualities of any record keeping system are 1) correctness, 2) decentralization, and 3) cost efficiency; yet, no ledger can satisfy all three at the same time. The key questions for each potential application are what are the priorities, and which tradeoffs are worth making to achieve advances or improvements in those areas?

4.1.5 Recommendation 5: Educate and Build Capacity

A key issue recognized by stakeholders in the maritime sector is the limited knowledge of blockchain by actors in the shipping industry, regarding key aspects of blockchain, including: challenges and limitations, differences in attributes of public and private blockchain systems, and distinctions and similarities between blockchain systems and legacy or existing systems, or alternatives. The general culture of the shipping industry, and hesitancy to move away from legacy systems has also been identified as a concern. Stakeholders, therefore, may wish to initiate, engage in, or otherwise support educational, training, or capacity building efforts, to ensure that key participants (or potential participants) in the maritime sector have an understanding of the potential benefits, costs, opportunities and risks presented by various blockchain systems. This may encourage stakeholders and partners to make informed decisions in the area of blockchain implementation, and may ensure against initiatives going too far down a path that may not be beneficial to participants—or may be prohibitively costly to cancel or dismantle. Similarly, training, education and capacity building for regulatory or other key entities involved in administrative roles or enforcement would also be advised.

4.1.6 Recommendation 6: Support Development of Standards

The lack of interoperability and common standards between applications is considered one of the greatest barriers to widespread use. Stakeholders may consider collaborating in or otherwise supporting efforts to address this issue, such as the earlier-mentioned Digital Container Shipping Association (DCSA), which claims to be working in the areas of standardization and interoperability in the maritime sector, and applies to all areas of information technology, not simply blockchain (Wagner and Wisnicki, 2019). The initiating partners of DCSA (i.e. A.P. Moller-Maersk, Hapag-Lloyd, Mediterranean Shipping Company and Ocean Network Express) "recognize the need for a neutral body acting in favour of all participants in the maritime sector" (Wagner and Wisnicki, 2019). This is an area where stakeholders, particularly those in the public sector, may wish to pursue involvement, or initiate or support similar efforts.

4.1.7 Recommendation 7: Provide Funding and Support

If and when certain blockchain systems or platforms are deemed to be beneficial and in alignment with stakeholders' goals, and thus worth pursuing and supporting, key stakeholders, including those in the public sector, may consider providing funding or technical assistance to address barriers of technological integration costs, lack of expertise, and general hesitancy by stakeholders in the maritime sector to invest in blockchain systems. Depending upon the system and purpose, stakeholders may also consider funding (or co-funding) the development of a blockchain platform and application for certain purposes.

4.1.8 Recommendation 8: Evaluate Regulatory Compliance

Given the potential ramifications in terms of diluting the intended effects of IMO 2020 or other regulations if fraud or falsification of records were feasible, stakeholders, particularly those in the public sector or regulating parties, will want to have assurances that data from any system used for verification purposes could not be tampered with prior to entering into the ledger, and that disinterested or unbiased parties (or those in a regulatory enforcement capacity) were serving administrator roles. Protecting the ledger from deliberate or accidental changes is crucial in the fuel quality traceability and assurance use case, to ensure that fraud is avoided, regulations are followed, and intended public health and safety benefits are realized, as well as to ensure safety and security for those relying on fuel quality verification, to avoid “bad bunker fuel” and ensure vessel functionality. The need for such assurances would also be relevant in ensuring that protocols were followed in shipping dangerous goods, and following other safety and security protocols, or any other area where regulatory compliance were at stake. This concern relates not only to the use of blockchain, but any other system of testing, data collection, documentation and storage.

On this note, much of the innovative work being done by companies and entities using blockchain (for instance the fuel tracing and assurance methods of BunkerTrace) does not involve or require blockchain, per se—but rather uses blockchain as a method to collect and store data, and to allow for verification. Feasibly, alternative systems (e.g. centralized databases) could also be used to validate, collect and store the data, though these would come with the acknowledged limitations of these systems.

