This workshop has been convened to consider, as its title says, the 'Implications of Decentralized Power Generation'. I can summarize the answer to the suggested question in a sentence. The implications of decentralized power generation are that electricity systems are going to change almost beyond recognition. However, whether they are going to do so smoothly and gradually, while keeping the lights on, is a lot less certain. We could be in for major trouble, even in places that now take electricity and electricity services for granted. Electricity research, both on technology and on institutions, has never before faced such a severe challenge. In my presentation this morning I'll try to explain why I think so, and why it matters.

The starting point is what I call 'traditional electricity', the common technical model that was replicated all over the world during the past century. In this model, large central stations, remotely sited, generate electricity as alternating current and deliver it to users over networks including long high-voltage transmission lines. The traditional electricity system holds a monopoly, granted by government, in its franchise area. Within this area no one else is permitted to generate electricity for sale. The monopoly franchise guarantees a revenue stream, and allows system planners to make very large long-term investments, notably in power stations and networks, because the captive customers of the monopoly bear all the risks. The cost of capital for investment is thus low; and since the capital investment makes up a substantial part of the cost of the electricity, the cost of electricity is likewise low.

Throughout the past century this traditional model was remarkably successful, making electric light, electric motive power and other electricity services part of the everyday fabric of industrial society. But the traditional model of electricity arose for one key reason: the economies of scale of the generating technologies then available, particularly steam turbines and water turbines. Making these generators larger steadily lowered the cost of the electricity they produced, up to generators of enormous size, even when the cost of the accompanying delivery network was deducted. The technical configuration of the traditional electricity system, with centralized production and a network for delivery, was modeled on that for town gas, for similar financial reasons; and the analogy was effective and useful for most of a century. Now, however, it is seriously misleading. The emergence of small-scale decentralized generation as an economic option invalidates the key premise underlying the traditional model of electricity. Moreover the traditional model has failed to deliver electricity services to some two billion people - one-third of humanity; and its key technologies - large dams, large coal-fired and nuclear steam-cycle stations, and overhead transmission lines - all face problems, particularly financial and environmental, that may become insuperable. For all these reasons, including decentralized power generation, the
entire conceptual framework of electricity, its role and nature in human society, now requires urgent and fundamental reassessment.

This is because electricity is different. Despite all the prevailing assumptions to the contrary, electricity is not a fuel, nor a commodity. A fuel such as natural gas comes out of a hole in the ground at a specific place; if you want to use it anywhere else you must physically transport it there. Electricity, by contrast, is a physical phenomenon happening instantaneously throughout an entire interconnected system. You can generate electricity anywhere on the system, at a price. You can store a commodity such as copper, wheat or coffee, and withhold it from the market until you get the price you want. By contrast, you cannot store electricity, in the form and quantity in which we now use it. If you are to satisfy your customers you must have a vast array of physical assets in place and in operation continuously, whether or not your customers want electricity from you. If you have a monopoly, that does not matter. If you don't, other factors come into play.

At the beginning of the 1990s the governments of Chile and the UK, ideologically committed to so-called 'free markets', overthrew the traditional model of electricity system, abolished the monopoly franchise and introduced competition in generation and supply to customers. The accompanying rhetoric claimed that the change was for the benefit of electricity users. Competition would improve operating efficiency; customers able to choose supplier would force suppliers to reduce electricity prices to users. But nothing else was supposed to change. Electricity systems would continue to look the same, and operate in much the same way. Such at least was the expectation of those who imposed the changes. The process of 'liberalization' soon spread worldwide, more for the benefit of government treasuries than of electricity users, except for large industrial customers. A decade later, the consequences are making many people uneasy.

