Beyond The Fire Age

Working Paper by Walt Patterson

'The Stone Age did not end because we ran out of stones.' - Sheikh Zaki Yamani

The Fire Age began in the early Stone Age. It began even before *homo sapiens* - but we are still in it. Indeed we have long taken fire for granted. Most of the time, in rich countries, we no longer even realize when we use it. But we do, every day. When you turn the key in the car ignition, you're using fire. When you turn on a light connected to a coal power station, or turn up the thermostat on the gas central heating, you're using fire. If you run an airline, a steel mill, a cement plant or a refinery you're using fire. Directly or indirectly, all over the world, we use fire all the time. Most of the time, in rich countries, we don't even see the fire. But it's there, almost everywhere, in our everyday lives.

We think of fire, if we think of it at all, as a key to civilization. If you ask people what they consider the greatest human achievements, the answers will probably include the wheel and the control of fire. For most of human evolution, fire has indeed been essential and invaluable. Even now we see fire as welcoming, cosy, what we like to come home to. But fire's greatest contribution may be one most might not yet recognize. Fire has made possible the human control of electricity. Electricity, in turn, may save us from fire.

For all its usefulness, cosiness and immediate appeal, fire is actually violent and extreme, a primitive brute-force process. It produces heat at very high temperatures, at least 700 Celsius, usually much hotter. It consumes the fuel that feeds it, turning it rapidly into waste, much of this waste unpleasant, possibly toxic and even upsetting to planetary systems. Everyone knows fire can be dangerous. That's why we tell toddlers not to play with fire, why we buy fire insurance. But the dangers from fire are now no longer merely local, of personal injury or damage to property. Fire in car engines, household heaters, factory furnaces and power station boilers is making the air in major cities around the world poisonous, almost unbreathable. Fire spews particles that clog lungs, bringing asthma and cancer. It releases gases that turn waterways acid and kill the forests around them.

Worst of all, the commonest gas that fire produces, carbon dioxide, is relentlessly heating up the planet. We are seeing the results all around us. Violent storms, hurricanes and tornadoes, floods, heatwaves, droughts, raging wildfires, vanishing ice sheets and melting glaciers are becoming what we may have to call the 'new normal'. Fire is no longer merely dangerous. The way we use fire now threatens the future of human society.

Fire and electricity

Fire is a chemical process, that rapidly degrades what it happens in, turning it to ash and other wastes, including smoke, soot and invisible gases, some locally toxic such as sulphur dioxide, and others, especially carbon dioxide, that are upsetting our earth's atmosphere. Electricity, however, is not a chemical process. It is a physical process that does not change what it is happening in.

As a process, electricity, too, can be violent and extreme. The lightning that first gave our Neanderthal forerunners fire is nature's own electricity, raw and vivid. But we now know that electricity under human control can also be subtle and delicate, like the currents in a microchip. The process of electricity can function at any temperature, down almost to absolute zero. It does not consume what it happens in, nor does it produce dangerous waste. Electricity, moreover, is endlessly versatile. Much of what we do with fire we can now do as well or better with electricity.

To be sure, for some human activities fire still prevails. In rich countries, for instance, those who can cook with natural gas are unlikely to prefer electricity as presently available. Natural gas is much more responsive and controllable. Those with the opportunity will warm themselves in front of a log fire in the fireplace. As yet, moreover, fire in internal combustion engines moves people and goods on land, on the sea and in the air, and that will not change much any time soon.

Fire has a long head start. It has shaped human affairs for many millennia. We learned to control electricity only two centuries ago. Fire still dominates. Indeed we still generate most of our electricity using fire. Since the turn of this century we have already invested in hardware using fire, that could last for decades to come. But change is under way. The roles of fire and electricity in human activities are now evolving faster than ever before.

What we do and how

In physical terms everything we do, everything humans have ever done, falls into just six categories. First of all, we control heat flow, using physical things: for instance, you put on a sweater to keep yourself warm, or open the window to let the heat out. Second, we adjust local temperature: for instance you turn the thermostat up or down. Third, we make light: for instance you strike a match, or switch on an electric lamp. Fourth, we exert force: for instance you lift a weight or open a door. Fifth, we move things - by exerting force, but moving things is so important you can call it a distinct activity: for instance you push a pram or pull a wagon. Sixth and last, but in some ways becoming the most important, we manage information: for instance you talk and listen, now not only in person but more and more remotely, with more and more ingenious devices. For these six activities we use physical things and two processes - fire and electricity. For the past two centuries, ever since we learned to produce and control electricity, electricity has been steadily supplanting fire, in more and more of these activities.

