Reinventing Fire: Three Energy Gamechangers for China and the World

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This decade China is set to regain the status it has held for 18 of the past 20 centuries: the world's largest economy. A major engine of historic success was China's inexorable drive to develop and deploy new technologies, far outpacing other civilizations. As Joseph Needham documented, and his student Robert Temple summarized in *The Genius of China*, about 90% of the technologies that underlay the West's industrial revolution were actually invented in China. Today, revitalizing China's innovation engine presents unique opportunities to accelerate the world's next industrial revolution—especially in energy.

China's recent decades of rapid development and urbanization have lifted hundreds of millions out of poverty but contributed to significant energy challenges. China is now the world's largest oil importer, posing energy security risks. Burning more coal than the rest of the world combined, China is the largest emitter of carbon dioxide, creating risks to which it is especially vulnerable. And a particulate emissions challenge is eroding public health and sometimes crippling whole cities.

The solution lies not in speeding along an accelerated and well-worn path blazed by many Western economies, but rather in leaping over energy insecurity, carbon, and pollution traps to innovate new energy solutions. Incremental improvements will not suffice. China can develop transformative solutions that decouple growth from material energy flows, and can embrace new sources of energy and prosperity that leave behind the fossil fuel fires of old. In ancient times, fire made us human, then fossil fuels made us modern. So Rocky Mountain Institute coined the term "Reinventing Fire" to chart how the global transition from fossil fuels to energy efficiency and renewable supply can create a new fire that makes us all durably prosperous, safe, secure, and healthy.

Reinventing fire will require technological, economic, and social innovation to retool China's economy for such leadership in the 21st century. Luckily, many of the building blocks exist today to supplant increasingly costly and polluting alternatives. Assembling and scaling the elements of the new fire will be a worthy challenge—not easy, but easier than not doing it, and worthy of China's impressive capabilities.

Specifically, three mutually reinforcing gamechangers have emerged as important enablers of the new fire: 1) achieving oil-free mobility, 2) adopting integrative design for radical efficiency in buildings and industry, and 3) redefining the future of the electric grid.

Our analysis suggests that an energy policy focused on these three transformations can be hugely profitable. A robust two-year investigation by our independent thinkand-do tank, Rocky Mountain Institute (RMI), found that by actively reinventing fire, the United States could support a 158%-bigger economy by 2050 while eliminating its use of coal and oil, saving $5 trillion in net present value, and reducing carbon dioxide emissions by more than 80%. Furthermore, these changes could be driven by business for profit at the local level, without the need for sweeping national legislation or regulation.

China, of course, has a very different starting point than the United States. Yet the benefit could be even greater for China, because it is almost always cheaper to build things right from the start than to fix them later; China has proven it can scale innovation with extraordinary speed; and the dynamism of the modern Chinese economy creates a crucible for innovation. Here are three gamechanging ideas for how China could rise to a leadership role in reinventing fire.

Gamechanger 1: Achieving Oil-Free Mobility

To shed a global addiction to oil, China could develop and deploy technologies to lightweight and electrify vehicles, dramatically improve mobility logistics, and help drive biofuel innovations to serve remaining mobility needs that cannot be fully electrified. Transportation is China's fastest-growing energy-using sector, so an early change in trajectory gains huge leverage over decades.

Ultralighting vehicles is the most critical step in making them superefficient and making electric vehicles economic. Two-thirds of the energy needed to move a typical car is caused by its weight—and every unit of energy we save at the wheels by reducing weight or drag saves six more units we need not waste getting that energy to the wheels, so it saves a total of seven units of energy at the fuel tank.

Replacing metals with ultralight, ultrastrong materials like carbon-fiber composites can provide safer, lighter, and more aerodynamic vehicles that consume severalfold less energy and could be simpler to produce with up to 80% less capital. Automakers have shown how such designs can reduce an automobile's total weight by 50–70%, reducing its energy needs by about half to two-thirds.

This makes electric propulsion affordable by needing only half to two-thirds as many batteries or fuel cells. Taken to volume production, as German automakers have begun to do in 2013, this approach could become cost-competitive with traditional Victorian stamping-die automaking, but enable radical flexibility and resource efficiency. China plans to nearly double its automaking by 2020. By leapfrogging from steel to carbon fiber and from gasoline engines to electric traction, this transformation would position Chinese manufacturing as preeminent globally in material and battery technologies for decades to come. Similar light-weighting and electrification approaches would prove invaluable in light trucks too.