To be sure, the first unexpected consequence was the dramatic advent of gas turbine generation, fueled by cheap and abundant natural gas, both economically and environmentally beneficial. But gas turbine generation marks a sharp change in the historical trend. Historically, a better power station was a bigger power station farther away. With the gas turbine, however, a better power station is likely to be a smaller power station, quicker to build and commission, easier to finance and to site, more efficient and cleaner, closer to users and possibly indeed right where the electricity is required. In a competitive context, a large-scale long-term investment in traditional hydroelectric or steam-cycle generation is seriously risky; and the risks are borne not by captive customers but by shareholders and bankers. If a less risky option is available, traditional generation loses its appeal. Gas turbine generation, smaller-scale and more decentralized, is opening the way for even smaller and more numerous generators, down to household scale, that will soon be commercially available and attractive. This is going to cause trouble.

The difficulty arises because traditional electricity is not merely an aggregation of individual components; it is a system, including generators, network and loads. To deliver the services desired, the entire system has to operate, continuously and coherently, not just minute to minute but second to second. What is at issue, therefore, is not merely the implications of decentralized power generation itself, but the corollary implications for networks, loads, system management, monitoring and control, and all the interactions and transactions between these parts of the system, as the whole system evolves. Nothing less will keep the lights on. Moreover the 'system' we mean is not just the technology, the hardware and physical assets; the system also includes the institutional framework for planning, management, transactions, finances and all other decision-making, including explicit assignment of responsibilities and risks.

Three years ago I published a book about this, entitled Transforming Electricity [1]. I called Chapter 6 of the book 'Bumpy transitions'. At the time, however, I did not fully appreciate just
how bumpy these transitions would prove to be. For the past three years I have been working on a
follow-up book, entitled *Keeping The Lights On*. The longer I work on it, however, the more
difficult I think keeping the lights on is going to be. Traditional central-station electricity is
simply not compatible with innovative decentralized electricity, either technically or
institutionally. Some systems embarked on liberalization from a basis of robust redundancy, paid
for by captive customers of the previous monopoly. Such systems have often been able to
withstand the stresses of liberalization. Others have not been so fortunate, those in developing
countries least of all. The mismatch between tradition and innovation, with its consequent
perturbations and dislocations, is intensifying. It will get much worse before it gets better.

This is most obvious with networks. Traditional networks are radial and one-way, designed to
carry large quantities of electricity at high voltages from remote large-scale generators, and to
divide the electricity up among loads several orders of magnitude smaller. Innovative
decentralized electricity, with very large numbers of small generators connected at low voltages,
broadly similar in size to the loads, will require meshed, two-way networks, different in both
configuration and function. Can networks evolve smoothly through such a dislocation? I hope so;
but I don't yet understand how.

We are already seeing problems arising from traditional networks, as a consequence of
liberalization. Traditional networks were never intended to function as a framework for market
competition between generators with different owners, and especially not across system borders,
much less national borders. Despite liberalization in Europe, the US and elsewhere, electricity
networks continue as regulated monopolies, effectively centrally planned, paid for by captive
customers as before. However, despite the brave words of groups such as the new European
Transmission System Operators, I do not expect to see a pan-European regulator in my lifetime.
Without one, the disputes and clashes will be relentless. Traditional networks also remain a
stubborn stumbling block in the way of decentralized generation, as the recent 'New Electricity
Trading Arrangements' in the UK have vividly demonstrated. The technical difficulties alone are
significant. I subscribe to an international internet discussion group devoted to so-called
'distributed generation'; it has recently spent many days debating possible ways to address issues
of system stability, reactive power and other technical issues arising from small-scale
decentralized generation. However, these technical issues are aggravated by the insistence of
traditional system people that any significant move to decentralized generation will endanger
system stability. They simply do not want to make any change away from their traditional
operating regime, or its approach to system stability. A fully decentralized electricity system
would offer an entirely different approach to stability; once again, however, the problem for
research is how to get there from here.