The appropriateness of blockchain for use in fuel quality assurance and other regulatory compliance is also important to consider given the data needs for reporting and analysis of data by regulated parties, regulating parties, and decision-making bodies, etc. As described in greater detail in the preceding section, blockchain has limitations with regards to relatability of, access to, and use of data for reporting and analysis. If blockchain systems were used in certain use cases, auxiliary or redundant data collection and storage systems would also likely be required, increasing system costs and complexity.

Understanding the nature of the system used to collect, validate, and store data in these use cases is therefore of the essence, as is understanding how different blockchain systems or “blockchain-based” systems compare to one another, and compare to alternative data collection and storage systems such as databases. It will be important to understand the form of blockchain platform (or other system) used, and its comparative advantages and disadvantages, opportunities for intentional falsification or external hacking, as well as how these systems compare in costs, complexity, transparency, immutability, time, energy/resource use and other areas of concern.

If and when stakeholders decide that use of blockchain systems is worthy to support for certain uses and applications, as discussed above, a clear policy and regulatory framework would be required. For instance, if blockchain were used to facilitate and document fuel testing and transactions, the conditions in which data from testing and transactions would be permitted for regulatory compliance (and where it would not) would need to be established.

4.1.9 References: Recommendations for Maritime Sector Stakeholders

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5 Conclusion

Blockchain has been proposed for, is in development for, or is currently being used in a number of applications, including in the maritime sector. This document has explored four use cases of such potential applications, including the problem, opportunity or goal of relevance to maritime sector goals and concerns, risks or barriers to achieving the goal or addressing the problem, the role blockchain may play in addressing the problem, example initiatives in the area, challenges, barriers and limitations of the use of blockchain for the use case (especially in the context of when the use of blockchain may run counter to maritime sector goals), what needs to be in place or addressed in order for the use of blockchain to move forward, and how stakeholders may support the use of blockchain in the use case, if and when the use of blockchain is deemed to be in alignment with stakeholder interests.

This report suggests that while there are a number of areas where blockchain is of potential interest and may play a potential role in improving the efficiency or effectiveness of certain areas of maritime operations or regulations, there are a number of significant concerns surrounding the use of blockchain, from the perspective of stakeholders in the maritime sector, including those in the public sector or regulating parties.

At this point in the development of blockchain technology, it is impractical to make definitive recommendations as to whether pursuing or supporting the use of blockchain technology in a use case is desirable, given the uncertainties in costs, benefits, energy and resource use, security and privacy, and other key variables and potential consequences. These uncertainties are even greater given the disparities in key attributes of blockchain by platform type and configuration (e.g. public, permission-less versus private, permissioned; choice of consensus mechanism; choice of administrators, validators and third-party oversight, etc.), and the tradeoffs associated with choices among platforms and systems.

What this means is that the decision to support or pursue the use of blockchain is highly context specific—it will depend upon the goals of the system, and the costs, benefits and tradeoffs associated with that unique system and configuration. For each use case and potential system, participants and potential supporters would be advised to seek to understand the costs of the system (such as energy use and technology implementation costs), the potential consequences of the system (such as environmental and health implications of energy use, privacy and security, and potential ramifications of shared information for that use case), and the participants involved (including stakeholders, administrators, and authorities or enforcement). Decisions will have to be made on a case-by-case basis, after analyzing, assessing and considering these attributes and potential consequences in detail, considering the particular platform type, system configuration, and anticipated scale of use and number of transactions, etc.

This work indicates that a deeper understanding of the challenges and concerns and related potential ramifications and consequences of blockchain will be important for maritime sector stakeholders and partners to pursue in the context of each use case. This is particularly the case if and when any data or information stored in blockchain will be used in regulatory compliance or enforcement. Efforts stakeholders may engage in to further this understanding and/or minimize risks include: developing (or participating in development of) a regulatory framework; examining the extent of energy and environmental impacts of blockchain platform; examining and better understanding the costs associated with blockchain, and understanding and/or minimizing security risks of blockchain. If and when these challenges and concerns are well understood, addressed and/or minimized, and stakeholders seek to support the use of blockchain, options for stakeholders include: education, training and capacity building; collaboration or otherwise support efforts for technical interoperability; and funding and or other support.