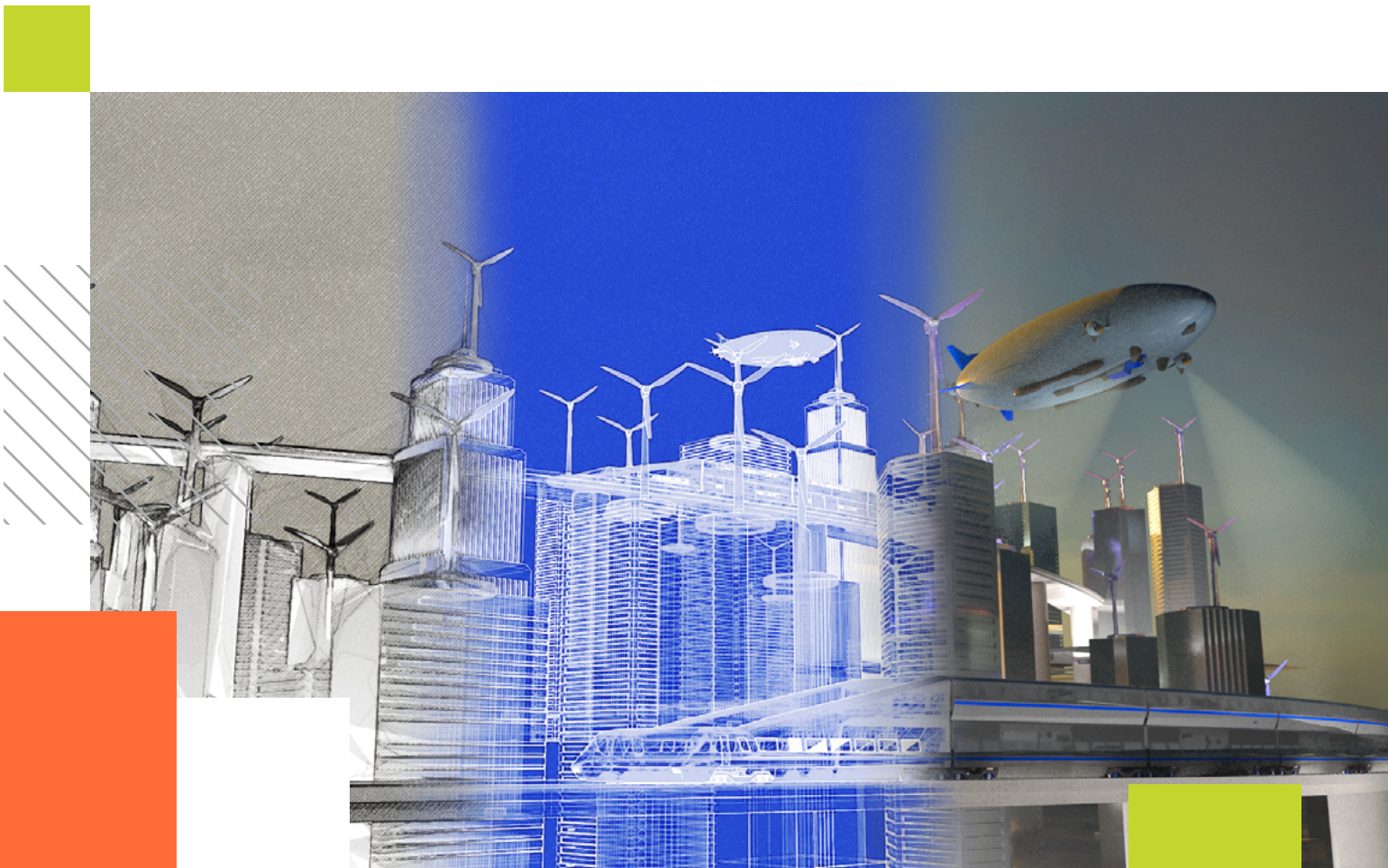


WHITE PAPER / THE FUTURE OF ELECTRIFICATION

Imagining an electric world

BY Doug Houseman

The electrified future is coming. For many industries and communities, being prepared for the changes can mean the difference between success and failure. Creating a road map for how to absorb the changes economically and culturally can help.



