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ON THE COVER: ELLEN K. LEVY *Transmission* (detail), 2019, mixed media on paper, 60 x 40 inches

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Wired and CERN

Steve Miller

On a trip to Brazil, artist Steve Miller was captivated by the tangled web of power lines in Rocinha, Rio de Janeiro, the largest favela in the country. Lacking access to basic services, residents tap into overhead cables, risking electrocution in the process. He photographed the wires and incorporates those images in his prints and paintings, thinking of the wires as "human drawings in three dimensions in space, based on our urgent need for resources."

On the other side of the world, in Geneva, Switzerland, is CERN, the European Organization for Nuclear Research, where physicists and engineers use some of the most advanced scientific instruments to study the basic constituents of matter: fundamental particles. In Miller's works, he incorporates mathematical equations and diagrams sketched out on chalkboards in CERN laboratories, making connections between the rapidly drawn chalkboard lines and the complex electrical networks that power CERN's vast magnetic fields.

The electrical wire imagery and CERN equations coexist in Miller's layers of ink and paint. The highly organized conduits that power CERN may seem like the antithesis of the chaotic, impromptu power lines of Rocinha, but both explore energy on a macro and micro scale. From an aesthetic perspective, the CERN chalkboard diagrams and the favela wires contain the same visual chaos. "Where a physicist sees knowledge, this artist sees abstraction," Miller writes.

Based in New York, Miller is recognized as an early pioneer of the "SciArt" (science-based art) movement. In 2013, the National Academy of Sciences (NAS) mounted his exhibition *Crossing the Line*, featuring paintings based on his collaboration with neurobiologist Rod MacKinnon. In 2017, NAS mounted his exhibition *Health of the Planet*, which included paintings, prints, and sculptures exploring the deforestation of the Amazon and the impact on the fauna living there. His forthcoming book is *Surfing the Cosmos* (G Editions, 2022). Follow Steve Miller on Instagram @stevemillerdotcom and see more of his art at https://stevemiller.com.

STEVE MILLER, *Data That Did*, 2018, inkjet, pigment dispersion, silkscreen on canvas, 22 x 16.25 inches

battery torches. Soot from kerosene lanterns and diesel generators are harmful to human health and are incompatible with climate action.

Igbatoro is remote and has difficulty accessing urban markets because of the condition of its roads. In 2017, a private company working as a social enterprise project installed a solar mini-grid, providing 20 kW of power, near a *garri* processing area of the village. After installation, every household in the community was connected to the grid. The hope was that the farmers would transition from using diesel-powered cassava grating machines and other manually operated machines to using electric-powered machines.

However, the electricity did not bring about these expected transformations. Most households used the electricity only for lighting. Lacking access to financing for new equipment, farmers continued using their diesel-powered cassava processing machines. And although the arrival of electricity had been promoted as a way out of poverty, residents' incomes were so low that they were unable to invest in goods such as sewing machines that could potentially raise their incomes. The town's distance from markets meant that most farmers earned only a seasonal income. Soon, residents of Igbatoro realized they could not afford the cost of electricity at all.

Within four months, every member of the community had disconnected from the solar mini-grid because they couldn't afford the cost. They returned to using kerosene lamps—and living amid both diesel exhaust and cooking smoke—and progress toward the other SDG goals was lost. The solar farm itself was dismantled and moved elsewhere by the company that had installed it.

When researchers spoke with members of the community, they learned that although a feasibility study had been conducted prior to the mini-grid's installation, there had been no clear considerations for a viable sustainability plan. Basic questions such as who would use the infrastructure and what they would use it for were never discussed. Astonishingly, the community was never asked if they would be willing to pay for electrical services. Ultimately, the people of Igbatoro said that the infrastructure did not address their real need, which was to increase their incomes to the point where they could purchase electricity.

Beyond passing electrons through wires

As this example shows, the challenge of providing energy access goes beyond passing electrons through wires. Historically, programs that have focused on increasing energy delivery have paid too little attention to improving lives, eradicating poverty, and improving economic empowerment through productive use of energy. This historical trend has limited, in various ways, the socioeconomic and developmental impact of access to energy. Now there is a need to rethink the existing energy access frameworks to include economic empowerment programs. More scholarship is needed to investigate whether economic empowerment can engender sustainable energy access and promote other SDGs to inform future energy policymaking.

Economic empowerment programs, at the broadest level, support activities that lead to income generation. More specifically, such empowerment demonstrates to people that their value is being recognized, respected, and rewarded fairly. These programs may include formal and informal jobs, skills development, financial services, and market information, as well as microcredit schemes that provide loans to low-income households so they can grow more food, for example, or make money by processing it.

