# Achieving a Global Perspective through Interdisciplinary Mini-Terms: Electric Power Development in New Zealand

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### *Background*

Two emerging themes in engineering education are an interdisciplinary approach to engineering problem solving, and exposure to how such problems are addressed in a global perspective. The engineering curriculum at Union College now requires an international experience to help attain this global perspective. One way that engineering students can satisfy the international experience requirement is by participating in interdisciplinary "Mini-Terms Abroad," a program funded, in part, by the Christian A. Johnson Endeavor and Keck Foundations. The mini-term curriculum typically consists of a series of seminars during the term preceding the travel abroad, a three-week field experience in a foreign country during the winter inter-term or summer break, and the completion and presentation of a research project by multi-disciplinary teams of students during the term immediately following the foreign experience. The authors have developed a mini-term course program that explores the technical, economic, environmental, sociopolitical, and cultural aspects of electric power generation in New Zealand. It was initially offered during the 2001-02 academic year, with the New Zealand field work in December (between the Fall and Winter trimesters at Union).

### *Course Focus: Why New Zealand?*

This course focuses on the significance of the generation mix in the management of electric energy supply of New Zealand, and the roles of both technology and markets in resolving the conflicts between increased availability (and lower cost) of electric power and preservation of the country's natural environment and cultural heritage. Recent deregulation and restructuring of the New Zealand electricity market, coupled with an unusually heavy reliance on hydro power for base load (75% of generation) and the resultant need for long-distance transmission of power, have created an extraordinary laboratory for such investigation. The mountainous topography and sizable river catchments in New Zealand, coupled with very high rainfall levels (especially on the South Island), provide ideal conditions for the development of hydro-based generation. Dwindling natural gas reserves, limited deep steam reserves (from volcanic activity on the North Island), a reluctance to exploit sizable coal reserves (because of environmental sensitivity to greenhouse gas emissions), and vehement political opposition to nuclear power development provide additional incentives for the country's substantial investment in hydroelectric power. Though the electricity is generated at very low cost (by world standards), the supply of power is weather sensitive. Indeed, at the time of the initial offering of the course, a major drought on the South Island in 2001 caused a spike in spot market prices and motivated calls for changes in the generation mix and a number of design changes and additional reforms in both the electricity market and in the management of the national grid. This is the context in which engineering and social science students worked in 2-person, interdisciplinary teams to analyze specific power projects and policies governing electric power generation and delivery.

### *Selection of Students*

Students are selected during a competitive process in the Spring term. Selection is based on academic background and standing, as well as on the submission of a personal statement that addresses the following:

- How the applicant's academic program at Union has prepared him/her for the proposed course of study;
- How participation will enhance the applicant's academic experience;
- How the applicant's personal development will be enhanced by participating in the program;
- How, if at all, the program relates to any avocational interest or previous experiences;
- The most challenging aspect of participating in this mini-term experience;
- The most compelling reason that the applicant should be selected over other applicants.

Careful screening of applicants is essential in order to identify those with a focused academic interest rather than those merely seeking a "tourist experience" in a beautiful part of the world. For the initial offering of the course (2001), 16 students were selected (8 social science and 8 engineering majors) from among the 40 who applied for the program.

### *Course Structure and Content*

The course requirements consist of: (1) the Fall trimester series of six seminars on the technology of generation sources, electricity market restructuring, and environmental/cultural issues; (2) completion of a substantial research paper addressing the technical and policy issues in electric power development (which are later presented to a campus-wide audience during Winter trimester); (3) a detailed journal documenting observations from three weeks of field work in New Zealand that includes visits to power stations (hydroelectric, geothermal, fossil-fuel, and wind-based generation), national grid and power company control centers, and additional sites with environmental or cultural significance.

*(1) Seminars Prior to Field Work Abroad*

The purpose of the seminars is to familiarize the students with the socioeconomic and environmental context in which power engineering decisions are made in New Zealand and to introduce the economics and technology of hydroelectric, geothermal, and wind power generation and the operation of New Zealand's recently deregulated electricity market. Of particular interest in the fall of 2001 were the ramifications of the extended drought which had drastically affected hydroelectric generation. The topics for each of the seminars are outlined below:

- Introduction to New Zealand geography, tour of Blackboard Web site, assignment of projects for two-person teams;

- Overview of New Zealand economy, environmental and natural resource management policies, and evolving role of indigenous peoples (Maori) in society, governance, and economy of the country;
- Overview of electric generation mix and development/operation of electricity market;
- Power engineering--hydroelectric generation;
- Power engineering--geothermal, thermal, wind-based generation;
- Brief (10-minute) presentations by teams outlining their research paper and identifying specific issues to be addressed during country visit.