To control heat flow, for survival and then for comfort, we have always used physical things: clothing and shelter - shelter particularly in the form of buildings. We have used solid materials - branches and skins, clay, stone, timber, brick, concrete, steel, glass, even blocks of snow - to surround ourselves with barriers and boundaries, to keep heat inside when outdoors is too cold, or to keep heat outside when outdoors is too hot. Such built shelter has enabled us humans to spread across almost the whole of the planet, regardless of the prevailing weather and temperature. In previous centuries we became very good at building effective shelter whatever the surroundings, whatever the materials available.

However, if and when the building itself does not control heat flow well enough to provide comfort, we have historically used fire indoors, to replace the heat the building allows to escape. In the past century, unfortunately, we have erected all over the world a vast array of buildings, from residences to skyscrapers, that do at best a mediocre job of controlling heat flow either in or out. Instead we rely on fire to keep these mediocre buildings habitable. We use fire to replace heat lost to cold weather. We use fire to drive air-conditioning to remove heat coming in from hot weather. In recent years, however, we have at last recognized and begun to capitalize on the opportunity to improve dramatically the performance of buildings, to make the building structure itself control heat flow much better, with much less reliance on fire. Many studies and analyses have shown that the potential for improving our built infrastructure is vast. Such measures alone could dramatically reduce the use of fire throughout global society. We can replace the function of fire, always short-term, with physical materials - materials that last.

To raise local temperature we have always used fire, and still do, especially for the universal human activity of cooking. In rich countries, cooking with fire, when we can we now mostly use natural gas as fuel, and take care to ventilate the kitchen to remove the combustion products. In poor rural areas, however, especially in Africa and Asia, women - almost always women - frequently cook on open fires burning wood or dung indoors, with limited if any ventilation. Inhaling the resulting smoke and fumes is a major cause of illness and death, for both women and children. Many programmes are now under way, replacing open fires with better cookstoves, adding chimneys, and, in some places, introducing solar cookers that do not use fire at all. But much remains to be done.

Many industrial processes, requiring much higher temperatures, use fire as the source of heat - smelting ores, making and forming steel, manufacturing cement, firing bricks and ceramics, refining petroleum and so on. Work has been under way for many years to minimize heat losses and reduce requirements for fire and fuel in such processes - everything from improved insulation through integrating and cascading temperature zones to complete changes of process technologies. Steel-making, for instance, now often uses an electric-arc furnace for specialty steels. Cement manufacturers, too, are developing alternative processes using much less fire and fuel. Again, however, much remains to be done.

Making light was almost certainly the most important original use of fire, dating back to our Neanderthal forerunners. Through the millennia humans learned to use many kinds of firelight - brands and torches, tallow candles, lamps burning vegetable oil, whale oil or kerosene from petroleum, and lamps burning gas from coal. However, from the mid-1800s onwards the advent of electric light, first arc-light, then the incandescent lamp, rapidly superseded firelight of every kind almost wherever electricity became available. The desire for electric light, and in particular incandescent light, drove the rapid expansion of electricity systems throughout Europe and North America, and subsequently through Asia and Latin America. In rural areas, however, especially in Africa, even now many people still remain without electric light or other services from electricity. Instead they still rely on firelight, notably from kerosene, expensive, smelly and smoky, aggravating indoor breathing problems. When they do have electricity it is often from fire in diesel generators, noisy and smelly, burning fuel that must travel often hundreds of kilometers over poor roads and is accordingly very expensive. As with cooking, major programmes are now under way in many parts of rural Asia and Africa, to provide local solar electricity systems for lighting, and also for managing information, such as television and radio and charging mobile phones, to reduce dependence on fire, kerosene and diesel.

Muscles, nature and steam

For most of human existence fire was of no use for exerting force. From the Neanderthals onwards, to exert force humans used muscles, their own and those of animals. In due course we learned to capture the forces of moving air and water, with physical things - sails, windmills and watermills - and redirect these forces for human purposes. We also used other physical things, what the Greeks called 'simple machines' such as the lever, the inclined plane and the wheel and axle, to manipulate and multiply forces. Then, just after 1700, came the steam engine. We used fire to boil water. As the water turned to steam it wanted to expand perhaps a thousandfold, exerting force on a piston strong enough to lift water out of a flooded coalmine. By 1800 the steam engine was steadily replacing muscles. Using fire to exert force brought about what came to be called the industrial revolution, initially in the UK, then ever farther afield.

The steam engine also made possible using fire to move things. Pumping engines moved water. Stationary traction engines pulled ploughs with cables. But the major breakthrough was to make the fire in the steam engine move itself. The first success was on water. A steam engine mounted in a boat could turn a propellor, replacing oars or sails with motive power from fire and fuel. Steamboats became successful particularly on inland waterways, where sails were of limited use and fuel could be gathered from the banks. They were less immediately successful on the open ocean. The wind was free, not so the fuel, which also took up a lot of space that might otherwise be paying cargo.

