The Energy Fog

How electric vehicles, blockchain, and fog computing will re-power the planet.

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The energy business needs a new paradigm

We need a much better way to 'do energy', don't we? Fossil fuels are dirty. Climate change is real. Nuclear power is dangerous. We need to waste less. We need to work out how to make renewable energy work. Properly work. And by the way, we will all be consuming more power, not less, in the coming decades - global demand for electricity is forecast to nearly double by 2050[1].

Meanwhile solar and wind power are both generated on a feast or famine basis. It's sunny/windy... or it's not. This lumpy, unpredictable supply doesn't match the 'always on' nature of demand.

Industry and governments have expended huge efforts trying to figure out ways to shoehorn renewable energy into the existing power grid. These workarounds are not the answer. The answer is a completely new, alternative infrastructure – so alternative that this infrastructure won't actually be a 'grid' at all. It will not replace the current grid – it will emerge alongside it. We will build it by smashing together two old industries; energy and automotive - and two new technologies; blockchain and fog computing. The unexpected collision of technologies and concepts that already exist, reframed and repurposed, creates something truly revolutionary.

One day, everybody will be a power utility

We can all, if we choose, already generate our own electricity. We are used to power being generated a long way away, in bulk, and transported hundreds of miles along vast networks of power lines. But that is about to change, because energy is coming home. Literally.

Nowadays almost any component of a domestic residence can be repurposed to generate energy. Your floors can generate electricity when you walk on them[2]. Your windows can generate electricity from light[3]. Your roof tiles may look like roof tiles, but are actually solar panels[4]. Out in the garden, submerged beneath that babbling brook could be a small hydro generator[5]. And when you pop

outside to check how it's doing, you can even be generating electricity from dynamos inside your shoes[6].

So we are technologically already at the point where anyone can not merely consume, but also generate power. And the technology only continues to get cheaper. We would naturally expect renewable technologies to reduce in price through the economic effects of the law of supply and demand. It is therefore no surprise that the Lawrence Berkeley National Laboratory has measured a steady downward trend in the installed price of residential PV systems since 1998[7].

Another factor in the downward cost of renewable technology is investment by governments, which continues to pour into renewable energy development around the globe. The Chinese energy agency has announced plans to invest $360 billion in renewable power by 2020, creating 13 million jobs in the sector[8]. In India, Australia and Germany, national governments are making great strides in lessening their dependence on finite resources in favour of renewables. On April 30th this year, no less than 85% of Germany's energy requirements were met by renewable sources[9] (thus breaking its own record).

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Technological factors are also in play, tipping the economic balance in favour of renewables. In January this year, Intel CEO Brian Krzanich stated that Moore's law was still, "alive and well and flourishing", while on the software side of the fence the use of code libraries continues to reduce the time for development cycles.

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Historically there's been something of a "use it or lose it" flavour to local renewable energy, but newer and better storage options are increasingly available. Systems like the Tesla Powerwall[10] show how 'smart' homes can store and process energy locally, rather than acting as 'dumb terminals' at the edge of a centralised grid. Storage costs are coming down, with battery pack storage now at around $230 per kilowatt-hour[11] (from almost $1000 in 2010). But while great strides are being made in domestic energy storage, there are still significant barriers to the transmission of energy between homes.

We are not yet at the point where anyone can be a power supplier. But it's not far off.

Energy infrastructure will look like a P2P computer network, not like the grid

You can share many things with your neighbour, if you're so inclined, but energy is not one of them. As far as energy is concerned, the house next door… may as well not be. Proximity to your neighbours doesn't matter much. This is because the grid system of power supply is a hub and spoke structure. We believe there is no alternative but to move away from a hub & spoke format, to a fully connected network topology.

Our predictions suggest that the energy grid is set to evolve in a way which closely mirrors the evolution of computing.

Back in the early Jurassic era of computing, when mainframes roamed the earth, small amounts of processing power required a container the size of an entire room, complete with its own air-conditioning. The computing was done centrally, and the consumers of computing received it via dumb terminals at the end of wires strung out from the centre. This is typically how energy is delivered in most developed countries.

Computing evolved over the decades to the point where clients, servers and local area networks had appeared. And then came the internet. A wide area network which made possible peer to peer communication.

What we are now seeing is the emergence of a fully networked P2P database, all governed by consensus. This is blockchain, a crucial enabling technology for a P2P energy infrastructure, and one we will return to shortly.

