Can micropower be as deep a game-changer as microprocessing?

by Roberto Verzola

Thank you for the invitation to talk about renewable energy. My talk will focus on future possibilities in the energy sector, using my long experience in the information technology sector as guide.

Why is information technology a useful guide in anticipating the forthcoming developments in energy technologies?

Because the energy sector today may be undergoing some very fundamental changes that more or less parallel the earlier and still ongoing technological revolutions in the information sector. These changes include: high to low prices, big to small installations, hardware to software control, unconnected to networked units, and wired/fixed to wireless/mobile. The grid, of course, antedates the Internet by more than a century, so going from “unconnected to networked” is not new to the energy industry. This also means that the energy industry should not be worried that distributed generation will make the grid obsolete.

Let me list some of the precursors of the forthcoming changes that may happen in the energy sector:

Table 1: A comparison of the information and energy sectors

Change	Information Sector	Energy Sector
Costs/prices	Declining cost/price trends	Observable in solar, wind, storage
Economic scale	Micro over mega	Observable in solar, perhaps hydro
Type of product	Gadget/appliance/embedded	Beginning to appear in solar
Technology	Digital electronics	Increasingly observable in renewables
Flexibility	Fixed hardware vs software programmability	Ongoing change to digital/programmable controls
Key components	Intelligence, storage, power source	Intelligence and storage rising in importance
Topology	Network of networks	Electric grid is the precursor of the Internet
Business model	Peer-to-peer vs client/server	Client/server dominates, peer-to-peer emerging

I have seen and was part of the information revolution in the Philippines from the beginning. From the entry of the very first microcomputers and microprocessors (Apple II, TRS-80, 8080, 6502, Z80) to the exchange of the earliest international emails and the access to the early Web (1994), to the earliest mobile phones (they looked like boxy radio sets with the familiar telephone handset). In its impact, this technological revolution has been like a series of tsunamis, sweeping aside old ways of doing things, reaching into every available nook and cranny of society, and revolutionizing not only information technology but also our livelihoods and our very lives.

From this hindsight, it is clear that the energy industry today is on the threshold of a similar revolution. These are exciting times for the energy industry. The signs are already there, but whether it will be as far-reaching or as deeply-changing as new information and communications technologies is still too early to tell, because the outcome will also depend on how the new rules of the game will be formulated and the kind of strategies that old and new players will adopt under the new rules.

Declining prices

The key factor – as it was in the information sector – is declining costs and therefore prices. This creates the economic forces that drive the changes, as the economic process called substitution relentlessly targets old expensive ways and replaces them with newer, lower-cost ways of doing things. In economics and in markets, all other things being equal (the most over-used term in economics), the cheaper way, the lower-cost product, will sooner or later replace the more expensive one.

According to conventional economics, lower prices will result from a general increase in supply. These lower prices then lead consumers to buy greater quantities of the product. However, lower prices also tend to discourage producers from supplying more. This restricts supply, pushing prices back up and eventually reaching an equilibrium of quantity and price.

Under certain conditions, however, this equilibrating mechanism works in reverse, and negative feedback turns into positive feedback. Instead of discouraging higher production, the increased sales enable producers to reach economies of scale that allow them make more profits by selling even more, at lower prices, which then encourage the market to buy more quantities of the product. The virtuous cycle of increasing demand and supply, coupled with declining prices, leads to an abundance that trumps conventional economics, which is fundamentally premised on scarcity.

Although we might prize scarce items highly, civilizations are built on abundance. It is the abundance of biomass that fuelled our early use of fire. It is the abundance of fossil fuels that propelled the Industrial Revolution. It is the abundance of silicon, transistors and electronic chips that launched the information revolution and propels it today. Although they are the game-changers, these foundational materials of civilizations do not usually get noticed, because their abundance makes it easy to take them for granted. It also makes them less interesting to economists, whose attention is instead focused on scarce economic goods which, precisely due to their scarcity, are poor universal material and energy sources for building civilizations.

The coming abundance emerging from the continuing decline in the investment costs of solar, wind, storage and other renewable energy technologies – together with their near-zero marginal costs of producing electricity -- will surely usher another technological revolution whose features we are yet to fully discern. And this is what I will try to do today.