Imagine a world where grilling a steak, drying clothes, staying warm and traveling is all powered by electricity alone. Close your eyes and picture yourself flying on an electric plane or riding on a high-speed electric train, lounging in your electric autonomous pod. Dream of a world filled with slow-turning wind turbines and fields filled with solar cells. In this world, the only uses of petroleum are for medicines and lubricants, plastics are made from plants, and steel is produced with electricity. Imagine a world with no smokestacks, where the worst air pollution comes from dust whipped up by the wind.

We don't know when we will reach this fully electrified future, but this world is certainly coming. In some places it will happen in a decade or two while in other parts of the world it might take a century, but it is coming. For many, this world can't come fast enough, but for others it is moving too fast. One thing, however, is certain: Change is inevitable.

Naturally, this kind of change presents challenges — challenges that offer opportunity to some and hardship to others. Some opportunists with a vision and the funding have already made a fortune on the transition. Others are seeing their future dim with the changes. Getting to a completely electric world in a manner that minimizes these hardships is tough, but it must be done.

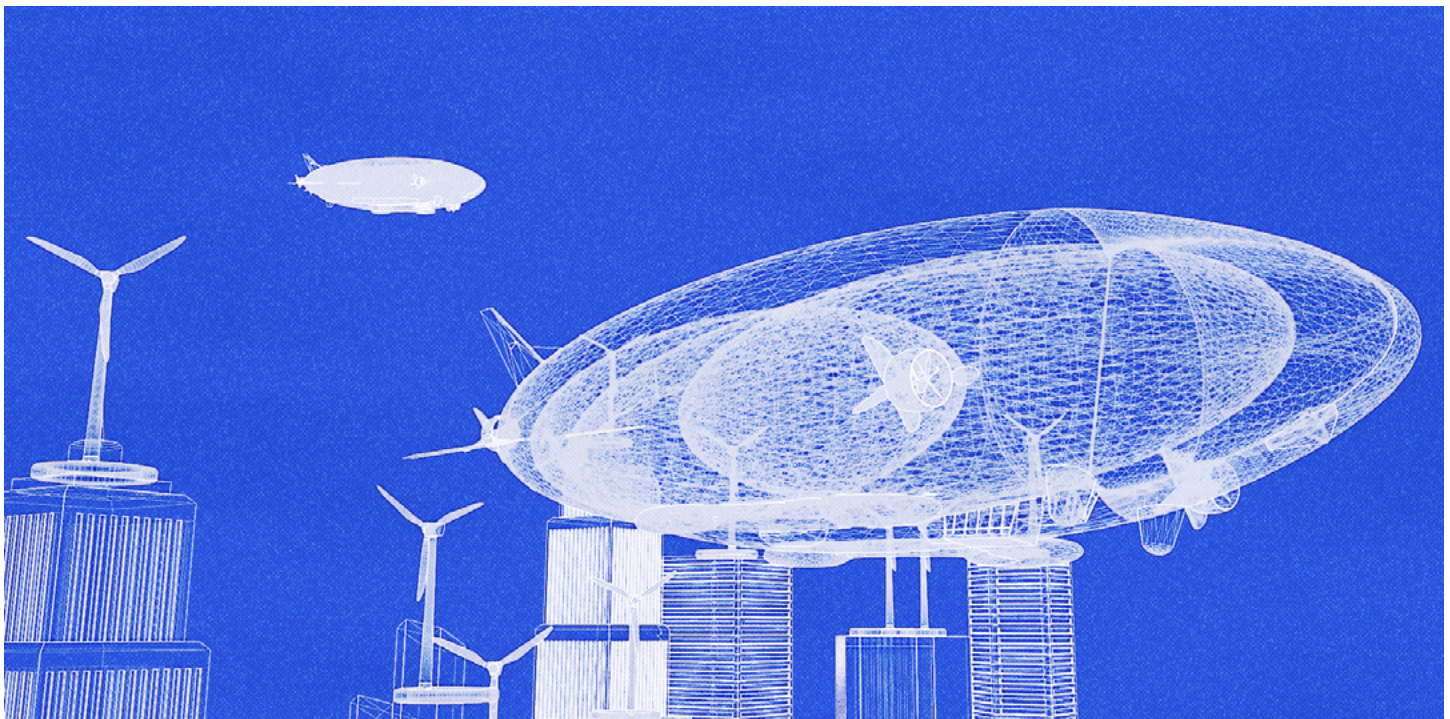
There are advocates for all types of innovations to electrify our future and researchers are continuing to create more. In many cases, it can be difficult to stay rational when talking about an electric future, especially when attempting to develop a business case. But it's important to remember that for every technology and solution there are opponents who have reasons to believe the technology should not be adopted.

