Blockchain for Clean Energy – A "Distributed" Approach to Saving the Planet

By Benjamin R. Zeter

I. Introduction

If you have listened to the news recently, you may have heard that climate change is becoming a bit of an issue.[1] No longer is the concern of the polar ice caps melting an ethereal specter hanging over anyone driving a Hummer. Rather, the latest projections paint a terrifying picture in the not-too-distant future where millions of people will be forced to flee rising sea levels and diseases once confined to the tropics will run rampant globally.[2] While everyone can "do their part" by recycling more and choosing sustainable products at the super market, it may be time to implement more drastic measures. Time and time again, throughout history, humanity has proven itself adept at innovating around potentially catastrophic situations. From the creation of the Great Wall of China to the development of vaccines, the age-old adage of "desperate times call for desperate measures" has rung true. Climate change, while potentially the most serious issue human

1 Carolyn Kormann, *The Dire Warnings of the United Nations' Latest Climate-Change Report*, The New Yorker (Oct. 8, 2018), https://www.newyorker.com/news/news-desk/the-dire-warnings-of-the-united-nations-latest-climate-change-report.

2 *Id.*

beings have ever faced, provides yet another opportunity for innovation to help society move forward. The advent of the technology age has propelled innovation at a staggering pace and the potential for technology to help rectify the current climate dilemma is, in the words of President Donald Trump, "huge."

One such technological development, blockchain, may hold great promise in addressing the litany of issues climate change presents. This note presents multiple blockchain applications in the energy industry that, through their implementation, could contribute to a reduction in global greenhouse gas emissions. This note begins with a high-level overview of blockchain and how the technology works. This part includes discussion of blockchain's inception and smart contracts. Next, this note turns to the energy industry as a whole and examines four different areas ripe for blockchain application: cap-and-trade programs, domestic energy markets and micro-grids, smart devices, and international energy trading. Finally, this note examines the possibility of a blockchain based international climate change agreement. Some of the blockchain applications this note advocates for may seem unconventional; however, if the United Nations' most recent predictions are accurate, unconventional approaches may be necessary to save the planet.[3]

II. BLOCKCHAIN AND SMART CONTRACTS – A PRIMER

This part provides a broad overview of how blockchain technology operates. First, this part addresses the history of blockchain and its origin as a way to circumvent financial institutions. Next, a conceptual explanation of blockchain technology helps to demystify many of the technology's varying nuances. Then this part defines the distinction between public and private blockchains followed by a discussion of the pros and cons of blockchain technology. This part then turns to smart contracts, defining the term and explaining how smart contracts operate on a blockchain framework.

A. BLOCKCHAIN

Blockchain technology has garnered a significant amount of attention in the media recently, largely stemming from the astronomical rise and fall of Bitcoin in 2017 and 2018.[4] While Bitcoin illustrates one potential application of the "distributed ledger" technology that is blockchain, there are countless other possibilities for the technology to be applied to, and disrupt, various industries. As one source as put it:

> the blockchain technology can be utilized in any application where it would be advantageous to avoid the necessity of a central or trusted authority in a "busy" ecosystem (where there are lots of participants that need to reduce counterparty risk), where there are problems with the existing market (which could be

3 Kormann, *supra* note 1.

4 *See generally* COINDESK, https://www.coindesk.com/price/ (last visited Mar. 12 2020) (On December 16, 2017, Bitcoin was valued at $19,343.04 per coin; Bitcoin's value fluctuates wildly).

clumsy, unscalable or slow), where there are rules that could be implemented on a platform, or where there are governance functions that could be automated.[5]

To fully examine just how far reaching blockchain technology may be used, it is necessary to first give a broad overview of what exactly blockchain is, why it exists, and how it works.

1. Blockchain's Inception

The benefit of having multiple parties individually maintaining new additions to the blockchain is fidelity, as blockchain is a system built on a presupposition of a lack of trust. Satoshi Nakamoto, the father of Bitcoin, invented blockchain to have a more secure system for financial transactions that removed third-party intermediaries, such as banks and governments.[6] In 2008, Nakamoto first published his white paper as the world was still in the grasp of the Housing Crisis. Risky business and astronomical economic damage had eroded trust in large financial institutions. As such, the impetus for blockchain was Nakamoto's observation of the "inherent weakness of the trust based model."[7] As Nakamoto said, "[w]e need a way for the payee to know that the previous owner did not sign any earlier transactions."[8] To accomplish these sorts of transactions without trusted third parties, "transactions must be publicly announced, and [the world needs] a system for participants to agree on a single history of the order in which they were received."[9]

Nakamoto's main concerns with the trust-based model were a lack of completely non-reversible transactions, transaction costs associated with mediating disputes over transactions, and fraud in the form of double spending.[10] Blockchain avoids these problems by "allowing any two willing parties to transact directly with each other without the need for a trusted third party."[11] The elimination of the trusted third party not only eliminates transaction costs, but provides for greater anonymity of the transacting parties while at the same time preventing double spending.[12]

Blockchains not only provide for transactional anonymity, they are also more secure than existing network-based transaction recording systems. "[B]lockchains are inherently resistant to modification of the data—once recorded, the data in a block cannot be

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5 Judith Allison Lee, *Blockchain 101*, Thomson Reuters, https://legal.thomsonreuters.com/en/insights/articles /blockchain-101 (last visited Mar. 12, 2020).

6 Satoshi Nakomoto, *Bitcoin: A Peer-to-Peer Electronic Cash System*, Satoshi Nakamoto Inst. (Oct. 31, 2008), https://nakamotoinstitute.org/bitcoin. There is much debate as to whether Nakomoto was merely a pseudonym. *See* Sophie Bearman, *Bitcoin's creator may be worth $6 billion – but people still don't know who it is*, CNBC (Oct. 27, 2017), https://www.cnbc.com/2017/10/27/bitcoins-origin-story-remains-shrouded-in-mystery-heres-why-it-matters.html.

7 *Id.*

8 *Id.*

9 *Id.*

10 *Id.*

11 *Id.*

12 Nathan Reiff, *Blockchain Won't Cut Out Intermediaries After All*, Investopedia (Aug. 13, 2018), https://www.investopedia.com/tech/blockchain-wont-cut-out-intermediaries-after-all/.

altered retroactively without creating an obvious incompatibility with later blocks, which depend on the original data from the earlier block as part of the hash."[13] The distributed nature of the blockchain also lends itself to security as there is not one, central server that can be hacked.[14] To modify a past block, an attacker to the network would have to redo the proof-of-work of the block and all blocks after it and then catch up with and surpass the work of the honest nodes. Blockchains are not impervious to attacks and the method by which a blockchain is implemented can be determinative of the likely success of an attack.[15]

2. *WHAT IS "BLOCKCHAIN"?*

A blockchain is a "shared, trusted, public ledger that everyone can inspect, but which no single user controls."[16] A blockchain is thus a "distributed ledger" as anyone can access and see the information stored on it. Due to the publicly available nature of information on a blockchain, the technology is well suited to operate as a record keeping mechanism in a host of different scenarios.

A blockchain starts as random inputs of information into a "master spreadsheet" that multiple parties, or "nodes," keep track of simultaneously.[17] The Bitcoin blockchain provides a useful example to "anchor" any discussions of blockchain.[18] Generally, blockchains operate by adding more blocks onto a "continuously growing list of ordered records."[19] Blocks are periodically added to a given leger via different rules laid out by different blockchain database platforms. In the case of Bitcoin, this is "a global list of transactions that have been agreed upon via a form of consensus by a subset of the Bitcoin community."[20] But Blockchains do not operate as simply as one party inputting a value and all other parties blindly acknowledging the veracity of the input. Rather, the system uses complex cryptographic functions to ensure both the validity of a given input and greater security.[21]

To illustrate how the system verifies new inputs for addition to a blockchain, let us return to the "global spreadsheet" example. When a spreadsheet has only a few different users, the total amount of information is significantly less than if that same spreadsheet were opened to the entirety of the world. To avoid the cumbersome computational task of having to review the whole spreadsheet every time the program makes a new addition,

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13 Lee, *supra* note 5.