Scale economics

Economies of scale lead to higher supplies and lower prices. Under certain conditions, the lower prices lead to higher demand that in turn create better economies of scale. Feedback turns positive instead of negative. Exponential growth in production and exponential decline in prices are the marks of these explosions of abundance. We already see them today in solar, wind and storage technologies. The impact of these technologies will sooner or later spill over to other renewables, like hydro, geothermal and biomass. To what extent depends on how players in those particular industries are able to learn from the information industry the lessons of increasing returns to scale..

Economic scaling may go both ways, though one direction may turn out to be better than the other.

Going bigger is one way to scale up. In the early days of computing, bigger was better, and mainframes tended to become more and more powerful.

Imagine yourselves IBM engineers during its mainframe heydays. IBM had been so dominant in the computer market that it was called “Snow White” and its competitors the “Seven Dwarfs”. Beside the IBM 360 or the IBM 370 mainframes, the Apple II must have appeared like a toy not worth bothering about. It took IBM around a decade to acknowledge the logic of a scaled-down computer that was two or three orders of magnitude cheaper than their mainframes. And when they finally jumped in, still without recognizing the game-changing nature of the microcomputer, IBM played by its own rules and made such major mistakes that they not only failed to dominate the microcomputer market but also lost their industry dominance.

A different kind of economic scaling took over when computers became smaller. The microcomputer and its various incarnations (desktop, portable, laptop, notebook, netbook, tablet, smartphone, embedded processor, etc.) created a product that operated on another type of scale economics. And it turned out to be one of the key innovations that triggered today's information revolution. Who uses a mainframe today? These machines still have a role, of course, but probably not a central one. Would you rather be the IBM or the Intel of the energy industry?

On a similar note, who uses a landline today? Likewise, these quaint devices will still have a role to play, but again probably not in the center of action.

Scale economics in solar

In the energy sector, the dramatic impact of economies of scale is best seen in the exponentially rising global production of solar panels. Its result, averaged over almost four decades, is the steady decline in prices of around 9% per year, and of 20-22% for every doubling of cumulative production. It is clear that scale economics is working well in solar production. As a result, solar rooftops are already the cheapest source of electricity in many parts of the Philippines today. This phenomenon will occur in each distribution utility service area over the next few years as solar PV costs continue their decline. Within a few years, rooftop solar will become the cheapest source of electricity nationwide. Look at the downscaling that mainframe took—from mainframes, mini, micro, desktop, transportable, portable, laptop, notebook, netbook, tablet, embedded, etc. It is not hard to imagine, in the not-so-distant future, a similar transformation for solar. When solar panels become the roof or wall itself, for instance, the new round of savings will trigger more virtuous cycles. Then, can solar tablets, solar wearables (hat, shirt, wrist band, etc.), and of course, embedded solar, be far behind?

Among the renewables, rooftop solar holds the biggest promise as a clean and abundant energy source for rebuilding climate-ravaged societies because of the following competitive edge:

Largest price declines. Solar PV has shown the largest decline in prices, averaging a 20-22% decline in PV prices for every doubling of cumulative production, which translates roughly to a 9%

decline per year over the past four decades.

Cheapest per-kWh price. Electricity from solar rooftops avoids all transmission and distribution costs, as well as other add-ons to the grid electricity price, like metering charges, VAT and other taxes, system loss charges, universal charges, etc. Thus, solar rooftop electricity enjoys a built-in competitive edge over all other grid-delivered electricity. In many service areas in the Philippines, rooftop solar is already the cheapest source of electricity.

*Shortest implementation times***.** Complete solar PV systems can be bought off-the-shelf and installed in a few hours. Larger systems may take a few days. No other technology, renewable or not, approaches the short install times enjoyed by rooftop solar.

*Smallest incremental investments***.** Solar PV investments can be done in small affordable steps, from a few watts to a few kilowatts for households and small business establishments, to a few megawatts for utility-scale solar.

*Most accessible to low-income households***.** No other technology today can do better than rooftop solar in enabling ordinary households to generate electricity themselves. The sun is also more universally accessible than steady winds, steep river flows, underground heat, or biomass.

