# The Path from Fukushima:

## Short and Medium-term Impacts of the Reactor Damage Caused by the Japan Earthquake and Tsunami on Japan's Electricity Systems

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# Report Summary

This study reviews and updates the Nautilus Institute report After the Deluge: Short and Medium-term Impacts of the Reactor Damage Caused by the Japan Earthquake and Tsunami[1], which discussed the implications of the Sendai Earthquake on electricity supply and demand in the Tokyo Electric Power Company (TEPCO) and Tohoku Electric Power Company service areas. This report examines the difficulties that these two companies will likely face in meeting electricity demand in their service territories, given the available generating capacity of power stations both immediately and into the near and medium-term. It includes a scenario for providing some of the electrical energy and peak power needs in these service areas with "demand-side"—that is, energy efficiency savings and distributed generation that occur at customers' sites, as opposed to at central power stations—and renewable resources, including both consumer-sited and other renewable and non-renewable power generation. Finally, the report offers our appraisal of how these two power systems may evolve over the coming years, outlining best case, baseline case, and worst case scenarios.

## Demand-side Approaches to Electricity Sector Rebuilding

For the purposes of this report, "demand-side" means energy generated or saved locally at the consumers' sites, rather than at a centralized power plant. An example would be an office building with a photovoltaic array on the roof that helps power the building. Excess energy from this array could potentially be distributed locally via a smart grid that can accept power inputs and distribute them at a local level. Alternatively, the lighting system in the building could be made more efficient thus, providing demand-side energy and power savings. Based on our analysis of the current and probable near-term future of the TEPCO/Tohuku electricity supply situation, Japan may wish to take this opportunity—albeit one both expected and unfortunate in its genesis—to examine carefully the costs of establishing a nationally integrated "smart grid". Such a grid would enable the use of intermittent renewable energy to be scaled up alongside an aggressive program promoting super-efficient end-use technologies, as well as energy conservation and peak power management at the end-use level. This approach may be cheaper, faster, environmentally cleaner, and more resilient in the short and the long-run than relying on largely coastal thermal and nuclear-fired power plants to make up for the immediate and long-term shortfalls in generating capacity. Our initial analysis of scenarios comparing approaches to address these shortfalls emphasizes, respectively "packages" of A) energy efficiency, renewable energy and distributed generation (EE/RE/DG), and B) central-

[1] Prepared by Peter Hayes, David von Hippel, Richard Tanter, Takase Kae, Kang Jungmin, Wen Bo, Gordon Thompson, Yi Kiho, Arabella Imhoff, Scott Bruce and Joan Diamond, dated March 17, 2011, and available as http://www.nautilus.org/publications/essays/napsnet/reports/SRJapanReactors.pdf.

station gas and nuclear plants. Our results suggest that while the former is more expensive in terms of capital costs, the annualized costs (that is, the annual costs of owning and operating the equipment—including, for example, high-efficiency appliances and other devices—and power plants included in the packages) of the two scenarios is similar enough ($11 versus $10 billion per year) that the more rapidly-deployed EE/RE/DG scenario easily becomes more cost-effective if the benefits of earlier recovery of otherwise unserved electricity demand in the affected areas are considered. The EE/RE/DG scenario of aggressive deployment, over the next four years, of energy-efficiency, renewable energy, and distributed (consumer-sited) gas-fired generation, is consistent with the work of Japan's Center for Low Carbon Society Strategy. The EE/RE/DG scenario provides, based on our initial estimate, the equivalent of 81 TWh of annual delivered electricity supplies to the citizens and businesses of the service territories after four years, and the equivalent of about 22 GW of delivered summer peak power. The EE/RE/DG scenario also results in 50% less $CO_2$ emissions than the central-station option, and thus contributes toward meeting Japan's ambitious greenhouse gas emissions reduction goals, as well as supporting the development of a "green economy" for Japan. Because the EE/RE/DG scenario starts to save and produce power almost immediately, whereas most of the elements of the central station alternative, even if fast-tracked, will take a minimum of two to three years to implement (and the other elements will take longer), the latter will incur economic costs due to the value of unmet demand. Taking this factor into account more than equalizes the cost of the EE/RE/DG scenario, estimated to be 14 cents/kWhe, with that of the central power station alternative, which is 12 cents before the cost of unmet demand is taken into account but much more afterward.

The need to rebuild a significant amount (estimated as high as$310 billion dollars, or over 25 trillion yen, according to recent news reports) of Japan's infrastructure provides an opportunity to construct new buildings, electricity supply grids, and factories with the most energy-efficient technologies in a manner that easily accommodates "smart grid" technologies. In so doing, the marginal costs of such improvements can be dramatically reduced, and much larger markets created for energy efficiency, distributed generation, and other demand-side management technologies, including technologies made in Japan.

The way that Japan's energy sector institutions, and the government agencies that oversee them, respond or are ultimately changed by the public's reaction to the earthquake, tsunami, and the Fukushima I accident will be crucial in determining whether Japan rapidly adopts a more aggressive posture toward energy efficiency and other demand-side and renewable resources, or whether it continues with a "business as usual" approach.

**Existing and operable TEPCO and Tohoku centralized supply-side resources:**

- Prior to the earthquake, TEPCO and Tohoku had a combined total of about 81,000 MW of supply-side resources, of which well over 7,000 MW were pumped-storage hydroelectric facilities used to store energy and provide peaking power;

- 7765 MW of thermal generating capacity on the TEPCO system was taken off line following the earthquake (of which 3665 MW of that capacity has since been restored as of April 9th, 2011). Thermal capacity on the Tohoku grid totaling 6146 MW was also damaged (of which 2750 MW of that capacity has since been restored as of April 9th, 2011), along with damage to transformer, transmission, and distribution facilities on the Tohoku grid;
- Under all but the most optimistic supply recovery/expansion scenarios, TEPCO and Tohoku will be unable to meet summer peak power demand in 2011 if peak demand is close to 2009/2010 levels.