We argue that coupling dedicated energy access programs with an economic empowerment component may yield better results than programs dedicated to energy delivery alone.

Integrating energy access and sustainable development

When the United Nations established the SDGs in September 2015, it precipitated a shift in international policymaking frameworks. Because the SDGs are integrated and interdependent—the successful realization of one may promote the realization of another—these goals cannot be viewed in isolation. In a 2017 meta-analysis of more than 100 studies involving energy access, David L. McCollum and his colleagues argued that there are positive linkages between the energy and the nonenergy SDGs, which include poverty eradication, zero hunger, good health, quality education, gender equality, clean water, and decent work. Moreover, they posit that the positive linkages outweigh potential negative ones—such as the effect of utilizing renewable bioenergy on food production—both in number and intensity. As the researchers write, energy access is "a necessary (but not sufficient) condition for delivering the type of services fundamental to escaping the poverty trap: education, employment, and quality healthcare."

We can zoom in to see more clearly some of those positive linkages of energy access and other non-energy SDGs. Access to modern energy (electricity and clean cooking fuels) frees up resources for other income-generating activities. It can also support agricultural productivity by providing the energy needed to reduce postharvest losses, by powering cold storage for fruits, for example—which in turn aids food security. In terms of health, electrification can reduce smoke-related deaths and provide the means to access clean water. Electrification is also central to climate change mitigation as it helps reduce the use of diesel-powered motors and generators that contribute to greenhouse gas emissions. If that electricity comes from low-carbon sources such as solar panels, it may reduce fossil fuel use even further.

Igbatoro's experience demonstrates that energy access programs alone are not enough. This is not a trivial consideration. By 2017, Nigeria's Rural Electrification Agency (REA) alone had overseen the installation of 2,800 mini-grid and solar hybrid projects. In 2018, international agencies provided REA with an additional $350 million to continue this work.

In order to provide sustainable energy access and realize other SDGs, we believe that the issue of economic empowerment should be addressed first. This can only be done if energy access projects are designed to improve livelihoods, which means aiming programs at revenue-generating activities rather than households. Here, we find it useful to consider energy and development consultant Kamal Kapadia's definition of productive uses of energy as the "utilization of energy—both electric, and nonelectric energy in the forms of heat, or mechanical energy—for activities that enhance income and welfare."

An illuminating success story

To understand how successful mini-grid programs enable economic empowerment, consider the community of Kigbe. Located in the Federal Capital Territory in North Central Nigeria, Kigbe's residents are mostly farmers whose crops include sesame seeds, maize, sorghum, guinea corn, and cassava.

In 2017, a company working with Nigeria's REA installed a 20 kW solar mini-grid that powers 145 households, 5 wells (providing clean water to the community), and several businesses. The businesses include a computer center (which provides typing, printing, and photocopy services as well as computer appreciation courses), two grain grinding/processing businesses, and several microbusinesses that sell cold sodas. The mini-grid also powers a rural clinic that serves Kigbe and other neighboring communities. The grid currently operates at about 50% of capacity.

After doing fieldwork in the town, it became clear that the success of the Kigbe project is the result of intensive citizen participation. For three years before installation, the solar company tried to understand the real needs of the community and how providing energy infrastructure could address those needs—while also enabling other economic

STEVE MILLER, *Intervention*, 2021, inkjet, pigment dispersion, and oil on canvas, 53 x 40 inches


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activities. In part, the program succeeded because the people of Kigbe had the opportunity to imagine what they would do with electricity access and how they might use it to change their lives. Households that had enough income to purchase a refrigerator, for example, also decided to open a microbusiness selling carbonated soft drinks.

Kigbe faced similar challenges to those of Igbatoro, such as remote location, poverty, and dependence on a seasonal economy. Yet Kigbe's use of electricity for economic development overcame these challenges to the extent that citizens had enough income to sustain the purchase, and therefore the production, of electricity. We argue that the Kigbe project has promoted the realization of at least four SDGs in the community: health and well-being, clean water and sanitation, affordable clean energy, and climate action. Furthermore, the mini-grid's successful implementation has led to more computer literacy among the younger population, more interest in education, and greater community cohesion. And now that the rural clinic has electricity, it can safely store medicines, benefitting not only Kigbe but surrounding communities.