14 Tamoor Khan et al., *Blockchain Technology with Applications to Distributed Control and Cooperative Robotics: A Survey* (2018), *reprinted in* arXiv 1–5.

15 *Id.* at 1–3.

16 Steve Myers & Scott J. Shackelford, *Block-By-Block: Leveraging the Power of Blockchain Technology to Build Trust and Promote Cyber Peace*, 19 YALE J. L. & TECH 334, 342 (2017) (citing *The Trust Machine*, ECONOMIST (Oct. 31, 2015), http://www.economist.com/news/leaders/21677198-technology-behind-Bitcoin-could-transform-how-economy-works-trust-machine [https://perma.cc/Q5XT-EXX7]).

17 Akshay Kore, *Blockchain for dummies*, HACKERNOON (Jan. 9, 2018), https://hackernoon.com/blockchain-for-dummies-ae786c6a5fe7.

18 Myers & Shackelford, *supra* note 16, at 343.

19 Lee, *supra* note 5.

20 Myers & Shackelford, *supra* note 16, at 343.

21 *Id.*

blockchains use "hash" values to correspond to a specific subset of information.[22] "[R]ather than checking the entire spreadsheet," a hash value can be created which is a "single, mathematically unique value" used to identify each entry in the "master spreadsheet."[23] That "single, mathematically unique value" is determined by way of a function.[24] A simple example is to create a function whereby "g(x)=<<Unknow Symbol>>x/2<<Unknow Symbol>>, divides x by 2, and rounds down to the nearest integer."[25] If we apply the numbers 1 to 10 to this function (inputting them for the x value), it will map any number between 1 and 10 to a number between 1 and 5.[26] The blogger Kore on Hackernoon.com explains how blockchains use hash values in the following way:

> We add the [identification numbers] of the [entity inputting the data] and the [data itself] in each column entry along with the date. . .which we store as the Hash value for the first entry in the spreadsheet. For subsequent entries, we use the same formula and add the hash value of the previous entry. This starts forming a chain of hash values that reference the entire spreadsheet.[27]

While hash values contribute to the overall efficiency of the system, blockchains add new pieces of information at a very fast rate.[28] To avoid having to conduct energy intense computations on a millisecond by millisecond basis, the program takes snapshots of the spreadsheet at given time intervals.[29] These chunks of transaction can then be added to [the] spreadsheet chain as a block, hence the name "block chain."[30] In a blockchain, "[e]ach block contains a timestamp and a link (such as a cryptographic hash) to a previous block, which creates a chronological record of the blocks."[31]

Hash values are only one piece of the entire blockchain picture. Security and anonymity are two of the hallmarks of a blockchain. These are achieved by utilizing "cryptographic hash functions."[32] Essentially, cryptographic hash functions serve to introduce "pseudo-randomness and collision resistance."[33] In the case of the Bitcoin blockchain, the SHA256 hash function (SHA256:{0,1}*#{0,1}) is used which "maps any finite binary string (denoted {0,1}*) to a binary string of length 256 bits (denoted $\{0,1\}^{256}$.[34] Pseudo-randomness and collision resistance come into play in the overall security of a

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22 *Id.* at 382 ("A function that maps a large, possibly infinite, set of objects to a smaller set of objects is called a hash function.").

23 Kore, *supra* note 17.

24 Myers & Shackelford, *supra* note 16, at 383 (think back to High School math where f(x) = x +4, etc.).

25 *Id.*

26 *Id.*

27 Kore, *supra* note 17.

28 *Id.*

29 *Id.*

30 Lee, *supra* note 5.

31 *Id.*

32 Myers & Shackelford, *supra* note 16, at 383.

33 *Id.*

34 *Id.* at 383–84 (citing Info. Tech. Lab., Nat'l Inst. of Standards & Tech., Fed. Info. Processing Publ'n on Secture Hash Standard (SHS) SECURE HASH STANDARD (Mar. 20120), http://csrc.nist.gov/publications/fips/fips180-4/fips-180-4.pdf [http://perma.cc/K7NY-6AJ3])).

blockchain's architecture. Pseudo-randomness is the principle that "when given a random input x of a fixed size. . .that is unknown to an efficient adversary. . .the output is indistinguishable from a truly random outcome to the same adversary."[35] That is to say that the efficient adversary (a hacker) would have no way of differentiating between the correct output and a random output of the same function. Collision resistance is best explained by returning to our previous function, "g(x)=<<Unknow Symbol>>x/2<<Unknow Symbol>>, divides x by 2, and rounds down to the nearest integer."[36] In this function, any even number plus one will return the same output as that same even number, meaning that multiple inputs will have the same output.[37] All hash functions inherently have collisions, however in a cryptographic hash function, due to the pseudo-randomness property, it is expected to take "2^{128}iterations" to discover a collision.[38] All of this is to say that brute force attempts to discern the correct key to a hash function are highly inefficient and that the security of a given blockchain is directly related to the cryptographic hash function utilized.

Continuing on our crash course of blockchain technology comes the all-important concept of "proof-of-work." The basic goal of a proof-of-work" is "to allow one party to prove to another that they have spent a certain amount of time working on a given problem."[39] Essentially, this is like giving someone a puzzle with no picture to guide them; the proof of work is the finished picture.[40] "To cryptographically achieve this same concept, we are going to ask you to find the output of a cryptographic hash function with certain properties."[41] A specific string, or data output, specified to a given hash function is analogous to the finished picture after the puzzle.[42] Finally, blockchains utilize digital signatures to ensure that only trusted parties can execute given transactions. "Anyone who has the key can retrieve the signing stamp and use it to 'sign' the signature of the individual whose name is on the stamp."[43] Digital signatures are used "to prove that a message originates from a specific person and no one else, like a hacker."[44]

To bring all of this together, consider the mosquito trapped in amber atop John Hammond's cane from *Jurassic Park*.[45] The mosquito in this scenario is the piece of information stored on the ledger. When the mosquito lands on the original tree sap, it becomes lodged on the ledger. The process of additional blocks can be visualized through the additional tree sap that entombs the mosquito, however the mosquito is always visible despite the amount of sap that coats it. This is analogous to using a hash to refer back to a specific piece of information. While a given blockchain does not take the millennia to generate as a fossil does, the "blockchain" can be visualized as the piece of amber that

35 *Id.*
36 *Id.* at 383.
37 *Id.*
38 *Id.*
39 *Id.* at 386.
40 *Id.*
41 *Id.*
42 *Id.*
43 *Id.* at 387.
44 *Id.*
45 *Nick Szabo Interview*, THE TIM FERRIS SHOW (Aug. 11, 2017), https://www.youtube.com/watch?v= 3FA3UjA0igY.

is seen on John Hammond's cane in the movie, the result of countless additions of amber entombing the mosquito, or blocks entombing a piece of information.[46]

3. Public vs. Private Blockchains

Blockchains can operate both publicly and privately. In a public blockchain, "[t]he public nature stems from the free and unconditional participation of everyone in the process of determining what blocks are added to the chain, and what its current state is."[47] The hallmark of a public blockchain is that it is accessible to all internet users. Bitcoin provides a good example of what a public blockchain is and how it works.[48] The Bitcoin blockchain creates a continuous ledger of transactions completed using bitcoins.[49] A reward is necessary to incentivize computers to carry out the complex mathematical equations to verify subsequent blocks, and in Bitcoin, the Bitcoin itself operates as the reward.[50]

In contrast to the open world of the Bitcoin blockchain, "[i]n a fully private ledger, write-permissions are monitored by a central locus of decision-making."[51] This means that private blockchains operate similar to any existing server that safeguards information in one location. A private blockchain "amounts to a permissioned ledger."[52] Commentators have expressed skepticism as to whether blockchain can truly operate as a "blockchain" absent some underlying lack of trust between transacting parties.[53] After all, if the impetus for developing the blockchain was to circumvent trust issues with third parties, ceding control over who can and cannot contribute to the validity of the blockchain defeats the underlying purpose of the system.[54]

4. Potential Blockchain Issues

While blockchain has been held out as a potential technological panacea to many problems facing modern society, the technology is not without its issues. Such statements connote Thomas Huxley's famous quote, "[t[he great tragedy of science [is] the slaying of a beautiful hypothesis by an ugly fact."[55] That is to say that while blockchain technology has great hypothetical promise, actual implementation of blockchain systems has left something to be desired. Blockchain technology is subject to many of the same

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46 *Id.*

47 Marc Pilkington, *Blockchain Technology: Principles and Applications* (Aug. 7, 2015), https://blog.ethereum.org /2015/08/07/on-public-and-private-blockchains/ (citing Vitalik Buterin, *On Public and Private Blockchains*, Ethereum Blog (Aug. 6, 2015), https://blog.ethereum.org/2015/08/07/on-public-and-private-blockchains/).