Waterways already existed. Roadways smooth and firm enough to bear the weight of a moving steam engine did not. But horsedrawn vehicles were already using wooden or steel rails to provide a more level track. By 1830 engineers and entrepreneurs had begun to use self-propelling steam engines - locomotives - to pull trains of wagons carrying people and goods on ever-expanding networks of railways, again initially in the UK but soon much more widely. Fire was becoming the key to increasing mobility on land, far beyond the capability of human and animal muscles. In due course fire also overtook oars and sails for moving things on water even in the open ocean.

In the steam engine, the fire was outside the cylinder in which the piston moved. By the mid-1800s engineers were seeking ways to ignite the fire inside the cylinder, to move the piston not with steam but with hot expanding gas from the fire itself - 'internal combustion'. Initial success came using as fuel the coal gas produced to make gaslight, injecting it into the cylinder and exploding it there. Gas engines began to compete with steam engines in factories. A gas engine of course required a permanent connection to the retort producing the coal gas. But another option soon emerged.

Beginning in the mid-1800s, entrepreneurs began paying serious attention to seepages of oil emerging from the ground in places including Romania and the northeastern US - oil that would burn, rock oil or 'petroleum'. Within a few years, drillers were producing petroleum to replace whale oil for making light. By distilling the crude petroleum they got a fraction called 'kerosene' that burned more reliably in oil lamps. They also got another fraction, that Europeans called 'petrol' and Americans 'gasoline'. It was dangerously volatile to use in an oil lamp. But it proved to be ideal to use in an internal combustion engine. You could have a tank of liquid fuel beside the engine. When injected into the cylinder it vaporized, so that a spark would explode it, thrusting the piston to exert a force to turn a shaft. By 1885 the internal combustion engine had become yet another way to use fire, both to exert force and to move things.

Amber to action

Throughout the 1800s, while the possible uses of fire were ramifying, another process was making its potential ever more evident. The ancient Greeks knew that if you rubbed a piece of amber, a hard translucent resin from trees, with a piece of fur, the amber would behave oddly, attracting scraps of parchment. The Greek word for amber is 'elektron'. The Greeks also knew that certain types of rock exhibited a similar behaviour, attracting iron nails. By 1600 scientists had described what came to be called 'electricity' and 'magnetism'. But a further two centuries passed before they began to yield practical applications. Then, between 1790 and 1840, scientists created the electric battery and electric current and recognized that electricity and magnetism were closely interrelated. They found that electric current flowing through a wire creates magnetism around it; that if you move a wire in a magnetic field electric current flows in the wire; and, conversely, that if you pass electric current through a wire in a magnetic field the wire moves. The discoveries led to the invention of the dynamo, to generate electricity from motion, and the electric motor, to create motion from electricity.

However, the first practical application of electricity was in the sixth of our human physical activities - managing information. With the exception, perhaps, of smoke signals and beacons such as those bringing news of the Spanish Armada, fire had never played a significant role in managing information. By the late 1830s, however, inventors showed that by starting and stopping the flow of electric current in a wire you could send coded information almost instantaneously along the entire length of the wire. The length of wires unrolled at breakneck speed, first across and then between continents, over mountains and under oceans. By the end of the 1800s the electric telegraph connected the world, in what we now call real time. The electricity it used, at least in its early stages, came not from fire but from chemical batteries, a chemical process starting a physical process, an early indication that fire was no longer the only process humans could use in our activities.

Even as the electric telegraph was demonstrating the potential of electricity for managing information, inventors were devising other ways to use electricity in human activities. Their next success was for making light. By the mid-1800s they had created what was in effect artificial lightning, a continuous electric spark across a gap between two carbon rods, so-called 'arc-light'. It was noisy and smelly and fiercely bright, far brighter than any form of firelight, utterly impractical for lighting indoors. But it was spectacular display-lighting outdoors. Electricity entrepreneurs persuaded wealthy clients to install complete electricity systems, including dynamo, cables, switches, arc-lights and controls. You could spin a dynamo either with a steam engine, using fire to generate your electricity, or with a converted water-mill, generating electricity not from fire but from natural forces. The distinction was going to become crucial.

The achievement of arc-light spurred inventors to seek a better form of electric light. By 1880 they had found it: a glowing carbon fibre inside an evacuated glass bulb - the incandescent lamp. Unlike arc-light, incandescent light was silent and free of odour, bright but gentle, eminently suitable for lighting indoors. Incandescent electric light soon supplanted firelight of every kind wherever you could access electricity; and the desire for electric light dramatically accelerated the spread of electricity systems, in Europe and North America and then farther afield.