This is a challenge to the electric future that must be faced. Additionally, rational thought must be brought into the discussion to better serve the future and ready businesses for an electric future, even if you aren't sure about barbecue from electric grills.

Transportation

Today, transportation accounts for roughly a third of global energy use. This means that the transportation industry will have to deal with the largest shifts in energy use in the electrified future.

Shifting transportation from fossil fuels to electricity will be a major challenge. Many railroads in Europe are already electric and we can expect this trend to continue. For parts of the world without electrified rails, this will create an infrastructure challenge that will not only cause railroads to build new



Conceptual blueprint of electric airship.

infrastructure, but also cause the transmission system to change in order to match rail routes. In other situations, railroads will need to realign to meet electric transmission rights-of-way.

Many rails-to-trails projects may have to be converted back to provide more electric rail capacity. The majority of long-distance freight capacity will move to rails. The question is: Are our current railroads designed for freight transportation in the future, or should we rethink trains completely?

Trucks currently haul much of the world's freight long distances, but this may not be the right choice in the future. Trucks are ton-mile efficient, but they use a lot of energy to move those tons, making it more feasible to use electric trains for freight.

The movement of goods in an electrified future will require systematic thinking and planning; a lot of jobs will be created and a lot more lost. This is the challenge in every facet of the economy during an electric shift.



Moving people

Airplanes may be our long-distance answer today, but maybe not tomorrow (although some organizations are working on electric airplanes). Whether the hyperloop is a realistic concept or not, it will continue to be explored and, if it works, the concept will challenge air travel.

Trains and electric buses, both for city transport and for intercity transport, are an important part of the electrified future, as are electric bikes and scooters. Cars will probably see the largest takeover. And autonomous cars, if perfected, might simply be offered as a service, rather than remain as vehicles that typically are owned. Some cars may be designed to ride the trains or hyperloops and drive directly on for long-distance service. Some people won't stop owning cars — carpenters, plumbers and farmers, for instance. The question is: Will the change to cars happen for cost, convenience or by policy and regulation? Only the future holds the answer.

Autonomous vehicles will come in a number of shapes, sizes and ranges. For a single commuter they will probably be microcars, with room for one or two passengers as ride-

sharing for multiple passengers may be the rule rather than an anomaly in the future. Shoppers may have a small truck show up to take them and their items home. People traveling across the country may have an RV-type vehicle show up. The range of vehicles will expand to meet the varying needs of people.

Downtowns will get denser, and hence need more energy — less per person, but more overall — as the need for parking disappears.

Electric ships will ply the ocean and passenger transportation may return to the sea — not just pleasure cruises, but actual transportation for work and sightseeing. Electric ships for passengers may look very different from cruise liners and may travel at speeds that are three to five times that of current cruise liners. Or maybe we will return to the age of airships where the gas bag provides the lift and the engines are only required for propulsion. The future is not written, and options exist for intercontinental transportation. Maybe we will build undersea hyperloops.

And yes, the gravel haulers and cement mixers will still travel the roads, because building projects will continue. On-site 3D printing of houses may become commonplace, but materials will still be needed on-site to do the printing.