48 *Id.*

49 *Id.*

50 *Id.*

51 *Id.* at 11.

52 *Id.*

53 Interview with Taeho J. Jung, Assistant Professor, University of Notre Dame, South Bend, Ind. (Sep. 19, 2018).

54 Paolo Tasca, *The Hope and Betrayal of Blockchain*, N.Y. Times (Dec. 4, 2018), https://www.nytimes.com/2018/12/04/opinion/blockchain-bitcoin-technology-revolution.html.

55 Tania Lombrozo, *Must Science Murder Its Darlings?*, Nat'l Pub. Radio (Jan. 27, 2014), https://www.npr.org/sections/13.7/2014/01/26/266784786/must-science-murder-its-darlings.

concerns as any other computer program such as hacks.[56] A particular concern for any blockchain system is a majority attack, or "51% attack."[57] A 51% attack is where a majority of the nodes in a network are controlled by a hacker. This means that the hacker can then substitute their own, falsified record, for the true chain and in the process reverse transactions that may have taken place or invent completely fictional transactions altogether.[58]

Another major issue facing blockchain is the current lack of regulation over its use. "Due to the lack of regulatory oversight, scams and market manipulation are commonplace."[59] Somewhat paradoxical to the core purpose of blockchain, a Pricewaterhouse Cooper (PwC) study found that "[r]egulatory uncertainty and trust are major barriers to blockchain adoption among businesses."[60] But this perceived problem with blockchain may actually be to its benefit. "An immature technology is a malleable technology and as blockchains inevitably have to develop, there is an opportunity to engrain compliance and respect for public policy objectives since the beginning."[61] Much as is the case for regulating any new technology, "[r]egulation should . . . allow for the protection of public interest objectives and stimulate innovation at the same time."[62] A complete discourse on blockchain regulation is beyond the scope of this note, however several articles have been published on the topic.[63]

The same PwC study previously mentioned also found that the ability to bring a network together posed another significant impediment to wider adoption of blockchain.[64] Further, "[t]he 'Establishment' has a vested interest in blockchain failing."[65] While this observation contains a healthy dose of cynicism, it is not entirely wrong. Centralized governments and financial institutions are inherently at odds with a system designed to disrupt centralized power. Banks, for example, "make huge amounts of profit from playing the middle-man role."[66] A former boss at Barclay's, in 2015, "de-

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56 David Black, *Blockchain Hacks and Losses Mount; Why Do Supporters Ignore The Facts?*, FORBES (Jan. 22, 2019), https://www.forbes.com/sites/davidblack/2019/01/22/blockchain-hacks-and-losses-mount-why-do-supporters-ignore-the-facts/#3c48d2452ca8.

57 *51% Attack*, INVESTOPEDIA (last visited Nov. 9, 2018), https://www.investopedia.com/terms/1/51-attack.asp.

58 Jimi S., *Blockchain: how a 51% attack works (double spend attack)*, MEDIUM (May 5, 2018), https://medium.com/coinmonks/what-is-a-51-attack-or-double-spend-attack-aa108db63474.

59 Bernard Marr, *The 5 Big Problems With Blockchain Everyone Should Be Aware Of*, FORBES (Feb. 19, 2018), https://www.forbes.com/sites/bernardmarr/2018/02/19/the-5-big-problems-with-blockchain-everyone-should-be-aware-of/#f423d491670c.

60 Ana Alexandre, *PwC: Regulatory Uncertainty and Lack of User Trust Inhibit Blockchain Adoption*, COINTELEGRAPH (Aug. 28, 2018), https://cointelegraph.com/news/pwc-regulatory-uncertainty-and-lack-of-user-trust-inhibit-blockchain-adoption.

61 Michelle Finck, *Blockchains: Regulating the Unknown*, 19 GERMAN L. J. 665, 682 (2018).

62 *Id.*

63 *See generally id.*; Tiffany L. Minks, *Ethereum and the SEC: Why Most Distributed Autonomous Organizations are Subject to the Registration Requirements of the Securities Act of 1933 and a Proposal for New Regulation*, 5 TEX. A&M L. REV. 405 (2018); Angela Walch, *The Path of the Blockchain Lexicon (And the Law)*, 36 REV. BANKING & FIN. L. 713 (2017).

64 Alexandre, *supra* note 60.

65 Marr, *supra* note 59.

66 *Id.*

scribed the interest and apparent enthusiasm of his sector as 'cynical' – stating that it stems from a desire to exert control or even block the usefulness of the emerging technology."[67] Whether blockchain will evolve and adapt to surmount these potential hurdles remains to be seen. If excitement around the technology continues at its current rate, enthusiasm for developing better applications of the technology will propel it forward.

B. Smart Contracts

A smart contract, conceptually, is a contract that is represented in code and executed by a computer.[68] Vending machines provide a useful illustration of how smart contracts work. "Smart contracts exist in digital code written to execute performance in the same manner as [a] vending machine."[69] This means that smart contracts operate on the same sort of "if, then" principle as a vending machine. In the case of a vending machine, when a coin is inserted, the machine assesses whether it is the correct denomination. Then, if the denomination is correct, the machine dispenses the appropriately selected item. The machine recognizes that a specific event has occurred and completes performance accordingly. This is the end of the transaction; "[a]fter money is deposited and a selection is made, delivery of the purchased item is irrevocably triggered."[70] One advantage of smart contracts is that "[g]iving machines the ability to determine whether a contract has been performed can dramatically reduce transaction costs."[71] Smart contracts are not limited to simple "if, then" scenarios and have recently utilized blockchain technology to carry out increasingly complex transactions.

Smart contracts are essentially the nexus of "two lines of technological development: electronic contracting and cryptography."[72] "Just as there are reasons to use a decentralized digital currency system even though traditional currencies are successful, there are reasons to use decentralized digital contracts to solve problems that the conventional contract system cannot."[73] Blockchain-based smart contracts provide many of the same benefits that blockchain-based currency does, namely "electronic enforcement" of promises. To illustrate the efficacy of smart contracts, consider a routine real estate sale. In most real estate sales in the United States, two parties agree upon a price, then the money is placed in "escrow," or with a trusted third party, until the "closing" of the deal. Closing is usually confined to a single date and criteria must be met prior to the transfer of money to one party and the transfer of title to the property to another. A trusted third party or intermediary is needed to watch over the money that is placed in escrow and to determine whether the criteria have been satisfied to trigger disbursement of the funds.

Now consider a scenario where the two parties conduct the exact same transaction, this time using a smart contract. The transaction from A to B is now encapsulated in self-executing code that will only trigger a disbursement of money from one party to the

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67 *Id.*

68 Eliza Mik, *Smart Contracts: Terminology, Technical Limitations and Real World Complexity*, 2 L. Innovation & Tech. 269-300 (2017).

69 Susan George, *Smart Contracts*, 81 Tex. B. J. 403 (2018).

70 *Id.*

71 Kevin Werbach & Nicolas Cornell, *Contracts Ex Machina*, 67 Duke L. J. 313, 320 (2017).

72 *Id.*

73 *Id.* at 331.

other and *vice versa* transfer of the title in the property once certain criteria are met. If the specific criteria, such as abandoning the property and removing articles from the property, are met, then the code self-executes and money is transferred from A's account to B while title of the property is transferred from B to A. The third-party intermediary is completely eliminated. This sort of contract is dependent on the code being able to access the financial accounts of both parties and a land title registry. Bitcoin and other blockchain-based currencies already provide an avenue for the financial side and some locations have already tested blockchain-based land registries.[74]

Another benefit of smart contracts operating on blockchain is that verification of contractual terms is a built-in feature. Remember that blockchains are ledgers used for record-keeping in a variety of situations. If a smart contract is entirely based on the blockchain, there is a clear record of any contractual terms agreed to by transacting parties.