The new electricity systems, however, faced one obvious difficulty. People wanted electric light after sunset and, more or less, before midnight - only a few hours a day. For the rest of the time the expensive investment in dynamos, cables and other hardware was idle, its owners probably paying interest on the investment but earning no revenue. Electricity entrepreneurs looked for a way for customers to use electricity in the daytime. The answer was the electric motor. Factories using steam engines to exert force found that electric motors have major advantages. Electric motors are not exactly quiet, but much less noisy than steam engines. Electric motors are not smoky or smelly; they do not require fuel bunkers, often dirty and intrusive, on the premises; and they do not produce ash needing disposal. They are also easier to control, over a wider range of sizes. Before the beginning of the twentieth century, both for making light with incandescent lamps and for exerting force with electric motors, electricity rapidly began replacing fire.

Electricity also began to play a role moving things. Just as the steam engine could move itself, so could the electric motor, as long as it could be connected to an electricity generator. Companies providing public transit in urban areas with horse-drawn trams found that they could introduce electric trams, drawing electricity from overhead wires. Electric trams were so successful that tram companies began installing their own generators, rather to the annoyance of the incumbent electricity companies, who wanted the tram companies as daytime customers.

At the turn of the twentieth century three different types of 'horseless carriage' were jockeying for position on the roads of Europe and North America - steam-driven cars, electric battery cars and internal-combustion cars. All three types of car were still rare luxury items, available only to the wealthy; but they were desired by the many watching on the roadsides as they passed. The invention of the assembly line, turning out cars by mass production, brought car-ownership to ordinary people. The motive power chosen was the internal combustion engine.

Electricity advancing

By the early 1900s, despite fire's long head start, electricity was steadily encroaching on fire's role in at least three of the six human physical activities. As the twentieth century unrolled, electricity advanced, while fire retreated and regrouped. To adjust local temperatures, for hot water and cooking, fire still dominated; but electric stoves and water heaters also became familiar, as did electric heat pumps such as refrigerators and air conditioners. Industry needing high temperatures continued to use fire; but specialized applications requiring tighter control began to use electric heating, often as infrared or radiant heat. For making light, in rich countries we used electricity more and more; firelight gradually faded from the scene. In poor countries, however, electric light arrived only belatedly, and mostly in urban areas. Rural villages still relied on firelight. For exerting forces we used more and more electric motors. In households, where no one had ever thought to use steam engines nor internal combustion engines, electric motors became commonplace, in vacuum cleaners, fans, food mixers, power tools and other domestic appliances. Factories too replaced steam engines with electric motors. Some factories also used fire in internal combustion engines.

Electric motors and internal combustion engines were gradually superseding steam engines, except in one crucial category. Although electricity was replacing fire for making light and exerting force, fire instead became the key to making electricity. Around 1900 a more advanced version of steam engine, called the steam turbine, came into use. It soon became the commonest form of driver for the successor to the dynamo, called the alternator. The steam-turbine alternator became the heart of most of the world's electricity generating stations. The steam came from boilers burning coal, oil or natural gas, or - since the 1950s - from heat released by nuclear fission of uranium in nuclear reactors.

Nuclear fission appeared for a time to offer great promise as an alternative to fire as a source of heat. But fission is a process more violent and extreme even than fire, with consequences that have proved to be acutely difficult and expensive to manage. Extracting the essential uranium fuel from ore has left many millions of tonnes of 'tailings', mountains of solid waste with radioactive contaminants such as radium that have poisoned waterways wherever uranium is mined, with no clean-up feasible. Radioactive spent fuel continues to accumulate in nuclear station cooling ponds around the world, while governments battle local authorities over disposal plans unresolved for many decades. Some nuclear power stations have proved economic, and performed well. But many have not, so much so that private investors now refuse to finance new nuclear plants without guaranteed and open-ended support from taxpayers and electricity users.

Insurers have always refused to offer coverage for possible nuclear accidents - understandable in light of the continuing and dauntingly expensive catastrophe at the Fukushima nuclear plant in Japan. The first generation of nuclear plants is reaching, or has already passed, its anticipated service life. The countries now building new plants have governments with central control, such as China, or governments whose interest in nuclear technology appears to include not only electricity but weapons. Although fission still has powerful adherents and promoters, after just over half a century its worldwide role in raising steam to generate electricity is already declining. It is unlikely to recover.

For moving things, throughout the twentieth century fire became dominant. Internal combustion engine vehicles, cars and trucks burning petrol and diesel, ruled the roads. On railways steam locomotives gradually gave way to diesel locomotives. On many routes in rich countries, however, fire was replaced by electricity, delivered to electric locomotives by a third rail or overhead wires. For moving things on water, fire supplanted sail for shipping, in steamships and diesel ships, eventually up to enormous size. For moving things in the air, balloons and other lighter-than-air vessels were overtaken by winged aircraft driven by fire in internal combustion engines. For aircraft the internal-combustion piston engine in turn was overtaken by another version of internal combustion, the gas turbine or jet engine.