Insights for policymaking

The very different fates of mini-grids in Igbatoro and Kigbe demonstrate that although modern energy access is an essential condition for achieving the SDGs, the greater energy access challenge is to support interconnected benefits that pull people out of poverty and improve welfare and livelihoods, which enables them to accomplish other goals. Energy systems, in short, should be built to enable economic transformation. Successfully accomplishing that requires not only top-down measures, such as providing capital for grid construction, but bottom-up adoption in communities themselves. Successful energy access projects should meet community needs and goals.

In contrast, the vast majority of energy access programs in the developing world, especially in sub-Saharan Africa, have focused on merely delivering energy that can support a few lightbulbs at the household level; they don't necessarily provide enough energy to support real nonhousehold energy needs. This may be a first step toward providing energy access, but it does not lead to meaningful, sustainable change. The harder part of the project is to get the involvement, consultation, and buy-in of the affected communities.

Government agencies, advocacy groups, international development organizations, nongovernmental organizations, energy suppliers, and financiers should transform their thinking about what is essential for energy access programs. Well-integrated interventions can improve livelihoods for people in low-income communities. And depending on the community's wishes, there are many potential interventions that could turn a failure into a success. In the case of Igbatoro, providing the mini-grid in conjunction with supporting the acquisition of equipment for agro-processing and other productive uses would likely have led to income generation, breaking the vicious cycle of poverty—and enabling the community to support the grid project.

Finally, while solar mini-grids are a start, truly transforming impoverished areas while accomplishing the SDGs will require reliable electricity sources that are significantly larger and capable of powering industry. Governments and utilities should consider revamping existing energy infrastructure while simultaneously building new installations to promote energy access. Some countries with low energy access levels today do not suffer from solely lack of electrical generation, but simply fail to deliver that energy to communities. For instance, Nigeria has about 12 GW of centralized electricity generation capacity, of which only around a third of this capacity is consumed because of a lack of transmission and distribution infrastructure, in part due to a failure to maintain existing infrastructure.

To promote economic empowerment on a larger scale, countries need to upgrade and expand both the generation and transmission systems to perform at their optimum capacity to help deliver on nonhousehold energy needs. In this way, the lessons learned from enabling economic empowerment at the community level should be applied at the state and national level to enable a progressive scaling of not only sustainable energy access but also wider economic empowerment.

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RECOMMENDED READING

Todd Moss, Morgan Bazilian, Moussa Blimpo, Lauren Culver, Jacob Kincer, Meera Mahadevan, Vijay Modi, Bob Muhwezi, Rose Mutiso, Varun Sivaram, Jay Taneja, Mark Thurber, Johannes Urpelainen, and Michael Webber, "The Modern Energy Minimum: The Case for a New Global Electricity Consumption Threshold," Energy for Growth Hub (Jan. 2021).

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KARTIKEYA SINGH

Bureaucracies for the Better

To continue to lift its population out of poverty, India should give its energy ministries a new mandate—moving the country away from coal and toward a more sustainable economy.

2006: Missed opportunities at an ice cream factory

It was a hot and humid New Delhi afternoon, and I'd recently returned to the country of my birth for a summer internship at the Center for Science and Environment, a well-known environmental think tank. I was shadowing my boss on a surprise inspection of an ice cream producer suspected of discharging untreated waste into one of the city's many open-air drains.

A guard nervously ushered us into the factory, where the air was heavy, the lighting broken, and the floor muddy. Along the way, the guard offered us, and the inspector from India's Central Pollution Control Board (CPCB), ice cream from one of the freezers. While my boss and I declined, the CPCB official did not hesitate to accept. The inspector remarked on the improper lighting and ventilation and collected effluent samples. Then we departed for the next inspection, at a meat-processing facility.

That was my first experience with the remnants of India's legendary "inspector raj," an entrenched system of onerous government regulation and inspection that has roots in the bureaucracy installed by the British in the nineteenth century. The regime falls hard on small and medium enterprises, which receive countless citations, fines, and closures for—among other things—polluting. I don't know whether the samples collected that day ever made their way to a lab or if the company was ever cited. The CPCB has doggedly pursued its mandate of inspections and citations for generations, but industrial pollution continues to rise.

Recently, I have been thinking about that inspection and others like it. Could the CPCB offer solutions, rather than citations? Could the agency's vast knowledge and staff catalyze new ways for firms to work? Is it possible that the owners of a sketchy ice cream factory and a frazzled government inspector could combine forces to produce hygienic ice cream, good jobs, and clean effluent and thus help foster a vibrant, ecologically sustainable economy? In other words, could the creaky old inspector raj be repurposed for the future?