Smart contracts, in conjunction with blockchain based systems, provide a potential avenue for automating many of the transactions that define daily life. The preceding primer on these technologies has attempted to provide a high-level explanation of how the technologies work. This note next turns to various applications for blockchain and smart contracts in the energy industry. From preventing double spending in a carbon trading market to ensuring that parties adhere to international climate change agreements, blockchain and smart contracts have the potential to revolutionize the modern energy environment.

III. ENERGY SECTOR BLOCKCHAIN AND SMART CONTRACT APPLICATIONS

The American energy industry has seen dramatic changes over the course of the past twenty years.[75] New technologies for natural gas extraction have generated a nearly ten quadrillion BTU increase in the use of the resource since 1990.[76] Renewable energy has also risen dramatically and now accounts for some 20 quadrillion BTUs, a little more than half of what petroleum and other liquids account for.[77] As the economy continues to grow at a rate of 2% annually, experts project that energy consumption will grow at 0.4% a year, "surpassing the 2007 peak by 2033."[78] Growth in the American energy industry must be juxtaposed against state laws that mandate reductions in greenhouse gas emissions. In total, "[t]wenty states plus the District of Columbia have adopted specific

74 Molly Jane Zuckerman, *Swedish Government Land Registry Soon to Conduct First Blockchain Property Transaction*, COINTELEGRAPH (Mar. 7, 2018), https://cointelegraph.com/news/swedish-government-land-registry-soon-to-conduct-first-blockchain-property-transaction.

75 *Annual Energy Outlook through 2050 Released by the US EIA*, PENN STATE EXTENSION (Feb. 7, 2018), https://extension.psu.edu/annual-energy-outlook-through-2050-released-by-the-us-eia.

76 *Id.*

77 *Id.*

78 U.S. ENERGY INFO. ADMIN., ANNUAL ENERGY OUTLOOK WITH PROJECTIONS TO 2050 (2017).

greenhouse gas reduction targets to address climate change."[79] The competing principles of a growing economy and growing energy demands on one hand and state legislation targeting how clean given energy production must be on the other have created an environment that is ripe for innovation. Increasingly, research is being done into blockchain technology's potential application to various aspects of the energy industry. The Department of Energy has even "requested proposals on the use of blockchain distributed ledger technology to ensure the security of energy transactions."[80]

This part will analyze in detail many of the different energy industry areas in which blockchain can be applied. First, this part analyzes how blockchain may be used to make cap-and-trade systems more efficient. Next, this part turns to a broad overview of the United States' energy industry and describes how power is generated, transmitted, and distributed to consumers, a process that many other countries mimic. An analysis of domestic energy industry applications follows, specifically focusing on micro-grids. Finally, this part concludes with discussions on smart devices and potential blockchain applications in international energy trading.

A. Cap and Trade

"Cap-and-trade" systems operate by "capping," or placing a ceiling on the total amount of greenhouse gases that can be emitted by an industry in a calendar year.[81] The "trade" element "is a market for companies to buy and sell allowances that let them emit only a certain amount, as supply and demand set the price."[82] To encourage companies in a given industry to reduce their overall greenhouse gas emissions, regulators decrease the "cap" on the industry over time.[83] The various greenhouse gases subject to a cap-and-trade program include, "Carbon Dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (N_2O)."[84] The goal behind cap-and-trade programs is to encourage companies to emit less greenhouse gases than they are authorized under their allotted credits and then sell those credits to companies that emit more emissions than their allotted credits.[85] In this way, greenhouse gas emissions are effectively "taxed" without really being taxed. As the total emissions ceiling for a given industry shrinks over time, the hope is that companies emitting more than their allotted credits will be forced to cut their emissions or continue to purchase credits from others.[86] The credits will, in theory, become more costly over time as the total supply shrinks, forcing companies to make difficult decisions about

79 *State Climate Policy Maps*, C2ES, https://www.c2es.org/content/state-climate-policy (last visited Feb. 7, 2020).

80 Keith Townsend, *Blockchain Technology Impact on Energy Market Transformation: Secured Distributed Energy Transactions in the Cloud*, 1 Geo. L. Tech. Rev. 469, 474–75 (2017) (citing U.S. Dept of Energy, Small Business Innovation Research and Small Business Technology Transfer Programs, https://www.energy.gov/science/sbir/small-business-innovation-research-and-small-business-technology-transfer).

81 Int'l Emissions Trading Ass'n, Cap and Trade: The Basics (Apr. 2015).

82 Envtl. Def. Fund, *How cap and trade works*, https://www.edf.org/climate/how-cap-and-trade-works (last visited Mar. 29, 2020).

83 *Id.*

84 Int'l Emissions Trading Ass'n, Cap and Trade: The Basics (Apr. 2015).

85 *Id.*

86 *Id.*

whether to cut emissions or face the costly endeavor of continuing to subsidize their own pollution.[87]

A major issue facing any cap-and-trade system is effectively monitoring emissions and enforcing the caps imposed. "[T]o administer a cap-and-trade program, a regulatory agency needs a full accounting of the emissions from each regulated facility in the program."[88] One can imagine just how complex this sort of monitoring becomes as cap-and-trade programs are scaled up from municipalities to states to entire countries. There are several different technological methods available for regulators to monitor emissions in a cap and trade system. One such method is through direct measurement using continuous emissions monitoring systems (CEMS).[89] CEMS are "a packaged system of gas analyzers, gas sampling system, temperature, flow and opacity monitors that are integrated with a data [acquisition] system to demonstrate environmental regulatory compliance of various industrial sources of air pollutants."[90] Another method to monitor emissions for cap-and-trade is "estimation using emissions factors."[91] Estimation using emissions factors provides a less expensive means of monitoring as compared to direct monitoring. "An emissions factor quantifies the amount of emissions produced per unit of an activity that emits pollutant. The general equation for emissions estimates is: 'Activity Rate x Emissions Factor = Emissions.'"[92] In instituting a cap-and-trade program, regulators must conduct cost-benefit analyses to determine whether it is more efficient for direct monitoring or estimations to be utilized.[93] The clear tradeoff is that direct monitoring is significantly more accurate than estimations, however these considerations are beyond the scope of this note.

Using blockchain technology can make cap-and-trade systems more effective. "The process of calculating carbon emissions and trading credits . . . can be a manual, time consuming and expensive process."[94] The first way in which blockchain can benefit cap-and-trade systems is through more effective monitoring of emissions.[95] One of the

87 *Id.*

88 Lesley K. McAllister, *The Enforcement Challenge of Cap-And-Trade Regulation*, 40 ENVTL. L. 1195 (2010) (citing Barbara Baird et al., S. COAST AIR QUALITY MGMT. DIST., Chapter Three - Legal Issues, in Over a Dozen Years of RECLAIM Implementation: Key Lessons Learned in California's First Air Pollution Cap-and-Trade Program I-3-2 (June 2007), available at http://aqmd.gov/reclaim/docs/Policy_Paper_ Part1.pdf).

89 *Id.* at 1203.

90 *Continuous Emission Monitoring System Products*, K2BW ENVTL. EQUIPMENT CO., http://www.k2bw.com/continuousemissionmonitor.htm (last visited Mar. 30, 2020).

91 Lesley K. McAllister, *The Enforcement Challenge of Cap-And-Trade Regulation*, 40 ENVTL. L. 1195, 1205 (2010).

92 *Id.* at 1206 (citing OFFICE OF INSPECTOR GEN., U.S. ENVTL. PROT. AGENCY, EVALUATION REPORT: EPA CAN IMPROVE EMISSIONS FACTORS DEVELOPMENT AND MANAGEMENT 3 (2006)).

93 *Id.* at 1210–11.

94 Lucas Mearian, *Now, Blockchain Can Turn Carbon Credits Into Tokens For Trading*, COMPUTERWORLD (May 31, 2018), https://www.computerworld.com/article/3277207/blockchain/now-blockchain-can-turn-carbon-credits-into-tokens-for-trading.html.