This is the future for energy. When we stop using the mainframe-like hub and spoke system to manage our energy, and instead move to a P2P network, people will no longer be mere consumers. They will be empowered to become energy generators and traders, within an internet of energy; prosumers not consumers.

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The grid doesn't work for renewables

As we noted in the opening section, the supply of solar and wind energy is lumpy. No sun, no wind... no power. Feast or famine. Unfortunately, energy users won't stop what they're doing to wait for the sun to come out. Traditional grids are geared up to generate and supply energy on demand, from fuel stored and moved within a vast infrastructure until it's burnt. Around 8% of all this energy simply gets lost in transmission[12], and the sheer size of the traditional grids increases their inefficiency. Traditional grids are pretty good at supplying energy on demand, at a price. Much better though, to have the creation and consumption of energy happen in close proximity.

When supply and demand are heavily out of synch, we have a problem. The greater the contribution of solar and wind energy, the greater that problem becomes. With the old grid we can't smooth out the supply and demand well enough.

"The alternative 'grid' must enable everyone to generate power, use power, store power, and trade power."

In April this year, California generated 67.2% of its energy from renewable sources. That sounds like great news, but there is another statistic that suggests otherwise. The California Independent System operator (CAISO) has flagged the increase in ''curtailment", essentially wasted energy. In February it reported[13] that, "Currently, the forecast is that we could have the need to curtail from 6,000 MW to 8,000 MW", thanks to new solar installations and favourable hydro conditions. There is simply more renewable energy available to be fed back onto the grid than they can cope with.

As more people start to generate power from solar, or other renewable sources, where will it go? Will we have to just use it or lose it? We need a new paradigm. The alternative 'grid' must enable everyone to generate power, use power, store power, and trade power. It would smooth out the lumpy supply that characterises many renewables. It would democratise energy.

To enable an alternative grid we need two things. First, a means to physically transport energy from one place to another. Second, a means to enable and record transactions. We now have the technology to deliver both of the above. But technology is all very well – the question is would people use it?

The rise of the trading/sharing/renting mindset

We believe society has been acquiring new mores that fit well with the new paradigm. Macro social trends are already at play, laying the groundwork for a decentralised peer to peer energy network.

The so-called Millennial generation (and there are around 80 million of them in the US alone) are social, collaborative, entitled, have high expectations of technology and indeed the values of the

organisations with which they interact. This group has driven the growth of apps; tools which are basically short cuts to personalised service. They value services that put them in control.

But this isn't just a Millennial play. All of our generations, from baby boomers to generation Z, have discovered a taste for the trading mentality. Platforms like eBay and Amazon have turned us all into occasional shopkeepers, even if our shop is of the transient 'pop-up' variety. We value services that enable us to trade with each other.

We have seen the rise of the 'on-demand' economy, driven by smartphone penetration and new services like Uber. Not only do we want a cab to arrive within minutes of ordering it, we also expect to view its journey towards us on a little handheld map, and pay a bargain price. We value services that deliver value - and the more disruptive the better.

We are now in a rental economy. We rent rooms out to each other through the new platform of Airbnb which enables us, collectively, to compete with the world's hotel industry. Many people don't own the car we drive. Unlike their parents who bought a car with a loan, these people have no intention of owning a car. We simply pay for the privilege of using the car through innovative finance arrangements. We value services that give us flexibility.

There has also been a rise in demand for green, clean solutions in general as a reaction to global warming and climate change. People no longer view concern for the environment as 'just for hippies'. People are starting to act collectively, and co-operate – something which has never been easier thanks to the internet – resulting in projects like the one in West Oxford[14] or indeed the remarkable self-sufficiency project on the island of Eigg[15].

The island of Eigg shows how it is possible to become self-sufficient in energy at a community level. But it also shows the limitations and difficulties of trying to do it while still tied to a grid model.

We would argue that the current grid model is increasingly unfit for purpose not only structurally, but also socially. There is a better way.

The electric vehicle swarm

We have already identified the need for a means to physically transport energy from one place to another, plus a means to enable and record value transactions, if we are to create an alternative grid.

Electric vehicles (EVs) solve the first requirement, by simple virtue of being big chunky batteries on wheels. There are now 2 million of them[16]. Consider them as individual nodes on an internet of energy; nodes that can be connected, yet physically move in relation to each other. Connected up, they're an energy swarm.

