After the Deluge

Short and Medium-term Impacts of the Reactor Damage Caused by the Japan Earthquake and Tsunami

Executive Summary

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Report Summary

This report is a rapid response evaluation of the implications of the March 11, 2011 earthquake and consequent tsunami off the northeast coast of Japan. It focuses on Japan's electricity system, its energy security, and the future of the nuclear power plants located in the earthquake- and tsunami-affected regions.

It will be updated in the near future as the situation concerning the Fukushima I and II nuclear power plants become clearer, for better or worse, and as more information becomes available about other consequences of the earthquake, the tsunami, the nuclear crisis, and their interactions.

In addition to this introduction, this report presents five substantive sections.

Section 2 provides an up-to-date (as of March 17, 2011, Tokyo time) overview of the status of the nuclear fuel facilities in Japan that were affected by the earthquake and tsunami on March 11, 2011, with particular attention to the reactors and spent fuel ponds at Fukushima I reactor complex.

Section 3 reviews the implications of the damage described in section 1 for electricity supply in the Tokyo Electric Power Company (TEPCO) and Tohoku Electric Power Company service areas. First it accounts for the status of nuclear and non-nuclear power stations that generate electric power in these systems. Next, it examines how these two companies are managing demand, both immediately and into the near and medium-term, given the abrupt loss of generation capacity.

Section 4 appraises how these two power systems may evolve over the coming years, outlining a best case, baseline case, and worst case scenario. None of these scenarios are able to deliver as much electricity as was the case prior to the March 11, 2011 earthquake. All of them, to varying degrees, entail recovery and restarting of damaged nuclear and non-nuclear facilities, but the shortfall in generating capacity varies considerably in the scenarios, and all require careful management of endues and a substantial investment in increasing endues efficiency, both technically, and via modification of the demand profiles of endusers (by forced reductions, and by conservation measures taken voluntarily).

Section 5 assesses the immediate impact on the prospects for nuclear power in East and Southeast Asia-Australia, where the primary growth in nuclear power was forecast before March

11, 2011—especially in China. Some direct and indirect impacts of Japan's nuclear disaster on geopolitical security, especially in relation to North Korea, are noted in this chapter.

Section 6 evaluates the stabilization and recovery of the hardest hit sites, at Fukushima I reactor complex. It notes the possible need for a massive international effort, perhaps mandated by the UN Security Council, to assist Japan in the huge task of dealing with multiple reactors and spent fuel ponds affected by the earthquake, explosions, meltdowns, and radioactive contamination

The writing of this first version was completed late on March 17, Tokyo time. It was produced by a team of analysts and editors: Takase Kae in Tokyo; David von Hippel in Eugene; Arabella Imhoff, Peter Hayes and Richard Tanter in Melbourne; Yi Kiho in Seoul; Wen Bo in Beijing; Jungmin Kang in Virginia; Gordon Thompson in Boston: and Scott Bruce and Joan Diamond in San Francisco.

After reviewing the dire state of the nuclear power plants and spent fuel ponds in the areas affected by the earthquakes and tsunami, plus what is known about the radiological releases and spatial distribution thereof, we examine the implications of the damage in the nuclear power plants for the electricity system, both in the short-term, and also looking forward to the medium-term.

We find as follows with regard to:
a) Power requirements on the TEPCO and Tohoku Electric Power Company systems:

- *In 2009, TEPCO plants generated just over 300 terawatt hours, about 30 percent of which was by nuclear plants;*
- *Tohoku Electric Power Company sales in 2010 totaled about 79 TWh;*
- *These levels of generation and purchased power correspond to average power requirements over a year of 34,000 MW and 9,900 MW for TEPCO and Tohoku, respectively;*
- *TEPCO's peak power demand in 2009 was about 52,000 MW, and Tohoku's 2010 peak was about 14,500 MW.*

b) Existing and operable TEPCO and Tohoku supply-side resources:

- *Prior to the earthquake, TEPCO and Tohoku had a total of about 84,000 MW of supply-side resources (21,250 for Tohoku as of 2009, and 62,700 for TEPCO), of which 10,600 MW were pumped-storage hydroelectric facilities used to store energy and provide peaking power;*
- *7150 MW of thermal generating capacity on the TEPCO system was taken off line following the earthquake (of which at least 350 MW of that capacity has since been restored);*

- *In addition, the Tohoku thermal power plants at Souma and Haramachi (totaling 4000 MW of capacity) are apparently heavily damaged, due to flooding and equipment damage, and may take 6 months or so to bring back on line;*
- *The newer Sendai thermal power plant unit #4 (446 MW) suffered flooding, as did the 950 MW Shin-Sendai thermal plant, which was evacuated due to a fire at the nearby oil refinery;*
- *Damage to transformer, transmission, and distribution facilities on the Tohoku grid occurred as well.*

d) Demand-side resources for power companies affected:

- *Both TEPCO and Tohoku have announced power rationing programs, consisting of rolling blackouts in many areas, but exempting some regions, including earthquake-affected zones and central Tokyo;*
- *In the TEPCO area, demand management by rotating curtailments seem so far not to have been as extensive as originally expected, probably because many businesses and industries have yet to reopen and millions of consumers have lost access to power supply altogether;*
- *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).*

e) Medium-term Implications for TEPCO and Tohoku Service Areas:

- *The three 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 4 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;*
- *TEPCO and Tohoku will need to rely on existing fossil fuel plants much more heavily, probably for many years, than they would have 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*

capacity that were to be developed at Fukushima I during the next decade seem highly unlikely to be completed, and the generation that would have come from those units will need to be replaced or compensated;