In order to facilitate the students' research and to provide a focal point for course management, a substantial reference base has been established on a Blackboard Web site. In addition to containing a wealth of information about New Zealand and the travel itinerary, there is extensive reference material on electric energy resource management in New Zealand, including links to dozens of other Web sites on power generation technology and recent developments in electricity markets. Students are required to download specific material from the Web site in preparation for each of the seminars.

By making the team project assignments at the outset, students are able to focus on their research project (in the context of the larger issues in power development) well before leaving for New Zealand. They are also required to formulate, and share with the larger group at the last seminar meeting, an extensive list of questions that they intend to ask plant managers and policy makers during their visits to the facilities. The objective is to make the most of the site visits by discovering in advance what is readily available on the Web and from other published materials.

*(2) Content and Format of Research Papers*

The purpose of the team projects is for the students to learn how to assess the contributions of technology and markets to resolving the conflicts among competing resource uses in electric power development. The students are given a set of detailed instructions with regard to the content and format of the research papers.

Each of the teams must first demonstrate general understanding of the context in which decisions are made regarding electric power development and knowledge of current electric energy resource management policy in New Zealand. This includes:

- Maori history and culture;
- Motivation for the existing generation mix;
- Technological and policy constraints on natural resource use;
- Environmental regulatory (i.e., resource consent) process;
- Political/economic motivation for reform of the electricity industry and the electric power market;
- Operation of the electricity market (including forces that have impacted the market and comparisons with markets elsewhere (e.g., California, Australia)).

Each 2-student team must then present an analysis of the relevant resource management issues raised by the particular technology or power scheme to which they have been assigned. In the initial course offering the topics were:

- National grid management and the electricity market (including the high voltage DC inter-island link, transmission bottlenecks, and the dispatch system);
- Thermal power development (including the Huntly 1000 MW coal/natural gas station and the proposed additional 400 MW combined cycle plants at Huntly and elsewhere);
- Geothermal power development (focusing on the environmental impacts of continued use of once-through cooling technology without fluid reinjection at the 40-year-old Wairakei power station);
- Geothermal power development (at newer stations using binary cycle technology, cooling fans/towers, and reinjection of extracted fluids);
- Wind power development (focusing on the 48-unit Tararua wind farm and prospects for expansion in New Zealand and elsewhere);
- Waikato River power scheme (focusing on the application to the Environmental Council to increase use of river water for power generation from the nine power stations);
- Waitaki River power scheme (focusing on the proposed development of the Lower Waitaki for both irrigation and additional hydro generation from six new power stations);
- Manapouri hydro station (focusing on environmental concerns and design issues with original development of the underground station and technical issues with the second tailrace tunnel).

In addition to demonstrating a familiarity with, and understanding of, the environmental, economic, and technological issues related to the specific technology or power scheme, the students are expected to present evidence, *especially first-hand observations*, of the impacts (past and projected) of the technology. Impacts that must be considered include:

- Magnitude and timing of net economic benefits (e.g., value of electric power generation);
- Enhancement/loss of recreational uses;
- Damage to the natural environment (e.g., from reduced water flow, pollution);
- Risk to preservation of cultural artifacts and infringement of Maori land claims;
- Modifications to technology (at additional cost) to mitigate undesirable impacts.

The students are also expected to recognize the relevance of the project's resource management issues to those arising from the other projects in New Zealand and in the rest of the world. Having identified the necessary tradeoffs among competing resource uses and technologies, as well as other immediate and future concerns, they make explicit recommendations for policy changes with regard to the project.

Abstracts of three of the research papers follow:

***Issues in Transmission Grid Management in a Deregulated Electricity Market: The Case of New Zealand***

In New Zealand's recently deregulated electricity market, generators can supplement long-term (hedge) contracts by offering electricity to the spot market for dispatch through the national grid. Transpower Ltd is the state-owned enterprise responsible for operating the grid and facilitating and coordinating the transmission of power from generation stations to supply companies (retailers) and major industrial users. In order to ensure the reliability of power supply and the dispatch of power at the lowest possible cost to end-users, Transpower operates a high voltage direct current line that permits large electric energy transfers between the South and North Islands. However, a transmission bottleneck south of Auckland, the country's main population center, has restricted trade across the grid and resulted in significant price differentials. A major drought in 2001 that caused a spike in spot market prices and the failure of some electricity retailers has motivated calls for further reforms of both the electricity market and the management of the national grid. This analysis focuses on the efficiency impacts of the entry barriers for new retailers and generators and alternative approaches to alleviating the transmission bottleneck. Evidence is drawn from public records and interviews with Transpower management and electricity market participants in December, 2001.