For managing information, electricity grew ever more versatile and ever more essential. In the twentieth century, after the electric telegraph and the electric telephone, inventors and entrepreneurs found ever more ways to use electricity for information. Thus far they have given us radio, television, teletype, facsimile or fax, the computer, email, the internet, server farms, social networks and smartphones, and the innovation appears to be accelerating.

In the twentieth century, meanwhile, fire demonstrated its dark side with brutal frequency. In war after war firearms slaughtered millions. Fire from explosives in shells and bombs pitilessly destroyed cities and countryside alike, soldiers and civilians alike. Electricity came late to warfare; but it too played a role. Unlike fire, electricity in warfare was not lethal; but it increased the lethality of fire. Radar located enemy aircraft and sonar enemy submarines, making them targets for fire. Radio communications aided troop movements and other logistics. More recently, electrical and electronic weapons-control systems have substantially worsened the destructive effects of fire, and made remote-control devastation feasible. Meanwhile an entirely new form of electric warfare appears to be emerging, so called 'cyberwar', threatening disruption and even destruction through the internet and the vast array of computers, control devices and other electronics that now interact in real time worldwide.

Both fire and electricity, therefore, can be damaging to human society and its global environment. But the damage done by fire far outweighs that done by electricity, in both peace and war; and it is growing steadily worse. Why, therefore, does fire still play such a major role in human activities? Electricity can now do many of the same things, and do them better - more cleanly, more elegantly, with less risk and fewer dangerous consequences. Why are we still struggling to emerge from the Fire Age?

Using fire

Start with history. As a species, *homo sapiens* has evolved with fire. Even before *homo sapiens,* fire gave our Neanderthal precursors a power not available to other animals. Humans are the only animals that can start a fire. That power has shaped human society, giving us materials and potencies humans alone can use. Fire is long since a fact of daily life, even now when in rich countries you see may open flame only on a gas cooker, a bonfire or a cigarette lighter. We have historically taken for granted, at least until the last half-century, the consequences of fire, in particular the smoke, particulates and gases it releases into the atmosphere. We have also taken for granted the need to feed the fire with fuel, which it will rapidly consume. Feeding a fire is akin to feeding a human - perhaps even more continuously demanding. We have accordingly created social arrangements to support feeding fire, arrangements that far predate human history. Ever since humans acquired fire, gathering fuel has been part of daily existence almost as important as gathering food. Both are continuous processes, dealing with requirements that demand continuous feeding.

As society evolved and stratified, gathering fuel became a distinct category of labour. Specialists such as woodcutters and charcoal burners made producing fuel a trade and a business. The concept of money emerged, to facilitate transactions. In due course, in some parts of the world, society established the rule of law, laying down guidelines for public behaviour that no longer depended on the whims of the strongest. One typical family of laws allowed businesspeople to group together, to form companies with so-called 'limited liability'. Such companies could borrow money and make financial deals without putting the personal property of individual company members at risk, greatly expanding the possibilities of business. Over time, among the many companies that formed were companies to supply hardware, such as stoves, boilers and furnaces for raising local temperatures, lamps for making light, and steam engines for exerting force and moving things; and companies to supply fuel, such as firewood, coal and lamp oil. The companies selling hardware sold it as an investment. The customer bought something durable, something that would last, for years or even decades. The companies selling fuel sold it as a commodity. The customer bought something to use up, to consume continuously, feeding a fire. The distinction was, and is, profoundly important.

The advent of gaslight, at the end of the 1700s, brought a new kind of company with a new kind of business. The gaslight company had to have a permanent connection to each of its customers, a continuous pipeline all the way from the retort producing the gas to the burner providing the light. Since the customers might be some distance, even a kilometer or more, away from the retort, the pipeline had to pass through space belonging neither to the company nor to the customer. To lay the pipeline the company had to get permission from whatever local government oversaw public space. It then had to maintain the pipeline network, not only for reasons of business but also for safety; a gas leak could lead to fire or explosion. The company had thenceforth a direct physical connection to the premises of each of its customers, unlike any of the previous forms of business supporting human physical activities. It fed the customer's fire continuously, from a distance.

Using electricity

While gas-light was becoming a practical commercial reality, electricity was still a laboratory phenomenon. As scientists rapidly came to understand it better, entrepreneurs looked for ways to use it commercially. The first, the electric telegraph, had some attributes in common with gas-light. The telegraph too required a permanent network through public space, and indeed eventually through space over which no government had jurisdiction, such as the open ocean. Telegraph entrepreneurs themselves made the investments, such as those in cable-laying, and bore the risks, which were often considerable. Where government was involved its role was similar to that for gas-light systems, merely to give permission where necessary.