95 Robert Greenfield IV, *Blockchain Enabled Carbon Credit Markets*, MEDIUM (Sept. 11, 2019), https://medium.com/@robertgreenfieldiv/blockchain-enabled-carbon-credit-markets-1a195520f0e1.

hallmarks of a blockchain is the fidelity with which it can store information.[96] As such, in putting a cap and trade system on a blockchain, there is a built-in "accounting methodology to automatically calculate the carbon footprint" while simultaneously creating an instrument that can be traded.[97] Blockchain helps to introduce transparency into transactions for carbon shares by having "'miners'. . . confirm that corporations have the proper amount of shares relative to their emissions."[98]

Blockchain technology may also be able to make the "trade" element of cap-and-trade more efficient. In May of 2018, "IBM announced [that it is] working with environmental fintech company Veridium Labs Ltd. to tokenize carbon credits."[99] These "tokenized" carbon credits could be traded on a blockchain platform such as Stellar, an open-source blockchain exchange.[100] In the IBM-Veridium context, and more broadly, "[t]he tokens will represent a portion of carbon credits" issued by governments under cap and trade systems.[101] Carbon credits are "equal to one metric tonne of carbon dioxide."[102] In creating a market for carbon credits that is more accessible to the average investor, cap and trade systems gain legitimacy in the eyes of the masses and can potentially become a more seriously considered option by regulators.

B. Energy Markets

1. *Overview of the Electricity Sector*

The electricity sector in the United States is defined by three main "phases:" generation, transmission, and distribution. Generation encompasses any process that "creates" electricity, from coal fired power plants to renewables. "The three major categories of energy for electricity generation are fossil fuels (coal, natural gas, and petroleum), nuclear energy, and renewable energy sources," with the majority of electricity in the United States coming from steam turbines powered by "fossil fuels, nuclear, biomass, geothermal, and solar thermal energy."[103] The next phase, transmission, is potentially the most limiting factor for the electric grid due in large part to the nature of electricity. Unlike capturing a stream of water in a bucket, the electrons that power everything from light bulbs to cars cannot be contained efficiently. This means that electricity must be transmitted from a production point to the place where it is to be used, resulting in massive, interstate wires interlinking electricity generators with their final destinations. More will be said about the transmission "grid" of the United States later, but for now it is sufficient to understand that the gigantic wires near your local power plant play an integral part in America's electricity industry. Finally, electricity must be distributed to

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96 Myers & Shackelford, *supra* note 16, at 342–43.

97 Mearian, *supra* note 94.

98 Grant Avalon, *BitTrade: Fair and Inexpensive Cap and Trade with the Blockchain (w/Dividends)*, Climate CoLab (June 5, 2015), https://www.climatecolab.org/contests/2015/us-carbon-price/phase/1306799/proposal/ 1319401.

99 Mearian, *supra* note 94.

100 *Id.*; *see generally* Stellar, https://www.stellar.org/how-it-works/stellar-basics/ (last accessed Apr. 1, 2020).

101 Mearian, *supra* note 94.

102 *Id.*

103 *Electricity in the United States*, U.S. Energy Info. Admin. (Mar. 20, 2020), https://www.eia.gov/energyexplained/index.php?page=electricity_in_the_united_states.

consumers. The electricity that comes from power plants "is transmitted at very high voltages and low currents to reduce the heat, eddy currents, and other transmission losses."[104] High voltages would fry home appliances though, necessitating transformer stations tasked with converting the electricity to a lower voltage for consumers to utilize it. From there, electricity flows to homes through a set of wires, sometimes from a phone pole and other times subterranean, where it can be used to power everything from a dryer to a television.

As the previous paragraph illustrates, electricity is unlike most other commodities in that there are inherent physical limitations on how a given individual can procure it. It is a direct byproduct of the nature of electricity that a person cannot go to a local "power store" and decide between several competing brands for where their power comes from as the requisite infrastructure for power transmission bars a given house or apartment building from having multiple power lines running to it from multiple producers. Power production in the United States enjoys a state granted monopoly similar to other common carriers, however federalism has had interesting consequences on how states and the federal government are able to regulate power production. Nationally, the Federal Energy Regulatory Commission (FERC) maintains jurisdiction over interstate power generation and wholesale power distribution.[105] States have authority over the regulation of public utilities and how prices are set. As a point of comparison, in the European Union "[e]nergy networks. . .have historically been constructed and operated on a national basis by vertically integrated monopolies, usually in full or partial state ownership, with the state's interest exercised either by central or regional governments."[106] The sheer geographic size of the United States has resulted in its differences from European regulation. Both systems, however, utilize centralization of power production and distribution. Centralization of a country's energy markets results from the nature of electricity in much the same way that the physical properties of electrons limit consumers' ability to choose from multiple power providers. But recent technological developments have resulted in a push for a more "decentralized" power production networks.[107]

Decentralization in power production and regulation, also known as "distributed generation," "refers to a variety of technologies that generate electricity at or near where it will be used, such as solar panels and combined heat and power."[108] As opposed to traditional power generation, which relies on a single producer supplying power to many consumers, distributed generation can "serve a single structure, such as a home or busi-

104 Sunita Sanguri, *How Does an Electrical Substation Work?*, BRIGHT HUB ENG'G, https://www.brighthubengineering.com/power-generation-distribution/71084-how-a-substation-works/ (last accessed Apr. 1, 2020).

105 Lawrence R. Greenfield, *An Overview of the Federal Energy Regulatory Commission and Federal Regulation of Public Utilities*, FED. ENERGY REG. COMM'N, (June 2018), https://www.ferc.gov/about/ferc-does/ferc101.pdf.

106 *European Union Energy Regulation*, ORG. FOR ECON. CO-OPERATION AND DEV., http://www.oecd.org/gov/ regulatory-policy/euenergyregulation.htm (last accessed Apr. 1, 2020).

107 *See* Eco Matser, *Why We Need Decentralized Renewable Energy to Power the World*, INTER PRESS SERV., (Aug. 7, 2018), http://www.ipsnews.net/2018/08/why-we-need-decentralized-renewable-energy-to-power-the-world/.

108 *Distributed Generation of Electricity and its Environmental Impacts*, ENVTL. PROT. AGENCY (Feb. 13, 2020), https://www.epa.gov/energy/distributed-generation-electricity-and-its-environmental-impacts.

ness, or it may be part of a microgrid (a smaller grid that is also tied into the larger electricity delivery system), such as at a major industrial facility, a military base, or a large college campus."[109] Distributed power has clean energy benefits as well insofar as when distributed producers are "connected to the electric utility's lower voltage distribution lines, distributed generation can help support delivery of clean, reliable power to additional customers and reduce electricity losses along transmission and distribution lines."[110] This part will discuss how energy markets can apply blockchain to maximize efficiency as well as promote clean energy.

2. Blockchain and Domestic Energy Markets

Distributed power generation is an area of energy markets that blockchain could dramatically impact. Solar energy generation, both residentially and by companies, is one of the fastest growing areas of energy production in the United States.[111] At present in the United States "[m]ore than 58 [gigawatts (GW)] of total solar capacity [is] now installed," which translates to "enough electricity to power 11 million homes."[112] Each new solar installation brings with it a new energy "generator" per the overview of the electricity sector previously discussed. A potential benefit of such production is that energy produced in excess of the needs of the individual producer can be fed back into the grid.[113] In some cases, under principles such as "net metering," the system can compensate individual producers for that excess production.[114] "Net metering is a billing mechanism that credits solar energy system owners for the electricity they add to the grid."[115] A potential shortcoming of net metering is that it relies on compensation from a utility company which inherently "undercuts the utility's core business of generating and selling electricity."[116] In fact, "[i]n parts of the country . . . utilities have gone to great lengths to curtail this practice."[117]

Blockchain has the potential to help "democratize" energy markets by cutting out the middleman, or utility company, altogether. Under traditional net metering or an analogous system, there is no way for someone who produces electricity at their home to

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109 *Id.*

110 *Id.*

111 *Solar Industry Research Data*, Solar Energy Indus. Ass'n (Feb. 13, 2020), https://www.seia.org/solar-industry-research-data.

