

100 YEAR
FORECAST

DEINDUSTRIALIZATION

THE END OF CHEAP FOSSIL FUEL

THE CHALLENGE

Achieving sustainable lifestyles worldwide with renewable resources

THE SHAPE OF TRANSFORMATION

From pipeline infrastructures to agile energy ecosystems

The energy transition of the 21st century is about more than a switch to renewables. Cheap fossil fuel has literally fueled the industrialization of the world, from long-span steel bridges, ubiquitous automobiles, and refrigerated ISO containers to fertilizers, fast foods, and plastic bags. Capital has flowed through the wide margins between the cost of extraction and the benefits to mass markets for consumer goods and services. But over the coming century, this profitable arc of mass production will bend downward as the costs of fossil fuel, including the environmental costs, squeeze the margins and retard the flow of capital through a global infrastructure built for scale.

At the heart of this shift in our vision of unlimited progress is a simple fact: there is no single silver bullet when it comes to replacing fossil fuels. The high-surplus flows of coal, gas, and oil will be replaced by much lower-surplus flows of perhaps dozens of technologies that provide less energy at higher costs. The silver bullet of industrialization will be replaced by a scatter shot of alloy pellets.

And this simple fact points to the shape of the post-industrial world at the end of the century. It will not be a world where we turn on the tap to abundant flows of electrical power or call in monster machines to power through bigger-than-life tasks. It will be a

world of precise, just-in-time application of power. The sources of power will be embedded in the activities of our daily lives. We will be skimming off charges from our own movements. We will tap into rebuilt environments designed to leverage ambient energy sources, from the sun and wind to photosynthesis, radio waves, and bacterial metabolism. Life will be battery-powered, energy will be mobile, and production will be organized to take advantage of short pulses—more like Internet packets than continuous currents.

The units of organization for the economy will be ecosystems, and the most resilient ecosystems will be those that have the most pathways for recovering and repurposing waste, whether it's lost heat or discarded material or even carbon emissions. In this sense, 21st century production continues the industrial engineering goal of finding profit in the elimination of inefficiency. What's different is that efficiencies will be found at multiple scales and using multiple technologies. What's also different is that 21st century engineers will be working with living systems, not against them.

And in the course of doing so, they will change the nature of living systems.

—Kathi Vian

THE CORE DILEMMA

The core dilemma as we transition to a world of agile energy ecosystems will be the desire to extract the most value from diminishing fossil fuels (and the production systems they support) versus the need to rapidly advance a new paradigm of human/energy ecosystems.

Dilemmas typically take shape when short-term benefits mask long-term costs— or when long-term benefits require short-term costs. These are particularly acute when one group experiences the costs while another experiences the benefits.

SHORT TERM

Costs

- High investment costs in alternative energy and infrastructure
- Potential loss of fossil fuel revenue from a too-early transition to alternative fuels
- Slower GDP growth in industrializing economies
- Loss of jobs in heavy industrial sectors and heavily industrialized cities

Benefits

- Near-term job creation in alternative technologies
- Immediate slow-down of fossil fuel emissions from some replacement technologies and from conservation

LONG TERM

Costs

- Higher costs of climate adaptation, the longer we depend on fossil fuel
- Increased disaster losses from climate change impacts as a result of delayed transition to clean fuel
- Increased probability of collapse of economies around the world due to failure to create next value curve
- Overall reduction in energy density of our systems

Benefits

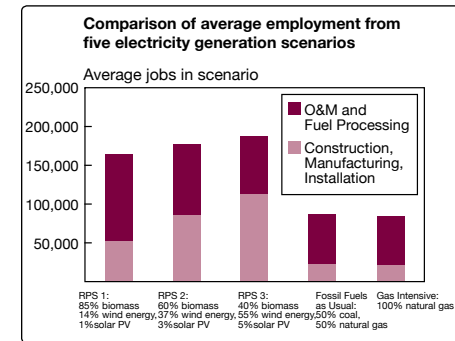
- Broader base of energy security, with lower risk of single-actor control of energy infrastructure
- More resilient energy systems in the face of natural and human-made disruptions
- More sustainable platform for economic development
- Leveling of playing field for under-capitalized nations if they leapfrog existing infrastructures

DEINDUSTRIALIZATION KEY FRICTIONS

DEINDUSTRIALIZATION

Power companies build out solar

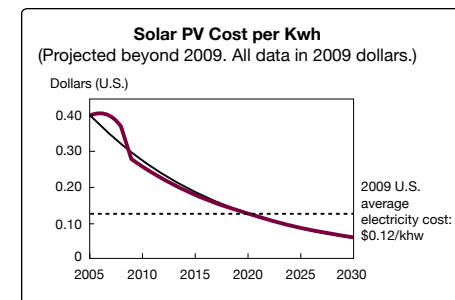
SIGNALS



rael.berkeley.edu

Renewable energy jobs

In three different renewables scenarios, renewable energy creates more U.S. jobs across diverse sectors than either a "Fossil Fuel as Usual" scenario or a "Gas Intensive" scenario.



DOE NREL Solar Technologies Market Report, Jan 2010; Projections by Naam 2011

Moore's Law of Photovoltaics

The cost of per Kwh of solar photovoltaics has declined exponentially for 30+ years and is projected to fall below the current cost of energy by 2020.