Lowest system losses. Longer wires have more resistance and larger losses. Even hydro, wind, geothermal and biomass electricity have to pass through transmission and distribution lines to reach consumers.

Most reliable long-term source. The sun is the most reliable source of energy. Humanity cannot deplete it or use it up. It rises predictably every morning. Even if regularly covered by clouds, its output over a week, a month or a year can still be predicted with good accuracy. And with better weather prediction tools, our ability to predict solar output with greater certainty will improve over time.

*Least environmental impact***.** Solar rooftops are the only energy source under which you can sleep soundly, without worrying about hazards to your health, safety and the environment. The health and environmental impact of solar PV manufacturing is by no means zero, but they are more easily mitigated and solved, compared to the super-massive impacts of nuclear and fossil fuels.

Remember too that rooftop solar is a demand-side – not a supply-side – approach. It reduces the demand for electricity over the grid and therefore enjoys all the advantages of demand-side management (DSM) approaches, such as incremental investments, minimal system losses, no transmission and distribution costs, and so on.

Remember finally that rooftop solar is only part of an overall demand reduction strategy, because it reduces grid demand only when the sun is up. The other strategy is the rapid deployment of LED lighting, to replace inefficient light sources like fluorescent and incandescent lamps. This takes care of the reduction in nighttime peak demand. The third strategy is energy storage, which should become increasingly competitive within the next several years. These three technologies are already showing the marks of a virtuous cycle, and can be considered the leading edge of the renewable energy revolution. Battery storage, in particular, will enjoy dramatic economies of scale because three major industries – the electric vehicle industry, the mobile telecommunications and computing industry, and the energy industry – are simultaneously at work to bring down their costs .

Scale economics in wind

What about wind, hydro, biomass, or geothermal? Are we going in the right direction in terms of scale economics?

Wind turbines in the past were kilowatt-scale machines. The wind industry reached a milestone with its first one-megawatt turbines. Today, 2-3 MW wind turbines are common, and 5-7.5 MW giants have started to come online.

To wind turbine designers, the larger scales are justified because the power that can be extracted from the wind increases as the cube of the wind speed. Wind speeds in turn steadily increase with height. Taller towers also allow longer blade spans, and the power that can be extracted from the wind increases as the square of the blade length. Indeed, this seems like a strong case for taller towers and larger turbines.

But are wind technologies scaling in the right direction? Or is this a similar case of building larger and larger mainframes?

Let us look at the other scaling aspects of wind turbine technology. As towers get taller, they become heavier. Strength generally increases with cross-sectional area. However, area increases in proportion to the square of the linear dimension, while weight increases in proportion to the *cube* of the linear dimension. Therefore the materials used must also be stronger. Clearly, there are technological limits to the heights that towers can be built.

There is also the problem of minimum and maximum speeds. The larger the wind turbine, the greater the minimum wind speed required to simply start it turning, wasting all wind speeds below this start-up minimum, even though low-speed winds are more common than high-speed winds. On the opposite end of the wind scale, the blade's tips will approach the speed of sound sooner as blade spans get longer, likewise setting a maximum allowable wind speed to prevent the turbine from tearing itself apart. Thus, the larger the turbine, the narrower its range of allowable operating conditions.

In the language of Internet designers, tower height and wind turbine size *do not scale up very well*. The direction they are taking will eventually mire the wind industry in the economics of decreasing returns.

The same thing might be said of hydroelectric systems. Megadams, like mega-turbines and mainframes, do not scale up very well and reach size limitations very quickly.

Note also how decreasing returns characterize the scaling up of conventional power plants. The largest conventional plant in operation today in the Philippines is the Sual coal power plant, which consists of two units of 647 MW capacity each. While larger machinery may, in some aspects, enjoy better efficiencies than smaller ones, these are negated by inefficiencies in other aspects. The requirements of grid reliability, for instance, mandate that in addition to a regulating reserve of 4% of the total supply, grid operators must ensure the availability of the equivalent of two more 647-MW units, or almost 1,300 MW, as reserve, charge to the consumer of course. Splitting the 647 MW among several smaller machines might be less efficient from one particular perspective, but it would have also spared us the recurring cost of maintaining and operating 1,300 MW of reserve capacity, year after year, purely for backup.