This swarm has the potential to achieve remarkable things. Nissan have worked out that if all 18,000 Nissan electric vehicles in the UK were connected to the energy network, they would generate the equivalent output of a 180 MW power plant[17]. Like a swarm of bees, individually each component is relatively insignificant, but get enough of them together and they pack a punch.

Nissan estimate that if that was scaled up in a future where all the vehicles on UK roads are electric, vehicle-to-grid technology could generate a virtual power plant of up to 370 GW. This energy capacity would be enough to power the UK, Germany and France. (In context, 115 times the output of the planned Hinkley Point C nuclear plant's 3.2GW.)

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EVs are a new means of transporting energy from one place to another, so that it can be exchanged. They are to energy, what a wallet is to money. You put money in, take money out, move it around. EVs are the means of exchanging energy. All we need now is the means to exchange value.

How Blockchain will track and transfer value within the swarm

Keeping track of large numbers of relatively low value transactions is a challenge. In the UK already, over 100,000 cars qualify for the Plug-in Car Grant[18] (excluding commercial vehicles). In the near future we are looking at hundreds of thousands of EVs, transferring energy back and forth between not only themselves but other nodes on the network (fuel stations, homes, offices, etc.)

Blockchain technology is the mechanism that will enable us to manage transactions in the alternative grid.

We can't assume that each vehicle will have one identifiable owner. When driverless EVs emerge, it may be that individual ownership of cars simply disappears. Cars could become 'public transport', used ad hoc and paid for accordingly. Or maybe every car will effectively become a taxi. All we do know is that increasing complexity will be the norm, and the old linkage between a car and its owner may be a redundant concept. In this kind of environment, we have an issue of identity as well as value. What is the price, who is the buyer, who is the seller, and how does the value exchange happen - and get verified?

"we have an issue of *identity* as well as *value*"

Bitcoin was the frontrunner in the development of the Blockchain; way back in 2008 Satoshi Nakamoto[19] took some existing technologies such as databases, encryption, peer to peer and digital signatures and collided (blended) them all together to see if they could be used to transact "cash" without the need for existing banking systems. The result was the creation of "The Blockchain" – a continuous record of transactions all governed by consensus computing. The system is not perfect. It's not very environmentally friendly for a start. The process of "Mining", which is used to maintain the integrity of the database, uses about the same electricity as a small country (to be specific, Slovenia[20]) per year, but it demonstrated that it is possible to use existing technologies in an innovative way to create a whole new "Internet of Value".

Since Bitcoin, a number of alternative "Blockchain" incarnations have emerged, the most prominent being Ethereum[21]. Ethereum moved the Bitcoin concept from just being about transacting cash to looking at all the "contracts" that are used in day to day life – from buying a house to getting married. Ethereum are also considering new ways to mine – moving away from the machine/energy intensive "Proof of Work" techniques currently employed to a vision of individual connected nodes on a network as small as IoT devices.

Add to this the ability to store more data in the "Blocks" on the chain and the number of projects and interested parties began to hockey-stick.

One of the key offerings from The Blockchain is the ability to create "Self Sovereign" or "Federated" identity models. For example, as a human being there are probably multiple versions of our "Identity" held by multiple organisations – your bank will hold information on you, as will your employer and the passport office, and google and Facebook – all of which will have a slightly different version of you held on their systems. This is both inefficient and prone to abuse.

The idea of a Self Sovereign Identity is one where the owner of the identity (in this case a human) holds all of their personal identity data on the Blockchain. This data is then shared with people and organisations who can attest or endorse the holder of the Identity as being who they are (such as the people who issue your passport); the more people and organisations attesting the identity of a person, the more sure you can be that they are who they say they are.

This principal can be applied to organisations and IoT devices as well as human beings – especially when it comes to EVs – essential for identifying the individual EV-nodes on the network.

There is another important concept in the world of Blockchain – the concept of "Smart Contracts". Smart Contracts is a glamorous way of saying "pre-defined actions" that can be coded and triggered when certain events happen, e.g. "when the price of energy increases, sell my excess energy to the highest bidder". In a decentralised energy world, Smart Contracts can be used to trigger events, for example;

- searching to find the best local energy rates (and buying on your behalf)
- setting levels where excess energy can be traded on the network, e.g. “when my energy storage reaches 60% start trading excess”
- governing the relationships between connected devices

Perhaps it would turn down the power on your air con and increase the power on your fridge, or optimise the energy use in your household. Or even identify areas in the locale who are not energy contributors and offer them incentives to get involved.