It is increasingly clear that the intergovernmental process to address climate change rests upon a presumption that countries must accept their "burdens to bear." This puts carbon management at the center of the problem, pitting entrenched institutions responsible (directly or indirectly) for management of the fossil fuel value chain against forces that rightly wish to turn the tide. This antagonistic conceptualization also ignores the flip side—that the energy transition offers opportunities to share in new technologies and ways to create value, a cleaner environment, and potentially a more equitable economy in which pollution doesn't fall hardest upon the poorest.

As a venture philanthropist based in the European Union, I believe tremendous opportunities could be unlocked if we could harness the power of entrenched bureaucracies for the better. India's dual challenge of reducing carbon emissions while raising the standard of living for its citizens is huge. The expertise of the country's enormous civil service, one of the oldest in the world, cannot be overestimated. Rather than relegating legacy energy management institutions to the past, India now has an opportunity to speed the pace of change by helping the people who work for them apply their knowledge and know-how to our future.

A laboratory for institutional innovation

Today, India's energy management institutions face an extraordinary confluence of challenges that, together, provide a once-in-a-generation opportunity for change. Not the least of these challenges is carbon. Under pressure to declare a carbon emissions reduction target, India announced a goal of net-zero emissions by 2070 during November 2021's COP26 in Scotland. This means the country has only 50 years to get off the coal value chain that is responsible for 70% of

its electricity, employs roughly 20 million people, and generates considerable revenues for the government.

A second and ongoing challenge is that India must constantly innovate to balance its growing intellectual capital—which is making it an influential player in information technology, space exploration, and biomedical sciences—with its pressing need to alleviate poverty and improve living conditions for hundreds of millions of citizens. Over the last decade, as part of this effort, India has provided electricity to nearly 50 million new users annually—equal to the entire population of Spain every year—culminating in electrification of virtually all households by 2019.

Almost simultaneously, in 2018, the use of coal for electricity generation peaked and began to decline as renewable energy became the cheaper option, putting terrific financial pressure on coal-dependent utilities.

The final straw was the arrival of the COVID-19 pandemic. India's energy management institutions, particularly cash-strapped, state-owned ones, are struggling to keep the electrons flowing while navigating this rapidly evolving energy landscape.

To recover from the pandemic and to meet its international climate commitments, India now needs to inject a significant amount of capital—much of which may come from outside the country—to fix the entrenched problems of its power sector and progressively transition away from coal. Managing this transition while keeping the lights on, maintaining economic growth, and reducing poverty cannot be done if fossil fuel ministries follow their old mandates. Moving forward will inevitably involve disruption: as new technologies and business models are created, these venerable ministries will need to learn to live with—and even embrace—obsolescence.

India's fossil fuel management ministries and government bodies, anchored so firmly to previous regimes and requirements, are still struggling to repair yesterday's problems. By changing their mandates and incentives away from specific fuels and toward the delivery of energy services and electrons, these bureaucracies could remake themselves to lead the country to a future economy that is environmentally, financially, and socially sustainable.

Institutional competence meets conflicting incentives

For decades, India has rightly argued that its people are energy-poor and require access to more affordable energy to improve their livelihoods. This argument makes a lot of sense in a country where the average per capita primary energy consumption is about 7,000 kWh (compared to nearly 80,000 kWh in the United States). However, it also encourages ministries to judge their progress by how much fossil fuel the country consumes. Despite the

STEVE MILLER, *Quantum System*, 2020, inkjet, pigment dispersion, silkscreen on canvas, 39 x 69 inches

transformation of energy markets and climate targets, India's ministries and corresponding state power departments, central- and state-owned utilities, and state-owned fossil fuel companies are incentivized to mine, deliver, and burn more fossil fuels. And they do their job very well. However, these conflicting incentives prevent the country from reaching larger goals, like achieving energy independence, reaching fiscal solvency, and meeting climate and pollution targets.

The problem of conflicting incentives at the institutional level is acutely obvious at India's Ministry of Coal, which has only one mandate: to ensure that enough of the black rock is mined domestically to continue feeding India's growing electricity demand. Meeting these targets provides essential income to central and state governments, while also carrying both revenue and purpose to other connected public entities, like Indian Railways, which transports the material, the National Thermal Power Corporation (NTPC), and Coal India Limited, the mining conglomerate that controls 90% of coal reserves in the country. Thus, the Ministry of Coal's mission extends through many sectors and organizations, employing between 13 and 20 million people.