So, what about scaling in the opposite direction? Can microhydro, microwind and similar micropower plants also enjoy economies of scale when they are made smaller?

Scale economics in hydro

A recent project I organized involved partnering with local governments to explore renewables at the community level. Part of the project involved engaging the services of microhydro experts to do the resource evaluation and site selection.

From what I saw, microhydro technologies have a long way to go before they can approach even a fraction of the impact that microcomputers made on the industry. Microhydro resource assessment, site selection and design today are not so different from mega-hydro design. Different sets of engineers are employed for the hydrological, mechanical and electrical aspects, many of the components are made to order and require all kinds of engineering skills, and each installation is highly site-specific. This is similar to how offices in the early days of desktop computing bought microcomputers that required hardware specialists to install and maintain them and software specialists to program and operate them. This was before the desktop computer became a nearly universal off-the-shelf consumer item that anyone could learn to use without much difficulty. The fact that the per-watt investment cost of microhydro (P100-200 per watt) is not dramatically lower —and might on occasions even be higher—than mega-hydro installations is clear indication that downsizing hydroelectric technology has not triggered any game-changing economies of scale and virtuous cycles, so far, as the change from mainframes to microprocessors did in the computer industry.

To get the microhydro effort on the right track, I propose a number of approaches that might be able to significantly raise the demand for small-sized hydro-electric units towards production volumes where economies of scale can start to operate:

1. Downsize towards operating pressures that are low enough to allow a shift from stainless steel and other expensive metal penstocks to plastic-based or other lower cost as well as lighter penstock materials. This change will result in a significantly lower penstock and installation costs.

2. Master pump-as-turbine (PAT) technologies, to turn the micro-electric generator assembly into an off-the-shelf item that, although somewhat lower in efficiency, is dramatically lower in cost. This will also shorten the project timeline, reducing financing and other time-related costs.

3. Initially, we can standardize on a limited number of off-the-shelf PAT sizes; it is much harder to standardize on site features. So, why not try an alternative approach that fits the site to standard PAT assemblies, instead of designing a turbine-and-generator assembly to uniquely fit each specific site? Once a mass market for microhydro emerges and establishes itself, the industry can then design more efficient turbine-generator combinations for this growing market to replace the less efficient centrifugal pumps used as turbines. But these micropower turbo-generators will then show features typical of mass-marketed commodities: standard sizes, a low-cost bare-bones set-up, optional accessories, and so on. One can imagine a secondary market eventually growing around the basic micropower installation.

4. Tame the “wild AC” output from microhydro installations with electronic technologies which are already standard in the wind industry, and bypass the need for hydraulic or mechanical

control mechanisms. Digital electronic controls enjoy the same advantage of declining prices as all other electronic equipment, especially if these are made for a growing mass market.

5. Develop “killer-apps” for micropower. For the early microcomputer, the first killer-application was the spreadsheet software called Visicalc. This killer-app transformed the microcomputer from a hacker's toy to a business machine that every office must have. And it was only the first in a series of “must-haves”, each one helping propel the continuous growth of the market.

6. Consumers and markets often show certain price “sweet spots”, below which products exhibit a dramatic increase in sales. For newly-introduced desktop computers in the U.S., for instance, the sweet spot was around a thousand dollars. For microhydro installations, the sweet spots may be higher for municipalities, and lower for farm owners with access to fast-flowing water. Just as solar panels had to drop in price by an order of magnitude or more, before they found those sweet spots that appealed to mass markets, microhydro vendors may need to strive for further price reductions, until the market responds enough to activate the economics of increasing returns to scale. The micropower industry should find these sweet spots and strive to reach them. To start off the discussion on sweet spots, let me offer an initial suggestion: microhydro installations for municipal projects should cost about as much as small low-cost housing. For farms, no more expensive than a cheap car. And for the do-it-yourself crowd, no more than the price of a computer. With such prices, one can almost imagine an impulse to buy, if only to try, the new technology.