- *Another 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 remaining operating nuclear units totals 4912 MW (this is the TEPCO nuclear capacity as of 3/17/11 that was not affected by the earthquake and subsequent events);*
- *Given that TEPCO's hydroelectric generating capacity is virtually all "pumped-storage" hydro, that is, hydroelectric capacity built to provide peaking power for the system by storing baseload (night-time) coal-fired and nuclear energy, virtually all non-nuclear generation will be fossil-fueled;*
- *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 a impossible capacity factor of nearly 100% for the thermal power plants available now, and a still-very-high 81% if all of the thermal power plants that were shut down during the earthquake are restarted quickly;*
- *Viewed from the perspective of peak demand, the short-term situation is even more constrained. TEPCO's peak demand in 2009 was apparently about 52 GW. This is a few GW greater than the total capacity of all of the TEPCO units available, including all thermal plants on the TEPCO system (assuming that all are available, including those shut down during the earthquake) plus the available remaining nuclear units, plus all of the pumped-storage hydro capacity;*
- *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 the Best Case scenario, assuming no significant damage is found in the review of the other nuclear and thermal plants that have been shut down, when those plants are restarted, in perhaps one to three years, much or all of the short-term electricity supply shortage in the area may be eliminated, especially, if new fossil-fueled plants (such combined-cycle natural gas plants, which can be constructed in a few years if gas supplies are adequate) are built starting very soon;*
- *We have not yet done the same preliminary analyses of scenarios for the smaller Tohoku electricity system, but we would expect to find similar results to that for the TEPCO system.*

In our base case scenario, we find that:

- *Nuclear plants (other than Fukushima I) in the earthquake-affected area will 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;*
- *In this case, the supply shortfall for the two companies is likely to last longer, perhaps several years longer (around five years total), and would need to be ameliorated by a combination of much more thermal generation, construction of new thermal generation plants (assuming availability of fuel), 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 solar photovoltaic (PV) generation, and gas-fired combined heat and power systems;*
- *Though northern Japan is not ideally suited to solar power production, solar PV generation offers an advantage that it will provide the most power in times of peak summer electricity demand in Japan, helping to reduce the summer peak that central electricity generating stations will need to handle.*

In our worst case scenario, we find 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 to balance available supply and demand over five to ten years.*

We suggest that the "next steps" in the power sector response should include consideration of the following issues:

- *Japan may wish to examine carefully the costs of establishing a nationally integrated "smart grid" that enables intermittent renewables to be scaled up alongside a massive program of fast, super-efficient end use efficiency in all sectors;*
- *This approach may be cheaper, faster, and more resilient in the short and the long-run than relying on coastal coal and nuclear-fired power plants to make up for the immediate and long-term shortfalls in generating capacity.*

In the fifth section of this report, we review some of the implications for the future use of nuclear power in East Asia in light of the disasters in Japan in the nuclear plants.

We find that:

- *China's State Council met March 16, 2011 to discuss the Japan nuclear crisis and to consider China's own nuclear planning, and reportedly decided to halt its plan to build new nuclear power plants, ordered a re-examination of the safety risks of nuclear power stations currently under construction, and decided to enhance the management of safety aspects of a nuclear power stations currently in operation in China;*
- *Chinese newspapers published a map outlining names and locations of all proposed Chinese nuclear plants, plants under construction, and those in operation. This is the first publicly released information on China's nuclear industry and planning. For the first time the Chinese public is able to know about many of these new nuclear plants and their locations;*
- *On March 15th, South Korea's monthly civil defence training, which usually aims at preparing for sudden attack from North Korea, instead focused on preparation for facing earthquake and tsunami disasters;*
- *Domestically, the Japanese nuclear crisis provoked sharp division between the government and opposition political parties and civil society critics of South Korea's nuclear power system;*
- *Opposition legislators in South Korea called for reconsideration of the nuclear power building plan, and particularly called attention to the fact that Korean nuclear facilities are at present built only to resist an earthquake of 6.5 on the Richter scale;*
- *It is unclear whether the nuclear crisis in Japan might affect North Korea's plans to move ahead with its program of domestic light-water reactors. It is possible that the accident in Japan will serve to encourage the North Korean leadership to accept international technical assistance on reactor safety, if such assistance is offered. It is also possible that South Korea and the United States may take a very hard line indeed against an attempt by the North to complete and turn on a small light water reactor in 2012 that is upwind and would be of highly dubious quality and reliability;*

- *Southeast Asia is often spoken of as the leading edge of a nuclear renaissance, in as much as a number of governments are in varying stages of moving towards nuclear power. Government and industry proponents of these nuclear plans in Malaysia, Singapore, and Indonesia dismissed suggestions that the Japanese nuclear crisis would have a negative influence on planning;*
- *Australia has a particular relationship to the Fukushima crisis: not only is Japan a major market for Australian uranium exports, but Tokyo Electric Power also has a strong relationship with the Australian uranium industry, including until recently a major share in the Honeymoon uranium mine. Share prices of Australian uranium mining companies plummeted, although some executives dismissed any suggestion of a long-term influence. Critics of uranium mining emphasised the direct links to the Japanese crisis through the flow of Australian uranium directly to the Fukushima reactors.*

In conclusion, we analyze the huge challenge posed by the virtual destruction of the Fukushima I reactor complex by earthquake, fire, explosions, and radiological contamination. We find that:

- *Site stabilization and recovery of the damaged and contaminated sites will take years, possibly as long as a decade, and will cost far more than constructing the plants;*
- *The necessary techniques exist, having been developed at Three Mile Island, Chernobyl, and in the routine commissioning of retired reactors;*
- *The stabilization and recovery effort likely will require an international mobilization of necessary hardware, equipment, and trained personnel, and may need a UNSC mandate to establish authority and funding management for the cleanup.*

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.

Finally, 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.