Heating and cooling

Heating and cooling is the next major area that will be impacted by electrification. Removing fossil-fueled furnaces and hot water heaters will be a tremendous challenge and finding the right high-efficiency answer will also be a challenge. In northern climates, heat pumps have limits to efficiency today and require low-efficiency resistance heating to fill in the gaps. Research will be required to close that gap.

The most efficient answer is geothermal systems, but using wells to bring up and reinject water may have a negative impact on groundwater quality if done en masse in a city. Use of oceans for heating and cooling of coastal cities may be possible, but again the risk of environmental impact is ever-present.

Moderating the temperature to which buildings are heated and cooled will take education and a cultural shift. Roofs in northern regions may be better used for making hot water and storing it than for electricity, or combination PV and hot water systems may be the answer.

One issue is that furnaces have a 20- to 40-year life. Boilers can exceed 60 years in operation and air conditioners typically have a life span of 20 years or more. How to meet these challenges without making it an economic burden is an enormous policy question. Obviously, improving the buildings people live in as far as energy efficiency is concerned will be needed.

Industrial

Industrial processes — like some forms of heat treating, specialized metals and alloy processing — are in some cases designed around changes in temperature that require fossil fuels today. Reengineering the process and equipment is a nontrivial problem that may impact tens of thousands of production facilities and even more products around the world.

Some products and alloys may cease to exist in an electric world. Food processing will change as well, both on the industrial and the commercial levels. These changes may not be as big individually, but most people have not realized the total required research and development and the overall impact on society yet.

Take fertilizer as an example. Fertilizers require a tremendous amount of fossil fuels to make. But fertilizers are relied on to feed the world's population. Changing agriculture to use no fertilizer or changing the way fertilizer is made are challenges to electrification.

Infrastructure

One of the biggest, overarching challenges will be the transportation and storage of the electricity needed for these areas discussed previously. Some argue that simply building more transmission lines will solve the problem.

As an example, the State Grid Corporation of China has proposed a global energy internet that would span the globe with wind turbines in both the North and South Pole regions, connected to other continents by undersea cables. This would solve the day vs. night generation issues solar presents. But could it be used to effectively move the amount of electricity the world needs?

A more modest proposal would be moving excess power from one region to another, continent by continent. However, little research has been done to show where excess production would occur, on an hour-by-hour basis, and where it could be shifted. Even less research has been conducted on how changes in polar vortex storms over the past few years could affect the potential for moving power from the poles. This is all work that must be done, and the answers may change as weather patterns shift.

Electric distribution

On the local scale, distribution must change. Not only will two to three times the amount of energy have to flow over the distribution lines than does today, but solar efficiency — now ranging from 12% to 26% in the U.S. — will mean that any solar power generated will need to be enough to cover all periods, including times when solar systems are not producing.

And it's not just a day/night shift that has to be dealt with, but a seasonal one, too. In June in Ottawa, Ontario, Canada, an average home needs 4 kW of solar to be net-zero. In December, it needs 40 kW. This increase is not only because of the reduction in solar irradiance, but because of the added need for energy to heat the home.

If one were to put 16-kW in place and store the remainder for the cold season, the home would net out as zero for the year. But to do that, more than 70% of the total energy produced

would have to be stored both for day/night shifting and for seasonal shifting. The issue gets to be less impactful as one moves farther south.

Further issues with solar

The need to generate and store far more electricity than is needed for an upcoming season means one of three things: very large storage at a residence, moving that excess energy to a storage location, or overbuild locally and turn off the excess for the day or season.

As an example, on a nice spring day in Michigan a typical net-zero home with 7 kW of PV generation on the roof will push more than 6 kW down the wire if there is no storage at the house. This same home peaks at less than 2-kW for demand with the AC running on a hot day. So, the distribution circuit will have to accommodate three times the electrical flow it does today — and most circuits were designed for growth of 10% to 50%, not 300%.