China's heavy trucking and freight industry is a massive consumer of energy, moving goods internally and transporting manufactures abroad. Fleets of trucks, boats, trains, and planes would benefit substantially from all forms of vehicle efficiency and operational improvements, limiting energy use during loading, idling, and hauling. Tripling the efficiency of heavy trucks and ultimately more than tripling that of jetliners appears feasible and cost-effective for China, too. Such technical improvements represent a transformative policy solution to China's existing pollution challenges: rather than curb oil emissions through limiting vehicle use, instead make these vehicles emission-free in the first-place.

Beyond these "technical" adjustments, there is significant opportunity for logistics optimization. Loading rates are one-third lower in China than in developed countries. This is partly due to highly fragmented ownership: 90% of all road freight is carried by providers with ten or fewer trucks, and an astounding 40% by single-truck carriers. Finding seamless ways to manage loading through multi-modal design, IT-enabled dispatch and load-matching via online markets, and transit-synergized urban growth models can help minimize the costs, burdens, and impacts of moving goods and people.

For a large fraction of heavy-duty trucks, and virtually all boat and air travel, electrification will probably never be economic. However, their oil can still be replaced. While natural gas may be a near-term answer in some applications, a longer-term migration to advanced biofuels would be beneficial, and some drop-in replacements, requiring no changes in infrastructure, are expected to become cost-competitive in the next few years. Hydrogen can also become a realistic option to fuel superefficient trucks and planes. China's rapidly growing appetite for petroleum creates strong reasons to lead in seeking such alternatives.

Gamechanger 2: Integrative Design

The factories and buildings that use nearly all of China's energy can save more energy than previously thought, yet at lower cost, by a new technique we call "integrative design." It rigorously applies orthodox engineering principles, but achieves radically more energy- and resource-efficient results by asking different questions in a different sequence to yield a different design logic. Optimizing whole systems for multiple benefits, not individual components for single benefits, can often yield *expanding* rather than the normal diminishing returns to investments in energy efficiency, making very large (even order-of-magnitude) energy savings cost *less* than small or no savings.

Energy productivity has long been a key to economic growth, and except for a brief lapse in 2003–2005, China has consistently improved its GDP per unit of energy input. Indeed, China is the only country where such improvement exceeded 5% per year for a quarter-century (until 2001). Best-practice sharing through programs like the 10,000 Enterprise Program, improvements in standards for such common systems as motors and boilers, and closing uncompetitive facilities have all helped boost these results. And while great progress has been made, much opportunity remains—especially in industry, which uses about two-thirds of China's primary energy. Energy waste can often be attacked at its source: in the very design processes for the furnaces, smelters, refineries, kilns, and other devices that drive energy consumption in the first place.

So what happens when integrative design meets China's energy productivity imperative? One example from a carpet factory in Shanghai illustrates the potential. Using integrative design concepts from a Chinese engineer in Singapore, the layout of a heat-transfer pumping loop was radically changed to replace long, narrow, crooked pipes with short, fat, straight pipes. The resulting design used at least 86% less pumping power to do the same job, and since the needed pumping equipment was smaller, the whole system cost less to build.

Industrial motors use about 60% of the world's electricity. And pumps and fans account for half of that power consumption. Thus, designing out typically 80–90% of the friction those pumps and fans need to overcome can yield staggering benefits across many energy-intensive industrial processes. For example, integrative design of a Texas Instrument chip fab saved much energy and water while cutting total capital cost 30%. A later fab design is expected to save approximately two-thirds of the energy and half the capital cost. Redesigning a Hewlett-Packard data center in England tripled its computation per watt at no extra cost, but full adoption of its integrative-design potential could have saved an estimated 95% of its energy and about half its capital cost.

Integrative design can also yield impressive energy savings in buildings. Residential and commercial buildings account for roughly one-fourth of China's energy use. And while some of the most spectacular and energy-efficient buildings in the world have recently been constructed in China, the average multifamily complex, high-rise commercial building, or historic hutong is poorly insulated, drafty, over-conditioned, and inefficient. Applying integrative design by considering the whole building as a system can yield remarkable savings in all types of buildings while valuably improving workers' health, comfort, and productivity.

In both new and old buildings, better-performing windows, insulation, and air-tightening can often make heating, cooling, and air-handling equipment much smaller, more efficient, and cheaper both to build and to run. Doing the right retrofit steps in the right order at the right time can often save 40–70% of the energy in existing commercial buildings, yet repay their cost within a few years, as RMI's retrofits of the Empire State Building and other big, old U.S. buildings demonstrate.