7. The government should conduct a thorough resource assessment of smaller rivers and produce low-cost publicly available maps that indicate liters per second or even potential watts per meter at five-meter interval contour lines as the rivers flow towards the plains. This can support a nationwide effort to tap what a Department of Energy official has called the “vast untapped resources” available for micro-level hydropower generation.

With some modifications, the suggestions above can also be applied to other micropower renewables. Imagine microwind turbines that turn at the slightest whiff of air, accumulating their micro-output in microbatteries and powering intelligent micro-devices in homes and buildings. In fact, these microturbines do not even have generate electricity. If they can move air, they can find applications in residential and commercial structures. If they cost about as much as a lighting fixture and its bulb, wouldn't people be interested? The idea is to reduce the barriers to entry and bring down the costs low enough that the resulting market expansion will move the industry towards an operating point where economies of scale start to take effect. The increase in the demand can then, under the right conditions, result in further cost reductions that will eventually pull prices further down instead of pushing them up, creating a virtuous cycle of expanding markets and declining costs.

While wind technologies today already show a similar trend, with wind costs falling and the demand for wind turbines rising, we need to watch carefully, whether the scaling up in size and height that is happening today in the wind industry, involves increasing or decreasing returns to scale.

Since, like hydro, geothermal and biomass electricity output can be controlled and ramped up or down with relative ease, they can play an important role in a 21st century grid where flexibility in output and/or very low marginal costs are more important than a steady but inflexible output for base loads.

The renewable micropower industry should also recognize the favorable winds blowing in its favor. These major drivers for the market expansion of renewables include:

1. With Philippine electricity rates ranking as one of the most expensive in Asia, consumers will welcome the fundamental shift that will occur when renewables like solar, wind and appropriate forms of energy storage reach parity. Rooftop solar is in fact already the cheapest in many service areas. Other renewables will soon follow suit. Precisely because our rates are expensive, we have crossed over grid parity earlier than other countries, making us a pioneer of sorts in the energy transition to renewables.

2. People who are fed up with endemic brownouts will be willing to spend much more on reliable electricity. Their areas will make ideal markets for introducting new micropower products. Off-grid and brownout-prone areas will comprise a significant market for solar panels.

3. As the impacts of climate change worsen, and with a growing international consensus for each country to commit towards greenhouse gas reductions, the renewables market can be expected to enjoy a boom, based on this single factor alone. In fact, as carbon pricing and carbon taxation become the international norm, fossil-fuelled power plants will soon be forced to internalize costs that they have so far ignored, such as health, social, and environmental costs. This will make them even less competitive compared to renewables whose prices are continually declining.

4. The continuing political instability in the Middle East suggests that the currently low oil prices will not stay that way for long. The very volatility in price of this fuel creates energy insecurity that makes it very hard for oil-dependent countries to make long-term economic and energy plans, giving us very good reasons to look for alternatives.

Speaking of the political environments, we can ask government to do a few more things to hasten the energy transition to renewables.

1. The government should liberalize the regulations that govern the use of solar, wind and river water for micropower generation, so that communities, families and individuals are less hampered by byzantine bureaucratic impositions. Requiring, for instance, a 500-watt solar panel owner to apply for a “Certificate of Commerciality” from the Energy Regulatory Commission is just one example of the bureaucratic barriers to the mass adoption of micropower. As is the utility imposition requiring the same owner to conduct a “grid impact study” and a change of meter before it allows net metering to happen.

2. The government should ensure that the provisions on net metering of the Renewable Energy Act are strictly observed, and not violated, by distribution utilities. Unfortunately, the utilities have ignored the law and implemented their own version, which leads to double-charging and has become a solid barrier against rooftop solar. Net metering is the simplest and least expensive way to account for the complex three-way transfer of values that occurs when a micropower installation alternately exports and imports electricity to or from the grid, and the utility sells the result of this exchange to other customers nearby. This matter is so important to the growth of the micropower industry that I have covered it in a separate paper. (Google “net metering by Verzola in cleantechnica”)

3. Finally, the government should review and update the Philippine Energy Plan 2012-2030, especially the sections on energy efficiency and on renewable energy. The PEP 2012-30 contains a remarkable possibility lurking within its pages: if the government had taken the PEP 2012-30

seriously and made sure that its targets were attained in both its energy efficiency project (PEEP) and renewable energy program (NREP), PEEP would have been able to reduce the growth in the demand enough that the NREP alone would have sufficed to meet the demand plus the required reserves. Under this scenario, already planned for and with firm targets in PEP 2012-30, there would have been no need at all to build new fossil-fuelled plants. This would have jibed perfectly with the Philippine commitment in Paris to reduce by 70% the country's greenhouse gas emissions by 2030.