Because of this, the distribution infrastructure will have to change. Given that most utilities are currently running with a conductor life of 60 to 100 years, it will take decades of business as usual to change to the capacity of the circuits to accommodate this change. Being proactive about changing design standards and using higher voltages and

larger wire is more prudent than ever before, but regulatory policy must allow for these design changes. Currently, most state commissions see these changes as overbuilding and padding the invested capital. Commissions must decide if it is acceptable to tell a customer with a new electric vehicle or who desires the addition of rooftop solar generation that such intentions cannot be accommodated. The fact is, many distribution circuits today will not handle 20% of the households with a single EV.

Roll this up and the substations that act as the transitions between the high-voltage electrical system and distribution systems will become chokepoints. Then the transmission system will be an issue when it comes to moving power.

While issues with both transmission and distribution will need to be addressed, the issues related to distribution likely will energy first — because distribution was designed to be highly economic and with little spare capacity. But don't take this to mean that substations and transmission are fine. Routing and building issues for new transmission lines can take a decade or longer to address, gathering the rights-of-way for a path and securing the permits. So, while not an urgent problem, starting on better transmission plans should not wait until the need is critical.



Storage

Like it or not, today pumped hydro is the lowest-cost option for storing large amounts of electricity for long periods of time. There may be breakthroughs on batteries or other technologies in the future, but today pumped hydro is the best answer from a cost and size standpoint.

Pumped hydro has its own environmental issues, but some may be mitigated by using open pit and tunnel-type mines to house storage. Another option is to create large, cubic mile-sized flood control projects and build secondary structures into which water is pumped from the flood control pits, then cycled back and forth. These massive structures would need to be assessed regarding potential environmental benefits and concerns but could help mitigate flooding and provide some amount of irrigation or aquifer restoration water as a side benefit.

Finally, batteries could provide day/night shifting for homes and businesses. While all storage inevitably involves losses — now about 10% for batteries, up to 20% for pumped hydro, and more than 30% for hydrogen — researchers should and will be working to develop ways to reduce such losses.

Energy efficiency

To make this whole transition work, it will require that we focus on energy efficiency. This will require right-sizing, insulating and avoiding waste energy. It may be that a direct current set of circuits may appear in all buildings to run the LED lighting and other DC-driven items in the home.

It may be that we retrofit insulation in existing buildings. Adding an outside wall to a commercial or factory building and putting insulation in the gap between the old wall and the new wall, could increase a building's overall efficiency. Painting roofs white to reflect the sun's rays in warmer climates has had a surprising impact on cooling loads. Taxes on the square footage of homes may reduce the volume of the new homes and potentially reduce heating and cooling requirements; however, older homes with high ceilings have been shown to have a lower cooling requirement, so more research is needed before any policy changes happen.

People and cultural changes

People are going to have to adjust to being in the natural environment more, living and working with more variation in temperature and lighting levels. The Carter administration's mantra in the 1970s was all about finding ways to use less energy. How we accomplish this change today will be one of the hardest challenges to figure out. Each culture, each family, each tribe, has a different way of living and puts a different

value on energy. There is no wholesale way to change habits — it must be done block-by-block, home-by-home, in a culturally sensitive manner.

Conclusions

This is not an easy problem, and no two communities will tackle it at the same pace or in the same fashion. Communities and existing infrastructure differ from community to community. The ability of a community to absorb the change economically and culturally will also vary.

The infrastructure community can start the transition now by changing building standards, designing to higher electricity requirements, looking for sites for energy storage, and making prudent investments that make the transition to electric vehicles and all electric homes possible.

There is a lot to do, and we have a long way to go. But putting a plan, strategy and road map together — and gaining stakeholder agreement for it all — is the first step. Systems thinking, not solution thinking, is critical to a successful transition. A lot of companies will not survive this transition and a lot of companies will be created. Millions of jobs will disappear, and millions will be created. Where will you be in this transition?

Biography

Doug Houseman is a principal consultant who specializes in the power industry and grid modernization at 1898 & Co., part of Burns & McDonnell. He is an industry veteran who is a member of the GridWise Architecture Council and chair of the IEEE PES Intelligent Grid and Emerging Technologies Coordinating Committee.

About 1898 & Co.

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