The Blockchain, or consensus computing, allows the customer to actually think global and act local and it provides the transparency required to allow the network to work even when there is no trust between parties. In that sense it is what the financial community refer to as ‘RegTech’ – tools to facilitate regulatory compliance. It provides the incentive to get involved due the fact there is now both a potential financial saving to be made, and also a financial reward.

It also allows us to identify everything from ourselves to the EVs that will be used to transport the energy we create – and how they interact in a peer to peer network.

Why smart cars need fog - the collision of enabling technologies

The appearance of the words ‘collision’, ‘cars’ and ‘fog’ in the same sentence is not something that would normally be a positive thing. But not in this case. The collision of cars, specifically electric vehicles, with new software and networking technologies will have a profound impact. While Blockchain can resolve the issues around identity and value exchange, we still need a platform that can enable that to happen in our alternative grid. This is the concept called fog computing[22].

Fog computing[23] is intended to “enable analytics and knowledge generation to happen at the source of the data”. Exactly what the new model grid and our EV swarm will need. An Energy Fog.

Computing that occurs away from centralised nodes, out towards the edges of networks, is essential to enable trading to happen between hundreds of thousands of EVs. The Fog concept shares some interesting common characteristics with blockchain, and it’s this observation that led us to figure out the relationship between energy, blockchain, the fog and EVs.

We believe that the stored value will reside within EVs, blockchain technology will control the value exchange, and the marketplace will transact its business in the fog around the edges of this network – with the user interface built around connected smartphones.

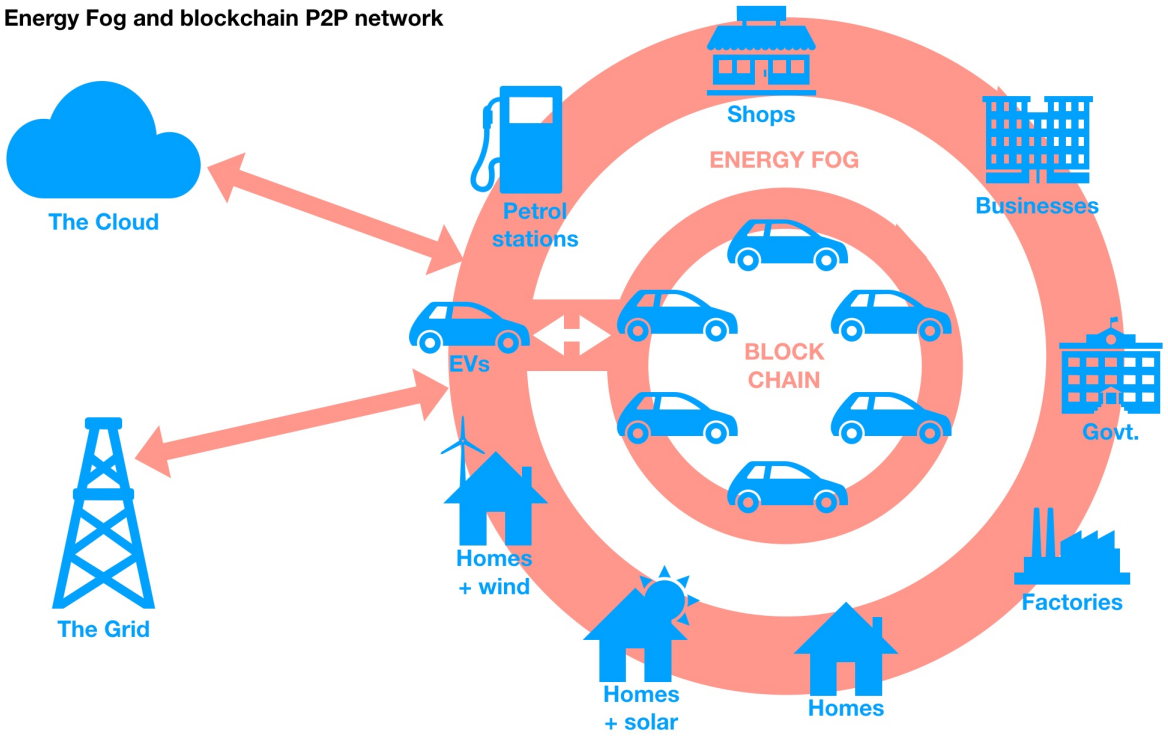
The EVs will be able to move energy around, with little or no human intervention (using smart contracts), able to drive themselves to a local hub station to upload or download energy. Using fog data from the EV swarm, they will even be able to optimise the timing and route of the journey to avoid congestion.