***Issues in Hydroelectric Energy Resource Management in New Zealand: An Analysis of the Waikato River Power Scheme***

The Waikato River is one of New Zealand's most heavily utilized and economically important rivers. Nine hydro stations supply nearly 15% of New Zealand's electric energy, and the Waikato provides cooling water for three other power stations.[7] The River is also a source of municipal and agricultural water supply, a venue for water-based recreation, and a significant freshwater ecosystem. The country's reliance on hydroelectric power has forced policy makers to address the conflict between the increased need for electricity and preservation of the natural environment and cultural heritage. Mighty River Power, the state-owned operator of the Waikato hydro scheme, has recently applied to the Waikato Regional Environmental Council for resource consents to continue to utilize the River for electric power generation. In particular, the company has proposed changes in lake levels and flow regime in order to have greater flexibility to meet peak demand in New Zealand's recently deregulated electricity market.[7] This analysis reviews the technological, environmental, and economic issues in the proposed operation of the Waikato power scheme. Evidence is drawn from government documents, company records, and interviews with company management, plant operators, and Environmental Council officials during site visits in December, 2001.

***Issues in Hydroelectric Energy Resource Management in New Zealand: The Case of Manapouri Power Station***

Endowed with mountainous terrain and high rainfall levels, New Zealand has relied heavily on hydroelectric power to meet its electric energy needs. However, the development of hydroelectric power has forced policy makers to address the conflict between the increased availability (and lower cost) of electricity and preservation of the country's natural environment and cultural heritage. The Manapouri Hydroelectric Power Station, the largest hydro station in New Zealand, was constructed in a remote wilderness area in the 1960's to provide power for an aluminum smelter at the tip of the South Island. The design of the plant included a powerhouse 700 feet underground and a six-mile long tailrace tunnel system, in addition to the proposed raising of Lake Manapouri by 100 feet.[4] This analysis reviews the technological, environmental, and economic issues that have arisen in the siting, construction, and operation of the original plant and during the recently completed expansion of the tailrace capacity. The impacts of the deregulation of New Zealand's electricity market and the availability of power from alternative hydro sources are also considered in an overall benefit-cost assessment of the Manapouri project. Evidence is drawn from government records and interviews with plant management during a site visit in December, 2001.

## *(3) Student Journal Requirements*

In order to assure that students would focus sufficiently on the academic purposes of the trip to New Zealand, they were required to maintain a detailed record of their observations as they traveled around the country. Students were provided with 6.5 x 9.5 inch spiral-bound notebooks, small enough to facilitate note taking during site visits and yet large enough to contain the entire record of their visit. They were given the following set of written guidelines for record keeping and submission of the journals:

- The journal is supposed to be a complete *chronological* record of your observations and impressions of cultural and natural phenomena, social behavior and attitudes, economic/political institutions, and infrastructure in New Zealand. It should include technical notes from presentations at the various sites, as well as your assessment of each of the site visits (what was good about it and what might have made it better). However, it should *not* include *personal* experiences on your free time that are not directly related to the focus of the mini-term program. You should keep a [separate] diary if you desire to have such a record.
- The journal will be spot-checked while we are in New Zealand to determine whether you are maintaining a *timely* record of your experiences. You are expected to update the journal at least once per day, i.e., the most recent entries should have been made within the past 24 hours.
- The spontaneous record of your experiences may be limited to brief (even cryptic) entries in the journal. However, by leaving adequate space, you will later be able to make more complete entries (e.g., in the evening) when you have more time to reflect on what you have seen or heard. This will preserve the chronology and yet promote legibility and completeness of your observations.
- The journal (in the original spiral-bound notebook) must be submitted for evaluation no later than the day you return for the Winter term. There should be no embellishments or corrections to journal entries after your return from New Zealand; however, you may include your overall impressions and assessment at the end.

Bases for evaluation of the journals (40% of the course grade) included:

- Legibility;
- Documentation (of dates/times, places, sources of information);
- Scope (breadth and depth) of personal observations;
- Completeness of technical notes;
- Completeness of assessment of site visits, presentations, related activities.