Technical issues such as these are complicated in turn by the decision-making and financial
procedures that have arisen with liberalization. The whole process of liberalization, as it has been
implemented in OECD countries and elsewhere, is based on what appears to me to be a
fundamentally misguided premise: the premise that electricity is a commodity, that the relevant
market is a commodity market in anonymous units of electricity as measured by a meter, and that
what matters most is the commodity price per unit of electricity. However, the price of a unit of
electricity is made up in substantial part by the capital charges attributed to the system assets,
especially the monopoly networks, as interpreted by the regulator. The price of a unit of
electricity to the final user is thus effectively arbitrary, a thoroughly unsatisfactory criterion by
which to evaluate the success or otherwise of liberalization or reform of any kind. It is also an
unsatisfactory basis for market transactions between system participants, especially when the
future evolution of the electricity system, reconfiguring its physical assets, is going to require
major long-term capital investment, on some acceptable basis, by someone.
As I wrestle with these problems I am sometimes bemused, that so many other commentators seem unconcerned - or perhaps not so much unconcerned as unaware of them. The reason may be that liberalization has drastically shortened the time-scale of thinking about electricity and its future. Under the traditional model, people were ready to think and to plan three or even four decades ahead. To be sure, their plans frequently proved nonsensical; but they did at least envisage a long-term future. Now, however, most electricity people are so preoccupied with the immediate future, in months, weeks, days and hours, that they have little time or inclination to look forward in years, much less in decades. To the extent that they have any long-term vision of electricity in society, they appear to believe that it will look and function much the same in 2020 and 2050 as it does in 2002. I think they are wrong.

Let me give you an example of why I think so. The risk profile of traditional large-scale assets is increasingly ill-suited to a commodity market in instantaneous and ephemeral units of electricity. In some liberalized competitive systems, including that of the UK, the unit electricity price is now so low that some generators cannot even cover their cost of capital. Some generators are already shutting down power stations that do not earn an adequate return for operating. This reduces the redundancy on the system, with a negative effect on reliability. For many modern loads, system reliability and power quality are already a problem. That makes the option of decentralized on-site generation more attractive, not least as insurance against disruptions on the network. If the growing proportion of sensitive users install their own generation and remove their loads from the system, more system generation will become surplus to requirements and face shutdown, further weakening the system. We could see a feedback loop developing, in which those users who can leave the system will do so in favour of their own decentralized generation, while users still dependent on the system have to accept steadily deteriorating service.

If we were starting now to electrify society, with the technologies now available, electricity and electricity systems would be very different. But we would strive to attain some of the key attributes we still associate with traditional electricity. We would want electricity services to be reliable, convenient and affordable. We would also, however, want attributes that traditional electricity does not and cannot achieve: we would want electricity services from systems clean and environmentally acceptable throughout; and we would want these services to be available to all, not merely to the fortunate two-thirds of us on the planet.

Let me give you a brief outline of what seems to me a promising vision. Electricity services such as illumination, comfort, motive power and refrigeration are not commodity services but infrastructure services. You don't measure them or buy them by the unit; you pay for the assets that deliver them to you when and how you want them - the buildings, the fittings, the appliances and so on. We have known for decades how to make these assets deliver much higher performance. We've called the objective 'energy efficiency', but I dislike the expression, because you do not measure either the energy input or the useful energy output of, say, buildings - much the most important part of our energy service infrastructure. Whatever you call it, for at least three decades we have failed to take advantage of the opportunities to improve infrastructure performance, for a variety of reasons, not least the so-called 'hassle factor' - 'I just can't be bothered'.

Now, however, with decentralized electricity generation, we have a whole new way to approach the issue. In my book *Transforming Electricity* [1] I advocated the development of local electricity systems, incorporating generation, networks and high-performance end-use technology, including buildings, integrated and optimized for maximum economic effect. Such systems would be attractive both to customers and to the companies that would design, establish
and operate them; they would create a long-term contractual link between company and customer, a much more stable form of business relationship than competing to sell anonymous units of electricity at a meter. I am increasingly convinced that decentralized electricity systems, with their economic, social, political and environmental advantages, will be a crucial step toward what I call 'sustainable electricity', in OECD, transition and developing countries alike.

But I am much less certain about how to get there from here. The disruption and dislocation involved may be severe. I would therefore like to invite you all, as participants in the International Electric Research Exchange, to consider carefully the scope of your research. I hope you agree that from now on it should address the critical issue of sustainable electricity, and how to get there from here. As you advance, do please keep me and my colleagues informed. This must be a truly global effort; and it must be global to succeed.


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