THE TECHNOLOGY

Solar vs. Everything Else

- Diverse technologies compete for share of fragmented market.
- Cost of solar electricity drops below current retail electricity between 2015 and 2020 (in some locations).
- Cost of solar drops much more rapidly than competing renewables.
- Off-earth solar distracts from land-based solar.
- New technologies, especially ambient radio wave and small-scale nuclear—raise health and safety concerns.
- Chinese and Indian solar technology out-competes U.S. and western replacement technologies.

THE SCALE

Centralized vs. Distributed

- Centralized fuel production continues to lose jobs unrelated to environmental regulation or shift to renewables.
- More distributed renewables industry generates more jobs per average installed megawatts (MWa) than more centralized fossil fuel industries.
- Measuring conservation becomes more difficult as energy infrastructure is distributed.
- Business models struggle to accommodate varying scales of efficiency.
- Small-scale human waste conversion competes with large-scale MSW systems.
- Waste-to-energy is most efficient in large, centralized operations, but waste management is increasingly decentralized.
- Residential solar competes with large-scale solar farms.
- Subsidies for residential solar buildout compete with solar R&D for government dollars.

THE COSTS

Conservation vs. Full Replacement

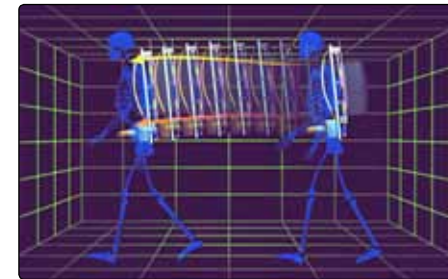
- Demand slows locally, but grows globally.
- Growing demand increases likelihood of climate disasters.
- Growing number of climate disasters decreases energy demand locally.
- Cost of climate disasters grows exponentially, while cost of conservation declines.
- While energy efficiency policies drive more jobs, the greatest burden of replacement of inefficient appliances and cars falls on the poor and unemployed.
- Lower energy costs in leapfrog nations drive economic growth, attract jobs and workers, and increase energy demand.
- Cost of solar electricity in 2030 is half of what electricity costs today, undermining conservation.

DEINDUSTRIALIZATION

Early smart grid applications emerge

Lightning pack

Suspended backpack transforms energy from up-and-down movement into enough electricity to power personal mobile devices.



lightningpacks.com

Household waste digester

Biogas digester from Indian manufacturer Sintex Industries turns manure into fuel for cooking and electricity.



engadget.com

10 YEAR FORECAST THE BIG POWER SHAKEUP

The rising costs of fossil fuels—both monetary and environmental—are already driving a shake-up, not just within the energy industry, but across industries, municipalities, and households. The industrial model of cheap fuel and big infrastructures is beginning to unravel as new, often small-scale power sources compete for market dominance and the workforce is restructured to produce power in new ways. Over the next decade, traditional fuel sources will become less tenable, well before renewable energy sources are ready to meet demand. As existing power players jockey to maintain control of the energy marketplace, the necessity to tap multiple renewable resources will drive fierce competition from new entrants, including consumers themselves. Technologies will compete with one another while integration into any universal grid will remain awkward. Conservation will result more from the high costs of energy, disrupted employment, and local climate disasters than from coordinated policies.

THE TECHNOLOGY: SOLAR VS. EVERYTHING ELSE

Solar technology is taking an early lead, with an exponential decline in cost of watts per hour for the past 30+ years. But even at a price point of less than half the current cost of electricity by 2030, solar is unlikely to meet the world's total demand for power. As a result, this decade will see the growth of a variety of niche technologies that meet specific energy needs and potentially shape the future of global energy production. Wind farms and biomass production will reinvent agriculture. Small-scale, modular nuclear will transform massive construction projects into factory floor projects. Ambient radio wave technology will activate small mobile devices and sensor networks, replacing batteries in things like mobile phones and heart monitors. Piezo-electric will redesign everything from our clothes to our architecture to take advantage of human-generated energy.

THE SCALE: CENTRALIZED VS. DISTRIBUTED

As fractious as the technology will be the battles to control the production, distribution, and profits of the new energy. On one hand, existing big energy players will try to choreograph a complex dance designed to make the most of their existing fossil fuel investments while attempting to enclose the emerging technologies in a centralized system of production and distribution. They will argue for large-scale solar farms over distributed rooftop panels and industrial-scale wind and biomass farms over small farm producers. On the other hand, increasingly sophisticated consumers will arbitrage the costs and conveniences of different energy forms, looking to smart grid protocols to create a packet-switching model for energy that gives them customized value—and perhaps reduces their energy footprint. This “application layer” of the smart grid will be the locus of innovation and profits.

THE COSTS: CONSERVATION VS. FULL REPLACEMENT

The decade will measure the gains and losses in this period of energy transition not only in energy prices and GDP, but also in jobs, in climate adaptation costs, and in the costs of climate disasters. The renewables industry will generate more jobs than the traditional fossil fuel industries, but a focus on conservation will amplify those job gains with replacement markets for energy-efficient appliances, automobiles, buildings, and industrial equipment. In the short term, conservation will be essential as we bridge the gap between fossil fuels and renewables—while avoiding even more extreme climate impacts.