The first form of electric light, arc-light, did not entail any particular business or institutional innovation. An entrepreneur agreed a contract with a customer, and installed the complete system on the customer's premises, perhaps a wealthy estate with a watermill that could turn a dynamo. But dynamos, water power and steam power all exhibited significant economies of scale; you could double the size without doubling the cost. In order to make electric light less punishingly expensive, entrepreneurs therefore promoted a new kind of system, with a larger generator supplying not one but many customers on many different premises. The invention of the incandescent lamp made such a system technically feasible. However, like gas-light, incandescent electric light also required a network through public space. From then on, governments as well as companies became steadily more involved in making light, with fire and without.

In practice, that meant governments being involved in making and delivering electricity, for any activity. Where companies set up systems to deliver electric light, governments oversaw their use of public space. In due course governments then granted companies monopoly franchises, to become sole sellers of electricity in a given locality. In many places, moreover, governments themselves, at first local governments of towns and municipalities, and eventually even national governments, decided to install electricity systems, often initially for public lighting. Within a few years these systems, both entrepreneurial and governmental, came to provide electricity for households, businesses and industry, not only to make light but to raise temperatures, exert forces, move things and manage information - all the human physical activities.

Complications

Because electricity is not a substance but a process, it must be generated more or less immediately as it is used, and vice versa. In effect each electricity system, with everything connected to it at a given instant, is therefore a single machine, often gigantic, functioning in real time, over an area that may extend thousands of kilometers, even beyond national borders. As the twentieth century unrolled, electricity systems expanded rapidly, becoming a distinctive part of the social fabric over much of the world.

We were still doing the same things we had always done; but the arrangements were getting much more complicated. To make light, you no longer simply bought, say, a candle from one artisan and a flint-and-steel lighter from another, at prices you agreed with each seller. Now, instead of simple transactions between an artisan and a customer for a price mutually agreed, making light might involve a customer, a company to supply the lamp, another to supply the lighter, another to supply the requisite fuel or electricity, and a government imposing laws and regulations with which all participants had to comply. Setting a price was no longer a straightforward bargain between seller and buyer. Moreover the costs involved were much harder to calculate.

One cost in particular was simply ignored: the cost of using fire. Someone paid for the fuel. But no one paid for the pernicious consequences of burning it. The smoke and fumes were released into the air as they had always been. When fire was the only available option, costing its consequences had little point. Either you used fire to make light, or you stayed in darkness. If the cost was too high, darkness was your only alternative. When electricity became an option, however, you now had a choice - indeed you now had a series of choices. Assuming you did not want to stay in darkness, you could now make light directly with fire, say candlelight or gaslight. Or you could make light with electricity - incandescent light. But you also had an additional choice. You could make the electricity with fire, or you could make it, perhaps, with a waterwheel turning the dynamo - not fire. If you chose that last option, you could make light without fire - and avoid its consequences.

In practice, of course, no one person had such a choice. Once electric light expanded beyond the arc-light system on one owner's premises, if you wanted electric light, electric heat, electric force, electric motive power or electric information management, you had to deal with other system participants, who had different and often contrary interests. The first systems for incandescent light charged their customers according to how many lamps they had. The customers were paying to have electric light available, whether they used it or not - much as they paid, say, rent to have a comfortable home available, whether they were in it or not. The electric entrepreneurs, in turn, had to optimize the entire system, generator, cables, switches and lamps, to keep what was then a very high cost tolerable. They were selling light - what customers actually wanted. Then came the invention of the electricity meter. That created an unfortunate conflict of interest - one that still bedevils human use of electricity.

From then on the entrepreneurs were selling not light but electricity, by the unit. From then on, the entrepreneurs actually benefitted by having a customer use lamps with poor performance. To get sufficient light, the customer therefore had to buy, and pay for, more electricity. This perverse incentive to poor performance, for lamps, motors and all the other things that deliver electric activities, persists more than a century later.

Electricity like fire

After the invention of the electricity meter, electricity systems evolved into a model closely akin to that for the gas-light form of firelight. Business arrangements treated electricity as a commodity, as though it were a fuel, to be consumed continuously, bought and paid for by the unit, just like a sack of coal. For most of the twentieth century, electricity settled into a pattern eventually established all over the world, a technical and commercial model that treated electricity almost as if it were fire. Indeed in many places electricity became a kind of fire at a distance. Some system operators generated electricity with ever-larger steam turbine alternators, in ever-larger power stations sited ever farther from users. Boilers burning coal, heavy oil or natural gas, or heated by nuclear fission of uranium, produced the steam to turn the turbines. Other operators dammed rivers, creating artificial waterfalls to turn water turbine alternators. Both kinds of power station, with fire and without, produced electricity from a stored commodity, either fuel or a reservoir of water, continuously using up the store as the station operated.