112 *Id.*

113 *What is Solar Energy and How Do Solar Panels Work?*, Sunpower (Feb. 13, 2020), https://us.sunpower.com/what-solar-energy-and-how-do-solar-panels-work.

114 *Net Metering*, Solar Energy Indus. Ass'n (Feb. 13, 2020), https://www.seia.org/initiatives/net-metering.

115 *Id.*

116 Jeremy Deaton, *These Companies Claim Blockchain Could Help Fight Climate Change*, Popular Sci. (Jan. 17, 2018), https://www.popsci.com/blockchain-climate-change.

117 *Id.* (citing Jeremey Deaton, *The Things Some Utilities Will Do*, Nexus Media (July 31, 2017), https://nexusmedianews.com/the-things-some-utilities-will-do-22e27a9eea77 ("Over the last several years, the Arizona Public Service Company (APS), the largest power provider in the state, has tried thwarting rooftop solar by getting utility-friendly candidates elected to the Arizona Corporation Commission, which regulates the state's utilities.")).

sell that power directly to other consumers.[118] Blockchain technology may provide an avenue for immediate transactions to take place between energy producers and consumers. This may be accomplished because "[b]lockchain, which functions as a public ledger or record, can take inputs like amount of energy produced from smart devices like solar panels, record them, assign a price and then send it out to smart homes on the grid while recording incoming payments for energy purchased."[119] Blockchain based energy markets could result in a situation where A, who produces enough energy to meet its own needs as well as excess electricity, can directly sell that excess to B, A's neighbor who does not produce its own electricity. Such a system would incorporate both companies and individual producers. This sort of system is what is known as a "microgrid," because it does not rely "exclusively upon a power plant that produces electricity for a region," but rather "allows residents in the area to better manage local usage and even generate and sell power through solar panels or other alternative energy methods."[120]

Local blockchain-based microgrid energy markets are already being used in various capacities around the world. LO3 Energy has already instituted a trial project in Brooklyn, New York utilizing the existing grid, smart meters and blockchain technology.[121] In the 'Brooklyn Microgrid,' "[w]hile the utility provider still maintains the electrical grid that delivers power, the actual energy is generated, stored, and traded locally by members of the community, for a more resilient and sustainable clean energy model."[122] These transactions utilize blockchain by storing and validating "data that permits direct transactions between energy producers and consumers."[123] This allows for scenarios where "when one user produces excess energy, it is automatically sold to another user in the neighborhood, which allows the neighborhood to lessen the amount of energy it draws from the central grid."[124] Further afield, in December of 2017 it was reported that "Korea Electric Power Corporation (KEPCO) will test" a blockchain-based service where consumers can sell electricity to their neighbors in Seoul.[125] Whether larger scale projects will be instituted remains to be seen, but success on a small scale in two of the most densely populated cities in the world[126] may yield greater utilization of blockchain for energy markets both domestically and abroad.

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118 Ben Hertz-Shargel & David Livingston, *Assessing Blockchain's Future in Transactive Energy*, ATLANTIC COUNCIL (Feb. 13, 2020), https://www.atlanticcouncil.org/in-depth-research-reports/report/assessing-blockchains-future-in-transactive-energy/.

119 Nikolaj Martyniuk, *Blockchain Establishes Decentralized Energy Market*, MEDIUM (Mar. 11, 2018) https://medium.com/wepower/blockchain-establishes-decentralized-energy-market-ae413952f6da.

120 Alan Cohn et al., *Smart After All: Blockchain, Smart Contracts, Parametric Insurance, and Smart Energy Grids*, 1 GEO. L. TECH. REV. 273, 301-02 (2017).

121 LO3 ENERGY, https://lo3energy.com/ (last visited May 22, 2020).

122 *Id.*

123 Townsend, *supra* note 80.

124 Cohn et al., *supra* note 120, at 302.

125 Cho Mu-Hyun, *South Korea to Trial Blockchain Electricity market for Consumers*, ZDNET (Dec. 5, 2017), https://www.zdnet.com/article/south-korea-to-trial-blockchain-electricity-market-for-consumers/.

126 *See* Joseph Gedeon, *30 Most Crowded Cities in the World*, MSN (July 24, 2017), https://www.msn.com/en-us/money/realestate/30-most-crowded-cities-in-the-world/ar-AAoMnhe (New York at #29; Seoul at #15 for population density).

3. Blockchain and Smart Devices

Another way in which blockchain may revolutionize the domestic energy industry is by better connecting smart devices to the grid. Smart meters, which are simply conventional electric meters that can send information to a utility about a users' rates of consumption,[127] are one such smart device. When a retail energy provider supplies energy to a consumer through the grid, it monitors "a customer's power consumption through a meter installed at the customer's home."[128] Billing then occurs on a monthly basis.[129] In contrast, smart meters allow a utility company to "provide a more accurate and up-to-date bill while also freeing the company from needing to send inspectors out every month to read the meters."[130] The positive here for consumers is that in theory, the rate for electricity at which they are charged will be based on when they used the electricity. Electricity rates are market based, in that when there is high demand and it is more expensive to produce the electricity, it is more expensive for consumers. In allowing consumers to see in real-time the price of electricity, non-essential power uses may be curtailed in an effort to save money.[131] A setback for smart meter technology has been the risk that hackers pose.[132] As one commenter has noted, "if smart meters are not properly secured, hackers could have large-scale access to sensitive consumer data."[133] The German Energy Agency, DENA, has commented that smart meters "can serve as an enabler of autonomy (freedom of choice), source of additional income and a means to contribute to sustainable use of resources, but they can also be exploited as a means of control, surveillance and illegal intrusion into the privacy of one's home."[134]

According to Andrew Arnold, there are two main security issues with a smart grid: "Authentication – The verification that someone 'entering' the grid technology is who they say they are; [and] Authorization – The verification that someone who does enter has the authority to do what they plan to do."[135] Blockchain provides protection from potential attacks to the smart grid due to its decentralized nature. As Christoph Jentzsch notes:

> [Through blockchain, single] points of failure can be avoided. When [information hubs, or nodes] are distributed, an attacker would have to hack each single device to obtain each single key. In addition, [the devices] talk to each other

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127 Hayden McGovern, *What is a Smart Meter?*, SmartEnergy (Dec. 16, 2016), https://www.smartenergy.com/what-is-a-smart-meter/.

128 Cohn et al., *supra* note 120, at 298.

129 *Id.*

130 *Id.*

131 Will Gans et al., *Smart Meter Devices and the Effect of Feedback on Residential Electricity Consumption: Evidence from a Natural Experiment in Northern Ireland*, 36 Energy Econ. 729, 729 (2013).

132 Andrew Arnold, *How Blockchain Can Help Increase The Security Of Smart Grids*, Forbes (Apr. 16, 2018), https://www.forbes.com/sites/andrewarnold/2018/04/16/how-blockchain-can-help-increase-the-security-of-smart-grids/#56565e20b489.

133 Isabelle Reiff, *Smart meters become more secure with the blockchain*, CEBIT (Mar. 9, 2018), https://www.cebit.de/en/news-trends/news/article_19520-854273.

134 Christoph Burger et al., Vulnerabilities in Smart Meter Infrastructure – can Blockchain Provide a Solution? 13 (Philipp Richard ed., DENA 2018).

135 Arnold, *supra* note 132.

over this decentralized blockchain, which does not have a single point of failure, too, for shutting it down. That is why there is such a good fit between blockchain and smart meters.[136]

A test case in 2016 showed that if a single wind turbine in a system was hacked, control of the entire system could be taken by an attacker.[137] Blockchain could prevent this from happening due to "identification security through public-private encryption" that underlies the technology.[138]

4. *Blockchain and International Energy Markets*

Just as the electricity sector in the United States pays no mind to state borders, countries around the world trade electricity on a daily basis. A 2010 estimate put "the energy share of the global economy [at about] 8.2 percent."[139] Considering that the Energy Information Administration (EIA) projects a "28% increase in world energy use by 2040,"[140] it is no surprise that novel approaches to energy distribution and markets are a hot button issue. Just as commentators have proposed blockchain as a solution for domestic energy market decentralization, international pundits see great potential for the technology as well. The hallmarks of blockchain, streamlined transactions and removal of third-party intermediaries, coupled with the increased security and transparency of the technology, lend themselves to making the lifeblood of the global economy function better.