**Demand-side measures and resources for power companies affected:**

- Both TEPCO and Tohoku initially announced power rationing programs, consisting of rolling blackouts in many areas, but exempting some regions, including earthquake-affected zones and central Tokyo. Power rationing in the TEPCO area has been much less extensive than expected, rationing in the Tohoku area has been thus far avoided, due to a combination of reduced business activity, loss of access to power supplies as a result of earthquake and tsunami damage to power plants and transmission and distribution infrastructure, and a massive and admirable effort of electricity conservation by the citizens of northern Honshu;
- Lack of generation capacity will spur TEPCO and other affected companies and their customers, to more aggressively pursue energy efficiency measures and generation of power on-site by consumers (or distributed generation) through the use of both renewable resources (such as solar PV, and solar hot water, which have the advantage of being largely coincident with peak summer power demand) or fossil resources (natural gas-fired units, for example).

**Medium-term Implications for TEPCO and Tohoku Service Areas**:

- The four affected Fukushima I reactors will not be reparable, and it may well be, given the explosion at Fukushima I unit 4, that a combination of damage and radioactive contamination at units 5 through 6 will render those units un-repairable as well;
- It is possible that other nuclear plants—a total of seven TEPCO, four Tohoku, and one Japan Atomic Power (the 1100 MW Tokai unit 2) nuclear reactor units, as well as a number of coal- and gas-fired plants, all of which went off-line following the earthquake—will also be affected, and be either un-repairable or require lengthy repairs;
- Absent implementation of demand-side resources on a massive scale, TEPCO and Tohoku will need to rely on existing fossil fuel plants much more heavily, probably for many years, than they would have needed to had they been able to use the nuclear plants.

We further analyze scenarios for how the TEPCO and Tohoku power systems will recover over the coming years. In our **Best Case** scenario, we find that about 4700 MW of nuclear generating capacity is gone, and must be replaced or otherwise compensated for by supply- or demand-side resources. Further, 2700 MW of new nuclear capacity that were to be developed at Fukushima I during the next decade seem highly unlikely to be completed, given the damage at the older units, and the generation that would have come from those units will need to be replaced or compensated for. An additional 6600 MW of nuclear capacity is likely to be offline for one to three years, 3300 MW at the Kashiwazaki-Kariwa plant is offline for inspection, and 4000 MW of thermal capacity seems likely to be offline through the summer. For the TEPCO service area, the annual output of the remaining operating nuclear units totals 4912 MW (this is the TEPCO nuclear capacity that was not affected by the earthquake and subsequent events). As a result, if demand in 2011 is similar to 2009 levels, TEPCO's thermal plants would be called upon to produce about 260 TWh of output in 2011, which implies that nearly all thermal plants must run nearly full-time. From the perspective of peak demand, the short-term situation is even more constrained. This implies that a combination of peak demand reduction measures, coupled with the decrease in electricity demand resulting from earthquake damage to infrastructure and the economy, will be required to get the TEPCO system through the next few years, even in this "Best Case" scenario.

In our **Base Case** scenario, we assume that nuclear plants (other than Fukushima I) in the earthquake-affected area will need to undergo more lengthy inspection, and/or inspections turn up problems that must be addressed, and/or local political opposition delays restarting the plants, and/or inspections at some thermal plants also turn up problems that mean that they are out of service longer, or need to be replaced. Here the supply shortfall for the two companies is likely to last longer, perhaps several years longer, and would need to be ameliorated by a combination of more thermal generation, construction of new thermal generation plants, and probably a significant effort to curb net demand for both electrical energy and peak power. Curbing demand could take the form of rotating power cuts, agreements with industry to curtail consumption at peak times (or, in fact, to move elsewhere, as unappealing as that is for the local economy), aggressive energy efficiency programs (which would have the added benefit of reducing fuel requirements and costs), and/or encouraging residents, businesses, and industries to develop on-site generation, including gas-fired combined heat and power systems and solar photovoltaic (PV) generation, which is particularly beneficial in meeting summer peak power demand..

In our **Worst Case** scenario, we assume that all of the nuclear power plants in the earthquake area are found to have significant seismic or other damage, leading to prolonged (more than 5 years) retrofit requirements, and some thermal plants are found to have been compromised to the point where they cannot be repaired and must be replaced (requiring several years). In addition, the results of inspections at the earthquake-affected power plants, coupled with nationwide public concern about the safety of nuclear plants, causes other nuclear plants (apart from the earthquake-affected plants) in the TEPCO/Tohoku service areas and maybe elsewhere in Japan to be taken off line on a rotating basis for damage assessment and/or earthquake retrofit. These additional conditions would likely result in the need for many more new thermal plants (and related fuel supplies) and an even higher reliance on demand-side measures (including power rationing) than in the base case if the country is to  balance available supply and demand over five to ten years.

Although we have labored hard to produce an accurate accounting of the impact of this disaster on Japan and the region, we recognize that data and analysis produced this quickly is inevitably error-prone.  Naturally, we request readers to notify us of any such errors.
We continue to offer our heartfelt condolences go to the Japanese people who are suffering from this combined natural and technological disaster and have commenced recovery with amazing calm and courage in the face of such calamity.