From each power station, long transmission lines operating at very high voltages carried the electricity, often hundreds, sometimes thousands of kilometers, to clusters of users in cities, towns and villages. The electricity, transformed to lower voltage, went through meters onto the premises of users, who paid a tariff usually including a fixed charge for the connection and a variable charge for the amount of electricity used. The system was a monopoly franchise, the sole supplier of electricity in the locality. To keep the monopoly from abusing its privilege, tariffs were decreed either by the relevant government or by a regulator it appointed. Entrepreneurs and governments replicated this traditional model of central-station electricity, emulating the fire of gas-light, over much of the world, with varying degrees of success.

The dark side of fire

As electricity expanded into more and more human activities, we began at long last to notice the dark side of fire. In December 1952 the smoke and sulphur fumes from open fireplaces combined with London's familiar fog into a suffocating and impenetrable blanket of smog lasting four days, killing some 4000 to 12000 people. Four years later Parliament passed the Clean Air Act, banning open fires in urban areas all over the country, the first legal constraint on the use of fire. Instead of burning coal in urban fireplaces, huge power stations began burning it right at the exit from the mine, sending electricity as 'coal by wire' into towns and cities. Tall smokestacks sent the smoke and sulphur fumes high into the air, where they were expected to disperse harmlessly. As we found out later, they did not.

When making light, exerting forces and moving things, people began paying closer attention to what happened to their surroundings - the impact of human activities on the environment. Fire and electricity both caused environmental problems. Using fire to make electricity compounded the problems. Expanding electricity systems with power stations in remote areas sent tall pylons striding across the landscape. Many people, however keen to use electricity, said 'not in my backyard', or even on the horizon. Dams to produce hydroelectricity flooded scenic localities. Power stations on lakes and rivers used their waters for cooling, raising water temperatures - so-called thermal pollution. Burning coal and heavy oil in power stations discharged smoke, fine particles, sulphur, mercury and other air pollutants. Cars and trucks burning petrol and diesel filled city air with carbon monoxide, nitrogen oxides, particulates and carcinogens. Producing and transporting oil to feed fires in boilers and internal combustion engines led to accidents with tankers and offshore rigs, causing oil spills that sometimes covered many square kilometers of the sea, fouling water birds and fishing grounds. Sulphur plumes from tall smokestacks drifted many hundreds of kilometers before falling as 'acid rain', poisoning waterways and killing forests, often in entirely different countries. Legislators, regulators and diplomats struggled to find ways to mitigate these increasingly serious consequences of using fire and electricity. It was an uphill task.

In 1988 an effect first identified almost a century earlier, an effect that had been worrying scientists for decades, at last caught the attention of politicians. Fire releases carbon dioxide into the atmosphere, forming a thickening reflective blanket over us, gradually warming the surface of the land and the oceans, with steadily more alarming results. At a global conference in Rio in 1992 and other conferences since, most of the governments of the world agreed plans to try to get the consequences of fire under control. Since then, however, fire continues to spread, its potentially catastrophic consequences ever harder to ignore.

Electricity evolving

At the same time, nevertheless, something more promising has been happening to electricity. In the late 1980s, even as the carbon dioxide problem was rising up the political agenda, the traditional model of electricity, with its resemblance to gas-light and fire, began to break up. Ownership and control of the systems by which we use fire and electricity became a political issue, and intensely controversial. It has remained so ever since. The initial impetus came from advocates of 'free markets', who deplored both the monopoly franchise and the role of government in electricity. As they assumed political power in several rich countries, they decreed that electricity systems owned by governments would be sold to private investors. They further decreed that the traditional centralized monopoly electricity suppliers would be broken up. The monopoly franchise would be abolished. Generators henceforth would compete for the right to sell their electricity to customers, just as though they were selling baked beans.

It did not work out quite like that. Abolishing the monopoly franchise meant that electricity users were no longer captive customers. The risks of investment by system operators now fell on shareholders and bankers. Traditional coal-fired and nuclear power stations, of enormous size, might take upwards of six years to build and bring into service - risky investments when no one could foresee with confidence how much electricity they could then sell, or at what price. Liberalization of electricity also happened to coincide with the successful demonstration of the industrial gas turbine for continuous operation, and the arrival of abundant cheap natural gas to fuel it. Traditional electricity assumed that a better power station was always a bigger one farther away. With the gas turbine, however, a smaller, better power station, clean enough to locate close to users, could be built in two years or less. Almost overnight, the preferred design for new power station anywhere with cheap natural gas used gas turbines and steam turbines together, so-called gas-turbine combined cycles, sometimes even in urban areas utterly unsuited to any traditional power station.