***Field Work in New Zealand (Site Visits)***

The key component of the course is three weeks of field work in New Zealand. The country, renowned for its natural beauty, consists of two islands (about 2/3 the landmass of California) located 1000 miles southeast of Australia. On the tour of power generation sites in December 2001, the group traveled over 2700 miles in two 10-passenger vans. The odyssey began on the North Island in Auckland, New Zealand's largest city, and ended in Christchurch, the largest city on the South Island. In between, we visited the national grid control center and two power company control centers, 9 hydroelectric power stations (including two underground plants), a 1000MW thermal plant that burns both natural gas and coal, three geothermal power stations (using different technologies), and a wind farm with 48 wind turbines on a mountain ridge north of Wellington.

The itinerary includes presentations by the operators of the national grid, power company management, plant engineers, electricity market traders, environmental council officials, and representatives of indigenous peoples (Maori). Each of the State-owned enterprises that own and operate the bulk of New Zealand's generation capacity has been very accommodating in arranging the half-day visits to the various power stations and company control centers and providing information requested about the management of the facilities.

*Hydroelectric Power Schemes*

By visiting a variety of hydro stations, the students are able to observe the similarities in the turbines, generator, and control equipment, as studied prior to the visit. However, they also see important differences in how the technology is adapted to the topography, flow, and particular location of a hydro scheme. For example, the students are able to observe the special design, construction, and safety issues with the underground facilities, the operation of different types of surge tanks, turbine bearing disassembly and turbine replacement at a plant down for maintenance, different types of turbine runners with some showing cavitation damage, different penstock configurations, and water being "spilled" to meet environmental mandates. They learn how a second tailrace tunnel will increase the generating capacity at one plant by approximately 13%. A range of generating and control equipment is observed, from museum pieces carefully maintained and still producing power to the most modern turbines, generators, and governors. Students sense the shear power of the water through the vibrations and noise permeating the rigid structural shell of the plants.

The Waitaki River hydro power scheme on the South Island is particularly interesting for three reasons: (1) its scale (8 stations with 1800 MW capacity and lakes containing 60% of national hydro storage);[5] (2) the vulnerability to reliance on hydro power evidenced by the severe 2001 drought on the South Island (and the subsequent need to import power from the North Island); and (3) the recent proposal by its owner-operator, Meridian Energy Ltd, to expand the scheme along the Lower Waitaki River by constructing up to 6 additional stations (570 MW) along a canal (7 meters deep and 80 meters wide) that would also provide irrigation water for farms.[6] Environmental assessment of that project, especially the flow-sharing regime between the canal and river, has already begun. In addition to first-hand observation of the design and operation of an extensive hydro power scheme, the students are introduced to the complexities of design, approval, land acquisition, and construction of a major engineering project with significant environmental and socioeconomic impacts.

*Thermal Power*

Conventional thermal power plays an important role in New Zealand's generation mix, accounting for 30% of generation capacity and 20% of electric energy generation. [Because of their significantly higher operating costs compared to hydro facilities, thermal plants have a lower load factor.] The biggest thermal plant in New Zealand is the 1000 MW Huntly power station, which burns both coal and natural gas (the choice depending on the relative market price of the gas and coal) and is a key source of power for the major population center of Auckland. Because of the plant's relative inefficiency (35-40%) and critical reliance on limited cooling water from the Waikato River (also a key resource of hydro power), as well as the perceived need to diversify the generation base away from hydro, the State-owned operator of Huntly (Genesis Power Ltd), has recently applied for a permit to construct a 400 MW combined cycle gas turbine plant (with cooling tower) on the same site.[3] At the Huntly station, students are introduced to the design features of a thermal power plant that can cycle the fuel source without shutting down, and they develop an appreciation for the differences between older thermal technology and cutting edge technology.

*Geothermal Power Stations*

Though it has a relatively insignificant (<5%) share of New Zealand's total power generation, geothermal power generation poses some interesting engineering and environmental issues. We visit three power stations, one of which (Wairakei) is the oldest and largest of the geothermal power stations in New Zealand and the first to tap commercially a wet steam field. Ten per cent of the flow of the Waikato River is pumped through its condensers for cooling and there is no reinjection of the waste fluids.[1] It is possible to take a walking tour of the steam field and observe the subsidence resulting from decades of extraction, the silica deposits in the wastewater channels, and the engineering design features of the 3-mile-long pipeline system to accommodate expansion and contraction. The environmental problems from this power station include arsenic, boron, and other contaminants in the waste steam and the thermal pollution of the Waikato River.