But this business model is unsustainable. Despite having the world's fourth largest coal reserves, bottlenecks in the domestic supply chain have long forced India to turn to expensive imports. By 2018, it became clear that coal couldn't compete commercially with solar and wind. Even before COP26, the International Energy Agency (IEA) estimated that India's use of thermal coal could decline from 70% in 2020 to 30% of the electricity generation mix by 2040. In addition, by 2030, India aims to quadruple renewable energy production, reflecting stunning success in bringing the costs of solar energy down while building access to global capital.

So, in an unforeseen twist, coal's successes are accelerating the fuel's demise. The bureaucratic and physical infrastructure around coal has played a key role in transforming the country's economy and industry. But as the Ministry of Power brought electricity to 500 million new customers over the past decade, it also hastened the system's financial reckoning. With the newly expanded service area, India's already beleaguered state-owned electric utilities required these huge numbers of new, largely agrarian customers to pay the cost of electrical generation to help recoup costs for a sector already operating in the red.

There's a productive irony here. While other countries have been debating the strategy of electrifying everything as a route to net-zero carbon emissions, India found itself going through this energy transformation almost passively as soon as renewable electrons were in a position to outcompete oil and gas molecules. And even though the Ministry of Coal, the NTPC, Indian Railways, Power Finance Corporation, and Coal India Limited understood this shift better than anyone else, none of them were able to move at the pace required to steer the process or respond to its new demands. Having started a revolution that electrified India, they could only stand by and watch it crush their collective business model.

Still tied to delivering more coal, the relevant government power institutions are unable to responsibly invest public capital in building a climate-aligned energy system capable of incorporating cheaper, cleaner energy delivery systems as they emerge. Meanwhile, similar mandates drive the whole system, so that the IEA's recent India Energy Outlook forecasts that India's imports of petroleum and natural gas, already a significant financial burden, could triple by 2040.

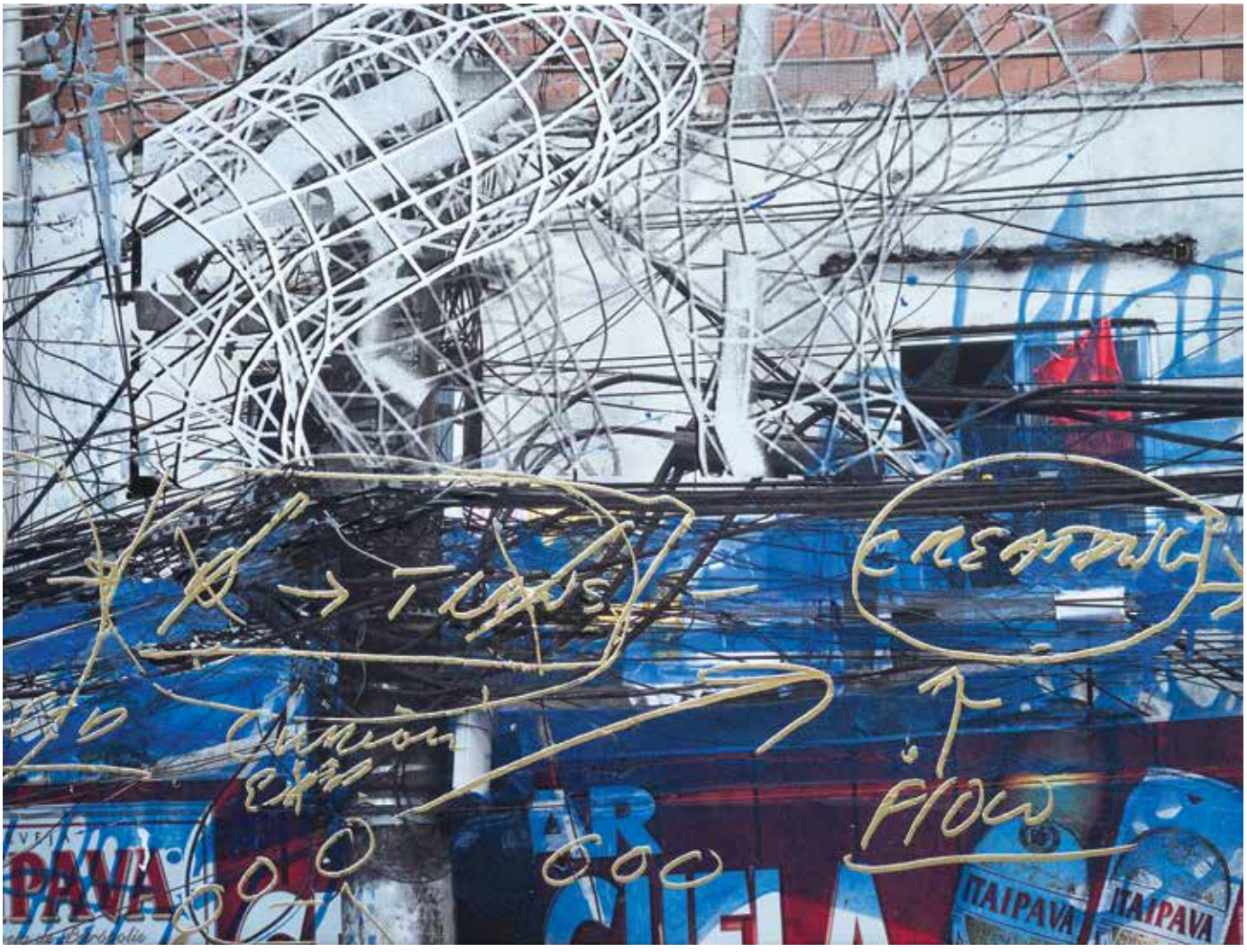
If the country's institutions were able to take advantage of this moment through new mandates, rather than remaining locked into energy targets from the past, they could very well power India's renewable energy ambitions, freeing up labor and resources all across the system. For example, if Indian Railways were freed from hauling coal, it could seize the opportunity to use its vast network and sophisticated logistics capacity to, among other things, dominate domestic freight transport, reducing the need to build more road infrastructure for trucking. Likewise, if the Ministry of Petroleum and Natural Gas were freed from increasing expensive liquified natural gas imports, it could shift to working with green hydrogen and renewable biogas in its pipelines. And, as these mandates move, the signals to allied industry would also move, so that, for example, Bharat Heavy Electricals Limited, the largest power generation equipment manufacturing firm, could pivot to making components for the renewable energy value chain that the country so desperately needs.