The energy fog changes everything

The new grid will exist side by side with the old, not separated but connected. The two grids will be complementary, as each will resolve the failings of the other.

The new model energy grid isn't really a ‘grid’ at all. Controlled by blockchain and enabled by the fog, this is a P2P network governed by consensus computing[24]. Like most wide area networks, it will comprise any number of local area networks and individual nodes.

In the early days small LANs will spring up as solutions to local problems; effectively local energy hubs facilitated by EVs. Local communities (like the one from West Oxford perhaps) using a ‘club’ type model, will be able to generate renewable energy when it’s sunny, but now they can save it for a rainy day. Only when they’ve collectively run out of renewable energy will they need to go to the



grid. Utility companies call this 'grid defection' and it is already happening in places like Australia and Hawaii – the sunny places with high electricity costs.

The energy fog will exist alongside the grid, but as a consequence demand on the grid will be reduced. Participants not only generate and share their own energy, but use the EV network to draw down more energy in off-peak periods to redeploy when demand is high. These local networks will of course not suffer the 8% transmission loss of the traditional grid.

Vehicle fleet operators will be early adopters. With ready-made clusters of EVs, they will be able to use fog data to optimise energy loading between vehicles and journeys, accessing energy at off peak rates. The base destination will no doubt host a wind turbine and/or solar PV panels to re-fuel the fleet on site.

Businesses will be able to create and host "club" style networks too, and will soon spot the potential. Supermarkets could make it possible for customers to trade energy onsite, and enable customers to trade the value as part of a loyalty programme. For example, while you are parked up at the store your EV could be uploading energy to the supermarket, and by the time you reach the checkout you could redeem your credit against your grocery bill. The value the store attaches to the energy could be flexed – they might offer higher credit at times of low footfall, to reduce congestion at peak shopping times. Or reward loyal customers with higher value. Meanwhile the energy gathered can be used to power the store, or be sold back to the grid.

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The petrol station of the future will perform many functions. It will be an energy trading hub, a leisure destination, a coffee shop, a restaurant… but probably not a place that sells much petrol. But they will capture a wealth of data, and for the first time know who their customers really are.

House builders will build connected community developments where the residents can create, consume or share energy, and keep track of it all. Each house will be both a power plant and storage facility, and each car on each driveway will be a node in the new grid. Each development would be capable of acting as its own energy 'bank' allowing deposits and withdrawals of renewable power at preferential rates. The smartphone in your pocket will be your window into your energy wallet.

The energy fog is the fourth 'internet'

There are at present three 'internets'. First there was the original internet - transport. Roads arguably opened up commerce for the first time, and helped keep the Roman empire in business for 2000 years. The railways were broadband for roads – faster and more efficient by an order of magnitude, and another commercial leap forward.

Then came the network of wires, pipes and infrastructure that make up the second internet, that of energy. Although structurally this network tended to follow the road layout, it was one-way traffic, and largely still is.

Finally we have the internet of data. Capable of connecting the globe, instantly, and a commercial breakthrough of enormous proportions. The energy fog brings all three together. Electric vehicles are how transport, energy and data networks come together to create a revolution in power generation and value exchange.

The energy fog's real revolution; a change in mindset

There is great developmental work going on within each of the four components; the two old industries of automotive and energy, and the two new technologies of blockchain and fog computing. There is also work going on between some of the components – for example the application of blockchain cryptocurrency to energy, using tokenisation.

The real change here is the collision of all four. This is what it is going to take if we are to meet the need for double the amount of electricity by 2050. Success depends not just on the efforts of a handful of industrial generators. Long term energy security requires change on a societal level.

"Long term energy security requires change on a societal level"

The energy fog is a radical alternative to the traditional energy grid which enables a whole new era of power generation and management. And it could all happen before Hinkley Point C becomes operational.

But it will *only* happen if a forum is created in which cross-industry, cross-technology expertise is brought to bear to make the energy fog a reality. This paper is intended as a call to action.

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