New buildings can save even more at little or no extra cost. Net-zero-energy buildings (now with normal or slightly lower construction cost in Europe) can combine high efficiency with renewable energy for daylighting, natural ventilation, and even power production. Integrating seamlessly with more conventional heat, power, and storage systems can create resilient buildings or campuses that draw on public resources where necessary, but offer standalone assurance when not. From individual single-family farms to large industrial parks, advanced control optimization and remote monitoring can provide comfort, efficiency, and savings enabling new business models focused on the end-results that customers really want: warm rooms in the winter; cool rooms in the summer; and lighting, electronics, and hot tea on demand.

Reimagined structures and design must be paired with a conscious attention to minimizing the plug loads within the buildings themselves. Here, through successive development of minimum efficiency performance standards, China has made great progress, but there is more to be done. As appliances, information technology, and other devices gain wider adoption, ensuring minimum standards are enforced and rewarding highest performers requires vigilance and drives more innovation.

Gamechanger 3: Redefining the Future Grid

Needing less electricity would ease and speed the China-led global shift to renewable electricity. Once radical energy efficiency has minimized the electricity needed by buildings, industry and a newly-electrified vehicle fleet, a right-sized grid can be architected to meet customers' exact demands. Options for that right-sized grid could be fully centralized, or hybridized with local, distributed energy resources.

RMI's *Reinventing Fire* project for the United States investigated three kinds of centralized grids (current asset profile, shift to nuclear and carbon capture and storage, and shift to large-scale 80% renewables plus natural gas) as well as a hybridized half-distributed, 80% renewable grid. The economic cost of the new grid throughout 2010–50 was roughly equal in all cases—about $6 trillion in net present value. But the cases differed profoundly in eight kinds of *risk*: financial, operational, security, climate, water, fuel, health, and public acceptance. Comparing these risks suggests the hybridized, distributed model appears far preferable to the others.

Even large amounts of distributed and centralized renewables, especially diversified portfolios of varying solar and windpower, appear resilient with minimal storage (<10% of generation). Such choreography has already been achieved in countries like Germany and Denmark (with 23% and 41% renewable electricity in 2012, respectively, but with Europe's most reliable supplies), and even at 48% in Spain and 70% in Portugal for the first half of 2013.

Distributed generation makes high-renewables futures easier and more secure. Denmark has already shifted from centralized power stations, mainly burning coal, to distributed wind turbines and cogeneration, often fueled by agricultural wastes. Denmark intends to reach 100% renewable electricity by 2035 and 100% renewable energy in all sectors by 2050 at essentially no extra cost. Denmark is also reorganizing its grid in a "cellular" architecture that prevents cascading large-scale blackouts, giving its citizens energy security and peace of mind. Cuba, too, aided by

Chinese efficiency technologies, has used distributed generation and microgrids to sustain vital services even when hurricanes shred its rural grid.

While China's grid has its own unique needs and attributes, the flexibility and security of a more distributed grid and the possibility of a highly renewable future are both worth considering—especially since China is the world leader in six renewable technologies. Interactive two-way smart grids that can use demand-side resources to balance grid generation, such as Tianjin is currently piloting, are another important building block of China's secure electricity future. And more distribution-level intelligence including autonomous controls can integrate microgrids and balance the complex network of loads and generators.

Achieving an 80% mix of renewables may be decades away, but with more new Chinese electricity in 2012 coming from non-hydro renewables than from all fossil-fueled and nuclear sources combined, the shift is gaining momentum.

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We stand at a rare moment in history, one where current knowledge and resolve can be applied to deliver abundant energy services reliably, cleanly, and affordably to all. For China today, the gamechangers we describe could offer an unprecedented opportunity. As a focal point for national innovation, reinventing fire begins with radical efficiency made possible by a redesigned industrial base, building stock, and vehicle fleets, delivering saved megawatts ("negawatts") and barrels of oil ("negabarrels") in abundance. This could create new world-leading industries, and redeploy supply-side capital to other national needs, strengthening the business case for clean energy. The net result is prosperity, security, and harmony—three virtues critical to a revitalized China.

Some 2,400 years ago, Chinese innovators drilled more than a kilometer down for natural gas and liquid hydrocarbons, delivered through bamboo pipes. Today, their descendents can reinvent fire and become the fulcrum for creating both a beautiful China and a healthier, richer, fairer, cooler, safer world.

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