Digital electronics and the flexibility of software

In the information sector, it is digital electronics that drives the trend towards declining prices. Digital electronics makes computing power, memory, and built-in intelligence available at a dramatically lower cost to industrial machines, including micropower plants. As these machines become cheaper and easier to use, these machines turn into virtual consumer appliances and their potential market expands dramatically. It is already possible to imagine this happening with solar panels. Further down the line, as their cost decline further, they can then be embedded within other consumer items, creating entire new markets and triggering the virtuous cycle I have repeatedly referred to in this paper.

Another key to drive costs down in the renewables sector is to gradually replace hydraulic, fluidic, mechanical and electrical control equipment with digital electronics, that will allow the benefits of scale economics in the information sector to spill over into the energy sector.

Digital electronics have a further built-in advantage: they can be designed to be highly flexible and easily programmable. Software changes can be made quickly, distributed easily and even installed remotely. Software reproduction and distribution also entails lower costs, compared to the fabrication of hardware.

The advantages of digital electronics can be further enhanced by having built-in logic and arithmetic processing power as well as memory and storage—already very cheap thanks to developments in the IT sector—within micro-electric machines.

And not only on the supply-side, but also on the demand-side. Behind-the-meter equipment can acquire the same built-in low-cost intelligence. This will enable rapid ramping up or down of demand in response to sudden changes in supply that will happen more often as variable sources like solar and wind increase their share in the electricity mix.

The grid will survive all these

Many utilities are worried that distributed generation, enabled by increasingly more affordable solar rooftops, will cause the demise of their business model. This has led utilities to put up various barriers to entry and undermine policies such as net metering for solar rooftops.

But our experience in the information sector shows that isolated systems will benefit from internetworking. To items and services that are already valuable in isolation, the network effect will serve to add further value. The emergence and spread of distributed generation—rooftop solar and home energy storage, in particular—will not make the grid obsolete, but will instead require the grid, to further enhance their value. Distributed micropower plants like solar panels connected to grid-tie inverters will find it hard to match their local requirements exactly. They will often be either above or below it. Thus, they will continue to need the grid to source electricity when they do not have enough, and to export the electricity when they have too much. Also, the grid will ensure that energy-poor areas will continue to get the same reliable electricity service as energy-rich areas. Finally, the grid can avert the loss of power that can occur in some areas due to cloudiness or lack of wind, by facilitating the instantaneous import of electricity from sections of the grid that enjoy a surplus.

Instead of providing simply a unidirectional flow of electricity from giant generators to millions of consumers, the nature of the grid will gradually change. The grid, will in the future, have to handle more and more connections that not only use electricity some of the time but also provide electricity at some other times. Some of these connections will involve large electric producers/consumers, but many will involve millions of users that produce electricity for their own use much of the time, but will regularly need to import or export electricity to and from the grid, whenever their requirements and their in-house output do not match. Thus the nature of the relationship between the big and the small connections to the grid will also change, from a client-server to more of a peer-to-peer relationship. The growing importance of peering arrangements among various producers, once they reach millions, will be another fundamental change in our electricity system.

Companies who can figure out ahead of the rest the features and requirements of this new type of grid can establish an early lead during the energy transition to renewables. But as the grid takes on more and more the nature and characteristics of a public commons, social planners should also consider whether it is time to take a careful second look at the social experiment to privatize it.