As anyone who has ever had to fill up a gas tank during some far-flung international crisis can attest to, the international energy trade is frustratingly dependent on factors outside the control of the market. Further, the global energy industry is one that is consistently marred by corruption and deceit.[141] This does not have to be the case, though, and blockchain offers a potential avenue to side-step many of the issues that plague the energy industry. As previously mentioned, transparency is effectively "built-in" to the blockchain architecture via its distributed nature.[142] Removing the possibility of human "error" and other abuses of accounting systems creates the possibility that every drop of oil or electron generated in a hydroelectric facility is tracked from creation to final use. Two Canadian companies, Blox Labs Inc. and Sonoro Energy Ltd., have already implemented this concept. The companies have "commenced development of

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136 BURGER ET AL., *supra* note 134, at 20.

137 *Id.* at 16.

138 *Id.*

139 *A Primer on Energy and the Economy: Energy's Share of the Economy Requires Caution in Determining Policies That Affect It*, INST. FOR ENERGY RESEARCH (Feb. 16, 2010), https://www.instituteforenergyresearch.org/uncategorized/a-primer-on-energy-and-the-economy-energys-large-share-of-the-economy-requires-caution-in-determining-policies-that-affect-it/.

140 *EIA Projects 28% Increase in World Energy Use by 2040*, U.S. ENERGY INFO. ADMIN. (Sept. 14, 2017), https://www.eia.gov/todayinenergy/detail.php?id=32912.

141 Rachel Owens, *Corruption in the Energy Sector is a Transnational Problem, Enforcement Must be Too*, GLOBAL WITNESS (Dec. 20, 2016), https://www.globalwitness.org/en/blog/corruption-energy-sector-transnational-problem-enforcement-efforts-must-be-too/.

142 Avalon, *supra* note 98.

PetroBLOX, a blockchain-based smart contract supply chain management platform for the global oil and gas industry."[143]

Blockchain as applied to the global energy industry does have skeptics though. One such criticism is that "the need to update a transaction on every single blockchain node creates significant inefficiencies."[144] Further, "proof of work," the concept underlying the veracity of blockchain, magnifies these inefficiencies because as the value of the blockchain transaction increases, the system requires increasingly challenging amounts of effort.[145] This may, in theory, be a byproduct of the lack of computational power presently devoted to blockchain. However, it could be a sign of a significant issue blockchain technology will face if it is to be scaled up to meet the demands of the global economy. As compared to Bitcoin's current maximum transaction speed of seven transactions per second, "Visa's blockchain-free payment platform is capable of handling up to 24,000 transactions per second."[146] Another oft-cited issue with blockchain is the energy *consumption* required to mine Bitcoins, which "is currently estimated to top 73 terawatt-hours a year, [which is] more than [the country of] Austria uses in a year."[147] Whether blockchain technology will be able to be scaled to accommodate the requisite deluge of transactions any application in international commerce would require brings to mind Thomas Henry Huxley's quote, "[t]he great tragedy of science [is] the slaying of a beautiful hypothesis by an ugly fact."[148]

Despite the potential technical issues facing blockchain, there are plenty of supporters for its use as a platform for energy markets. To address the truly astronomical energy demands of blockchain, Ethereum, a public blockchain network, "is readying for a shift away from proof-of-work to an alternative low-energy consensus mechanism called proof-of-stake."[149] Regarding the scalability issues of blockchain, one proposal is to change the time period over which transactions are verified. As opposed to a second-by-second basis, "there is no reason why a day's worth of energy transactions could not be registered at one time, on a single blockchain block."[150] Further, future iterations of blockchain technology may be able to sustain significantly more throughput than ex-

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143 *Blockchain Market in the Global Energy Sector - Forecast to 2023: CAGR to Grow at 50% - Smart Contracts to Witness the Fastest Growth - ResearchAndMarkets.com*, BUSINESS WIRE (Aug. 17, 2018), https://www.businesswire.com/news/home/20180817005254/en/Blockchain-Market-Global-Energy-Sector—-Forecast.

144 Jason Deign, *Why Blockchain May Not Be the Best Tool for Energy Trading*, GREENTECH MEDIA (July 2, 2018), https://www.greentechmedia.com/articles/read/blockchain-might-not-be-best-for-energy-trading#gs.2XDCYFA.

145 *Id.*

146 *Id.*

147 Jason Deign, *Energy-Blockchain Advocates Hit Back at Criticisms of the Technology*, GREENTECH MEDIA (Aug. 7, 2018), https://www.greentechmedia.com/articles/read/energy-blockchain-advocates-hit-back#gs.0H0BXIs.

148 Tania Lambrozo, *Must Science Murder its Darlings?*, NAT'L PUB. RADIO (Jan. 27, 2014), https://www.npr.org/sections/13.7/2014/01/26/266784786/must-science-murder-its-darlings.

149 Deign, *supra* note 148.

150 *Id.*

isting blockchain networks.[151] Current blockchain networks were not designed to handle the transactional load of a system to accommodate real-time trading of energy.[152] There is nothing to say that future blockchain systems designed for the express purpose of commercial energy trading will not be able to surmount current scalability issues.

IV. INTERNATIONAL CLIMATE CHANGE AGREEMENTS AND BLOCKCHAIN

The third area of potential applicability for blockchain to impact climate change is to generate more robust international climate change agreements. A major pitfall of past climate change agreements has been ensuring compliance.[153] This challenge arises in part because climate change agreements, like all international agreements, are voluntary.[154] While such climate conferences as the Paris Climate Accords in 2015 have produced robust approaches to combat climate change and reduce global greenhouse gas emissions, inherent issues with the enforcing such agreements persists. The most influential climate agreement to date, the 1997 Kyoto Protocol,[155] has seen mixed results in terms of adherence. Sweden, which allowed a 4% increase in emissions, achieved a reduction of 13%.[156] Canada, on the other hand, aimed for a 6% reduction, but actually increased emissions by 27% which precipitated Canada's withdrawal from the Kyoto protocol in 2011 to avoid "a legal violation of its commitments."[157] It is highly problematic that a country would be able to simply "withdraw" from an agreement on the predicate that they had failed to meet its obligations. Withdrawal sans repercussions represents an entirely unacceptable possible outcome to an agreement tailored to protecting the planet; in United States contract law, Canada's action would be considered a breach and is an actionable offense. Using blockchain to memorialize international climate change agreements may result in better adherence and easier enforcement.

Blockchain as applied to international climate change agreements could hypothetically work by combining many of the previously discussed technological advances. At its inception, a blockchain-based international agreement on climate change would operate

151 *Id.* ("EWF, for example, is designing its platform to handle 30 times as much throughput as public Ethereum. Another technology, Iota, is supposed to be infinitely scalable, so transaction costs disappear.").

152 Hertz-Shargel & Livingston, *supra* note 118, at 2.

153 *See* Anders Corr, *Expect Climate Catastrophe: Paris Agreement Lacks Enforcement*, FORBES, (Dec. 1, 2016, 10:34 pm), https://www.forbes.com/sites/anderscorr/2016/12/01/expect-climate-catastrophe-paris-agreement-lacks-enforcement/#945108433130.

154 *See* Michael Greenstone, *Surprisingly, a Voluntary Climate Treaty Could Actually Work*, N.Y. TIMES: THE UPSHOT (Feb. 13, 2015), https://www.nytimes.com/2015/02/15/upshot/surprisingly-a-voluntary-climate-treaty-could-actually-work.html.

155 *Kyoto Protocol Fast Facts*, CNN (Mar. 21, 2018), https://www.cnn.com/2013/07/26/world/kyoto-protocol-fast-facts/index.html.

156 Paul G. Harris and Taedong Lee, *Compliance with Climate Change Agreements: the Constraints of Consumption*, 17 INT'L ENVTL. AGREEMENTS 779, 780 (2017) (citing UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE, KYOTO PROTOCOL REFERENCE MANUAL ON ACCOUNTING OF EMISSIONS AND ASSIGNED AMOUNTS (2008), http://unfccc.int/resource/docs/publications/08_unfccc_kp_ref_manual.pdf).