In contrast with Wairakei, the Poihipi station uses conventional steam turbine technology powered by low pressure, dry steam wells. It has a forced draft cooling tower (and so power output is impacted by humidity because of slower evaporation in the cooling cycle) and the waste fluids are reinjected at the fringes of the steam field. Unlike the other geothermal stations, it is a non-base load station (because of environmental restrictions) and operates at minimal power (3MW) at night. Ironically, the plant was purchased unused from the Geysers geothermal project in the U.S. after that geothermal field ran out before the plant could begin operation.[2]

The third geothermal station, Mokai, uses state-of-the-art binary cycle technology and is owned by the Tuaropaki Trust, which represents the interests of a Maori tribe that has been granted title to the land above the steam field. The students are surprised to learn that, despite modern instrumentation, the extent of the reserves in the Mokai steam field is not yet known and that the drilling of rather costly exploratory wells (the so-called "suck and see" approach) continues to be necessary. The Mokai plant uses a dual cycle generation scheme, the first being a steam-binary turbine combination, and the second a lower-temperature brine unit connected to a second binary turbine.[2] In addition to observing the advances in geothermal power technology, at the Mokai facility the students see how government policy has enabled indigenous peoples to participate in the economic growth of New Zealand.

*Wind Power*

Although wind power accounts for a negligible amount of electricity generation in New Zealand (and elsewhere), it is of particular interest for future development for four reasons: (1) a considerable endowment of wind resources (i.e., New Zealand is a very windy place); (2) the need for a more diversified generation base; (3) the country's emphasis on the *sustainable* management of natural resources since passage of the Resource Management Act in 1991; and (4) the environmental concerns about greenhouse gas emissions (from burning fossil fuels) and the irreversible impacts on the landscape from hydroelectric developments. TrustPower Limited, a private company, owns and operates the Tararua Wind Farm on a mountain range north of Wellington on the North Island. It is considered one of the best sites in the world for wind power, as the average wind speed exceeds 20 mph and the wind turbines are able to operate more than 85% of the time with a capacity factor approaching 50%. There are currently 48 turbines (Vestas V47-660kW) in operation with a combined capacity of 32 MW. Permits have been issued for another 55 turbines at the site.[8]

At the Tararua Wind Farm the students observe how the use of lattice towers and color selection minimizes the visual impact of the structures, how the topography affects the distribution of the turbines over the 1700 acre "farm" in order to maximize energy capture, and how the blades (with full feathering ability) and the turbines are adjusted automatically to changes in wind direction. The sight of hundreds of sheep and cattle grazing on the land beneath the towers underscores a significant advantage of wind over hydro power—that alternative land uses in the vicinity of the power station are not adversely affected. During the staff presentation about wind turbine design and cost issues, the students learn that, in spite of substantial capital costs and *no* government subsidies, the wind energy generated at Tararua is cost-competitive with small hydro facilities. Though wind-generated power has become increasingly more economically viable (as larger-scale units are developed) and is environmentally quite "friendly," the inability to harness the available wind energy on a large scale (at least with current technology) makes it unlikely that wind power will constitute a significant part of base load in the future.

*Natural Wonders and Sites with Cultural Significance*

In addition to the power station tours, the students have many opportunities to experience the culture and to explore the many natural wonders of the country. The itinerary includes tours of the national museum (Te Papa) in Wellington and the Rotorua Museum of Maori cultural history, attendance at a Maori feast (hangi), and living for two days on a sheep station at the base of Mt Cook (at 12,500 feet, the highest peak in the Southern Alps). Exploration of New Zealand's natural wonders included boating through fiords with hundreds of hanging waterfalls and hikes through rain forests and active geothermal fields, along endless beaches, and around pristine mountain lakes, glaciers, and volcanoes. Such first-hand experiences provide students with a much greater appreciation of the value New Zealanders attach to preserving the country's natural environment and cultural heritage. It is an essential component of a truly global experience.

***Course Assessment***

Student and faculty feedback indicate that interdisciplinary courses such as Electric Power Development in New Zealand give engineering students a real appreciation for the significance of the socioeconomic and cultural context in which global technology decisions are made. In this particular course they have the opportunity to observe first-hand the complexity of designing and managing electricity generation and transmission in an unregulated market environment. Because the students interact directly with the various stakeholders and work in teams to evaluate the consequences of the decisions, they learn the value of a multi-disciplinary approach to issues of technology. The enthusiasm and sense of accomplishment of our students was evident as they presented their work to the campus-wide forum, and several characterized the course as the "academic experience of a lifetime." The engineering curriculum is clearly enriched when such opportunities can be made available.

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