2009: The "gas" station of the future

One reason to think that repurposing India's old ministries toward new goals could be successful is that the country's private sector has been exceptionally flexible, investing in renewable energy technologies and disruptive business models and seeking to profit from changes that might seem heretical in other countries, where fuel modes are more entrenched.

In 2009, I returned to the country as part of the Indian Youth Climate Network to help plan an epic 40-day, 3,500-kilometer electric vehicle (EV) journey from the south Indian city of Chennai to the capital of New Delhi. Though the vehicles were made by an Indian manufacturer, vast tracts of the country still didn't have electricity access. This was a challenge, as we needed to stop every 120 kilometers to charge the lithium-ion batteries. A particularly dark stretch on the map between Bangalore and Hyderabad looked problematic—so I went off to scout for power.

At an Indian Oil gas station on National Highway 44, the owner listened intently as I asked whether he had the right voltage for us to charge our vehicles. He pointed to several outlets in the station. None had the voltage we needed. Then he took me to a shed in the back of the lot near



STEVE MILLER, *Crisis Led to Insight*, 2019, inkjet, pigment dispersion, silkscreen on canvas, 22 x 29 inches

the edge of a farmer's fields, where there was an electric sugar cane-processing machine—as well as a higher-voltage connection. It was exactly what we needed.

Several months later, when we stopped at the station in our EVs, the owner was ready. As our vehicles charged next to the processing machine, we answered his questions. He immediately understood the business potential in supplying electricity as a fuel—and voiced his own concerns about pollution caused by gasoline and diesel. In fact, as a franchisee fuel distributor, he suggested that the Ministry of Petroleum and Natural Gas and the Indian Oil Corporation needed to be sold on the vision of selling electricity as a fuel. But the entrepreneurial transformations he had witnessed in his lifetime made him confident that he could navigate an unknown future full of change and challenges.

In this way, emergent technologies, new business models, and electricity as a common-denominator power have been converging in India for some time. The Indian Oil Corporation recently followed the instincts of that gas station owner by installing solar panels on its stations, is considering adding EV charging at thousands of locations, and has started venturing into the hydrogen space. Entrepreneurs are also piling on. Private sector Reliance Industries, led by India's richest man, has pledged to help bring down the cost of producing green hydrogen from $3–7 per kilogram to below $1.

Scaling such entrepreneurial efforts will require strategic alignment of policies at the top of current energy management institutions, as well as attention to who profits and who suffers at the grassroots. The possible transformation in this move to electrons must benefit all of society to be politically, as well as ecologically, sustainable.