157 *Id.*

no differently than any other international climate change agreement. Parties would have to come together to determine acceptable limits placed on carbon emissions and then each party would have to determine their own commitment. The first real "blockchain"-based aspect of this agreement would be memorializing the parties' commitments on the blockchain. This would theoretically be no different than a traditional international agreement as it would serve the purpose of providing a secure record to rely back on when assessing various parties' performance under the agreement. Next, the system would need to institute some form of carbon monitoring to ensure parties are keeping with their promises. A discussion on international monitoring of carbon emissions follows. Whatever monitoring mechanism is used, it would also have to feed back into the blockchain to verify parties' performance in real time. A blockchain-based climate change agreement would assess performance on a pre-determined time scale, such as annually, every five years, or every decade, just as existing climate change agreements do. The novel approach of putting the agreement on the blockchain would result in the potential for "smart contracts" to self-execute when performance is met or not met. A discussion on how these smart contracts may work and the types of collateral to be used follows.

Real-time monitoring of signatory countries' greenhouse gas emissions would form the backbone for any agreement. While it is not feasible to require every carbon emitting source in a country to be monitored due to the cost and the sheer magnitude of such a program, there are other more cost-effective methods for measuring carbon output.[158] One such approach would be to put carbon sensors on commercial aircraft that could then monitor the carbon emissions over the area that the plane travels.[159] As noted in a Scientific American article, "[c]ommercial aircraft provide scientists a unique high-altitude platform for monitoring real-life atmospheric conditions."[160] At present though, such an idea has not "taken off" in the United States.[161] Another option would be to utilize satellites to monitor carbon emissions. This option also presents issues though, based on cost and the fact that computer models "'have all kinds of biases' that make it difficult to reach the precision needed to accurately measure man-made emissions."[162] However, choosing the definitive technological source for measuring carbon output is beyond the scope of this note. More relevant to a discussion of blockchain is the fact that whatever monitoring system is put in place needs to be able to send information directly to the blockchain for verification.

Blockchain, under Bitcoin, was developed to facilitate transactions in a system affected by trust issues and there is no greater system marred by trust issues than international relations. As noted by one scholar, "[t]rust is the belief that another has assurance game rather than prisoner's dilemma game preferences—that he or she prefers mutual

158 D. Bastviken, et al., *Technical Note: Cost-EfficientApproaches to Measure Carbon Dioxide (CO2) Fluxes and Concentrations in Terrestrial and Aquatic Environments Using Mini Loggers*, 12 BIOGEOSCIENCES 3849 (2015).

159 John Fialka, *Inside the Quest to Monitor Countries' CO2 Emissions*, SCI. AM. (Feb. 28, 2017), https://www.scientificamerican.com/article/inside-the-quest-to-monitor-countries-co2-emissions/.

160 *Id.*

161 *Id.*

162 *Id.*

cooperation to exploiting and suckering others."[163] The constant second guessing of whether an adversary or ally will adhere to or disregard an international agreement likely results in promises made with apprehension because, "[t]rust is fragile, and once lost it is hard to rebuild."[164] The inherent lack of trust that overshadows most, if not all, international agreements provides a prime area for blockchain to make a difference. Removing enforcement responsibilities from the purview of an international body and placing them with self-executing code under a smart contract automatically reduces the ability of a party to renege on a promise made using blockchain. As previously outlined, smart contracts operate by self-executing once a specified condition occurs. This approach has wide ranging benefits as applied to international agreements because it removes the requirement that a centralized body waste resources prosecuting an entity that may not end up fulfilling their promise for several reasons. Bernhard Reinsberg has noted that blockchain, as applied to international agreements, can be thought of as a sort of "institution."[165]

> [B]lockchain technology can enhance the credibility of state commitments by allowing for guaranteed execution of inter-state contracts. In addition, it offers a secure way of making side payments as part of agreements, hence allaying distribution problems. Finally, blockchain technology can also address information problems by leveraging distributed consensus to generate reliable information.[166]

Returning to the application of blockchain to international climate change agreements, the collateral for ensuring a party cooperates with its promises may be as simple as a monetary amount. However, as smart contracts become more sophisticated, and depending on a given country's willingness to cede control of certain processes, it does not seem farfetched to hypothesize that certain elements of a country's electric production infrastructure could be tied to a smart contract as well. Consider a scenario where in lieu of a fine, to be imposed via smart contract, a country agrees to allow a certain number of its power plants to be shut down or severely limited in capacity due to their non-compliance with an agreement. This is sure to be seen as a drastic and highly unlikely scenario to unfold but "drastic times call for drastic measures."

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163 Brian Christopher Rathbun, *Trust in International Relations*, THE OXFORD HANDBOOK OF SOCIAL AND POLITICAL TRUST (Aug. 2017), http://www.oxfordhandbooks.com/view/10.1093/oxfordhb/9780190274801.001.0001/oxfordhb-9780190274801-e-31 (citing Andrew H. Kydd, TRUST AND MISTRUST IN INTERNATIONAL RELATIONS (2005)).

164 Stan Wisseman, *Broken Promises: How Trust Affects Cybersecurity*, TECHBEACON (2016), https://techbeacon.com/broken-promises-how-trust-affects-cybersecurity.

165 Bernhard Reinsberg, *Blockchain Technology and International Relations: Decentralized Solutions to Foster Cooperation in an Anarchic World?*, CTR. FOR BUS. RESEARCH, UNIV. OF CAMBRIDGE, WORKING PAPER NO. 508 (Sept. 2018).

166 *Id.*

V. Conclusion

Blockchain technology, which reached international attention through Bitcoin, has received the aplomb of many.[167] Clear cut applications in many industries, from finance to real estate, have caused many to wonder whether blockchain will supplant the need for bankers, brokers, and in some cases, lawyers.[168] Less conventional applications of blockchain could include changing how voting works and even smart property.[169] Considering that it has only been a decade since Satoshi Nakamoto first published his white paper on Bitcoin,[170] the true potential of blockchain technology is yet to be seen. One thing is for certain though, blockchain provides a unique framework to operate various systems and for this reason, this note has largely concerned itself with applying blockchain to addressing climate change. While the technology itself has no real positive or negative impact on the climate,[171] through applications as a backbone for cap and trade systems, decentralizing energy markets, and providing a stronger framework for international climate change agreements, blockchain can positively impact global efforts to stop climate change. Relying on the "ledger" function of blockchain, cap and trade systems may be revolutionized to better account for carbon transactions and also make these systems more efficient. As applied to energy markets, blockchain has the potential to help "decentralize" the grid into a system where local energy production can be used to directly meet local energy needs, such as the microgrid currently in use in Brookly, New York. Smart devices that tie into the grid may also be positively impacted by blockchain due to greater data security resulting from the distributed nature of the technology. Finally, blockchain may prove to be a boon for international climate change agreements through smart contracts. No longer will any international action need to be taken to enforce an agreement as the self-executing nature of a smart contract removes any doubt as to whether performance has been fulfilled. It is not the opinion of this note that blockchain is a panacea to be applied to all conceivable aspects of daily life, rather, blockchain is seen the same as any other tool developed to confront a specific problem. Just as one would not use a hammer to paint a picture, blockchain cannot be used to cure the common cold. However, the energy industry is one of many that blockchain will likely impact, so the industry should encourage, rather than stymie, its utilization.

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167 *The promise of the blockchain technology*, The Economist (Sept. 1, 2018), https://www.economist.com/technology-quarterly/2018/09/01/the-promise-of-the-blockchain-technology.

168 John White, *9 Industries That Will Soon Be Disrupted By Blockchain*, Inc. (2018), https://www.inc.com/john-white/9-industries-that-will-soon-be-disrupted-by-blockchain.html.

169 George Foroglou & Anna-Lali Tsilidou, *Further Applications of the Blockchain*, Conference Paper (May 2015).

170 Nakamoto, *supra* note 6.

171 This may not be entirely true, due to the astronomical energy demands of Bitcoin mining; however, new and improved iterations of the technology may result in more energy efficiency.