Paradigms

The debate between keeping the commons public and privatizing it, settled in favor of the latter in the Philippine case, is an example of a paradigm debate, which forces us to examine the very fundamental assumptions underpinning our societies. When some commodities become so cheap to produce that they are practically free, do we share or do we find other ways to sell? More of these paradigm debates will come to the fore as technological and social change become intertwined. Just to give a few examples:

The "No Smoking" paradigm. I use "No Smoking" to represent what has become the dominant social mindset today, making smoking in public places a social taboo, as least in the more civilized areas of the country. A similar thing is bound to happen sooner or later with coal and other fossil fuels, as we all feel the increasingly real impact of climate change. It has already happened to nuclear, as a result of the Fukushima disaster.

The "do-it-yourself" paradigm. DIY as a movement has existed for a long-time, but only recently identified by marketeers as a global trend. Solar panels fit into this paradigm. Microwind and microhydro too.

Client/server versus peer-to-peer. This clash of paradigms arises from the emergent potential in every household, enabled by solar technology, to generate its own electricity and share self-generated electricity with others, leading to a deep change in grid topology from one-way to multi-way flows of electricity.

The free software and open-source paradigms. The free and open sharing mindset that these paradigms encourage will spill over into the energy sector, once the price of electricity from sun, wind and other renewables become "too cheap to matter". They will give rise not only to the "free" as in "free wifi" and "unli" offers so common in the information sector, but also to the more political "free as in freedom" mindset of the copyleft movement.

Business models

Given the expectation of diversity in future connections to the grid, we anticipate a similar diversity in business models and the different ways of creating the values and generating the cash flows that will drive and sustain the operations of the various grid elements.

The highly centralized model of a single monopolistic utility dispensing electricity to millions of client-customers may persist in modified form, but many other models can be expected to emerge.

On the Internet, for instance, the client/server business model remains dominant, because it fits perfectly a private enterprise system where a business firm provides a particular Internet service, perhaps in competition with other firms but possibly in a monopolistic situation that every business enterprise aspires to. But an increasing number of Internet players are switching to the peer-to-peer (P2P) model, where value is created and shared in a distributed, commons-like manner, and a way is found of sharing the cash flows and other returns generated by that value among those who contributed to its creation.

Consider the mainframe computer. Only the biggest institutions could afford them. Those who couldn't afford a mainframe paid for computer time or for computer services, based on the usual client/server model. Downsizing the mainframe towards the mini-, and later the microcomputer, created a mass market, turning the computer itself into the product – a very different business model. This is exactly the case with solar PV technology, which turns a micropower plant into a consumer product with the potential for a huge mass market.

The solar market alone can be served by a variety of business models, from direct sales to leasing to power purchase agreements. In the future, many more business models will need to be evolved, as the market grows and starts to mature. Once the abundance of solar power is fully tapped, providing practically free electricity after the initial investment costs have been amortized, perhaps the business models so common on the Internet based on providing some services for free while charging premium on add-ons may also make their appearance.

To summarize: *to be a deep game-changer, the renewables sector must find a way to scale down, not up, the power units in energy systems, enough to activate the economics of increasing returns to scale and trigger virtuous cycles of greater demand and lower prices.*

Under the right conditions – including the appropriate technologies that make economies of scale possible, the right business models, and a responsive market – things may fall into place and the ensuing virtuous cycle of a growing market and declining prices driven by increasing returns to scale can create a cascade of abundance that improves the lives of millions.

Perhaps, with a deeper understanding of how such a market can emerge and evolve, your company can position itself as a leader in these developing markets for products and services associated with renewable energy.

Thank you very much.

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[This is the keynote speech prepared by Roberto Verzola, Executive Director of the Center for Renewable Electricity Strategies (CREST), for the annual meeting of the Geosciences and Reservoir Engineering Group of the Energy Development Corporation. EDC is the world's second largest geothermal firm and is also active in the renewables industry. Verzola wrote the book *Crossing Over: The Energy Transition to Renewable Electricity*, which was published in March 2015 by the Friedrich Ebert Stiftung, a German foundation (for the full text in PDF, google “crossing over by Verzola”). He subsequently set up CREST to complement his ongoing work on renewable energy. Verzola may be reached at rverzola@gn.apc.org, 0917-811-7747, or 0939-117-8999.]