This break with tradition changed the criteria for operating and enlarging the network. It also coincided with striking progress in generating electricity using wind, water and sunlight - not fire - in much smaller units. Traditional steam and water power have always been based on anticipated economies of scale. But innovative smaller-scale generation exhibits economies of series manufacture, with a swift learning curve. Unlike the fire-based model of traditional generation, which consumes fuel or stored water that has to be continuously replenished, innovative generation uses natural forces. Popular terminology calls this electricity 'renewable'. A more accurate description is 'infrastructure electricity'. You invest in a physical asset such as a wind turbine, a microhydro turbine or a solar array. It becomes part of the infrastructure - infrastructure that generates electricity to use in any activity you desire. Harvesting natural forces it needs no fuel, nor does it consume anything. It does not fit the traditional model of electricity based on or emulating fire. Innovative electricity is creating a quite different model for adjusting local temperature, making light, exerting force, moving things and managing information. The central concept of this innovative model is not a commodity but a process. The transactions involved are not batch sales of a commodity, but longer-term contractual relationships based on investment and access to the process.

In the past two decades, since a number of countries liberalized electricity, infrastructure electricity has become a significant and rapidly growing contribution to total commercial electricity supply worldwide. But much of it sits uneasily with traditional centralized fire-model electricity, for several reasons. To the system, an offshore windfarm looks much like a traditional power station. But photovoltaic panels or cladding on individual buildings, or other decentralized small-scale generation, does not. It is connected at low distribution voltage, and looks more like what might be called a negative load, putting electricity into the system rather than taking it out. In doing so, moreover, it can reverse the current flow in nearby circuits, confusing protective devices and otherwise complicating system operation.

Yet more troublesome is the question of finances. What value does decentralized generation contribute? Who benefits, who pays, on what basis and how much? These questions are becoming steadily more pressing as the role of infrastructure generation steadily increases. As the technical model of electricity systems evolves ever more rapidly away from the traditional, institutional and business arrangements are becoming rapidly more incoherent and unstable.

Firefight

As the stress on traditional electricity intensifies, it is aggravated by a fierce counterattack in defence of fire. Confronted by ever more dismaying evidence of global damage from its consequences, many governments around the world have - in effect - declared their intention to eliminate fire from most human activities within the coming half century if not sooner. Electricity is a particular focus of their plans. But feeding fire is one of the world's largest economic sectors. Huge companies, and entire countries, draw much of their revenue from producing and selling fuel to feed fire. They are understandably unhappy about suggestions that they are poisoning cities and threatening the planet. They insist, with some justification, that they are doing what society wants them to do. If society wants them to change, society itself must change, and change the ground-rules that still make fire central to human activities, despite its destructiveness.

Electricity holds the key. With electricity we can control heat flow, adjust local temperatures, make light, exert force, move things and manage information. We can do so without fire, by harvesting natural forces with infrastructure electricity. Human activities can become process, not consumption. But we need to overcome our crippling inability to acknowledge and account for the true cost of fire. If we do not, spurious comparisons of cost will lead us to choose disaster.

Some might even argue that the fire model has long applied not only to electricity but much more widely. Apart from food, fuel to feed fire is the only product we make that is intended to be consumed continuously, needing continuous replacement. Everything else we make - clothing, footwear, furnishings, tools, vehicles, buildings - is, or should be, durable, something that lasts. But we have created a global economy modeled on fire and its consequences - a 'consumer society' whose central function appears to be to turn resources into waste as fast as possible. The oxymoron 'consumer durables' succinctly pinpoints the paradox. From this perspective, moving away from fire as the model for human activities will entail changing the model of our global economy - a daunting but exhilarating challenge.

As electricity evolves, and as it supplants fire, it is already moving away from the traditional fire-based model. The technical configuration now emerging has generation and use ever closer together, both in space and in size. Sensing and control equipment allows uses and generation to interact in real time, both helping to keep the system stable. Local microgrids, making system interconnections less crucial and less vulnerable, reinforce reliability and resilience. Infrastructure electricity channels natural forces to raise and lower local temperatures, make light, exert force, move things and manage information, without extremes of temperature or pernicious waste. The electricity meter evolves into yet another active sensor, no longer merely counting kilowatt-hours but maximizing opportunities. You invest in infrastructure, and infrastructure keeps the lights on.

The primitive brute force of the Fire Age has brought us this far. But we have to leave the Fire Age behind. We need new ground-rules for human activities, based not on commodity and consumption but on process and access to process. Electricity may show the way. In the longer term, we may even see the fire model of the global economy overtaken by a model informed by innovative electricity - less short-term, less brutal. The pathway beckons. Let us take it.

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