EUROPE'S BATTERY: THE MAKING OF THE ALPINE ENERGY LANDSCAPE, 1870-1955

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ABSTRACT

This study examines the environmental history of hydropower development in the Alps from the mid-nineteenth to the mid-twentieth centuries. Analyzing government archival files, associational journals, conference proceedings, and published contemporary material from several Alpine countries, it seeks to determine how and why Europeans modified the Alpine landscape to generate hydropower, and to explore the consequences of these decisions. I argue that during this time period, Europeans thoroughly transformed the Alpine environment, creating what I call "Europe's Battery": a gigantic system for storing hydropower and distributing it on a continental scale.

This study shows how nineteenth-century innovations in energy technology contributed to a dramatic shift in the perception of the Alps as a landscape of "white coal." It demonstrates how at the outset of electrification, Europeans modified Alpine waterways on an unprecedented scale in order to tap into the power of flowing Alpine water. I show how after the turn of the twentieth century, Europeans took advantage of the unique mountain environment to store water, first by converting existing lakes into reservoirs. The practice countered what was perceived to be the greatest disadvantage of white coal: its climate-influenced inconstancy. This study shows the importance of war, and especially the First World War, in the forging of the new Alpine landscape. Finally, this study illustrates how from the interwar period to the aftermath of the

Second World War, Europeans put the finishing touches on the new Alpine energy landscape by creating large reservoirs behind dams and feeding Alpine hydroelectricity into a burgeoning European electricity grid. By 1955 the Alps had become one of the most important energy landscapes in Europe.

This history of the Alpine energy landscape contributes to a number of historiographical fields. It represents an important chapter in the environmental history of one of the world's most iconic landscapes. It sheds light on the hydroelectric energy transition and shows the environmental impacts of electrification. Finally the history of Europe's Battery illuminates an alternative regional history of energy development and industrialization in Europe, one based on water and electricity and not coal.

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INTRODUCTION

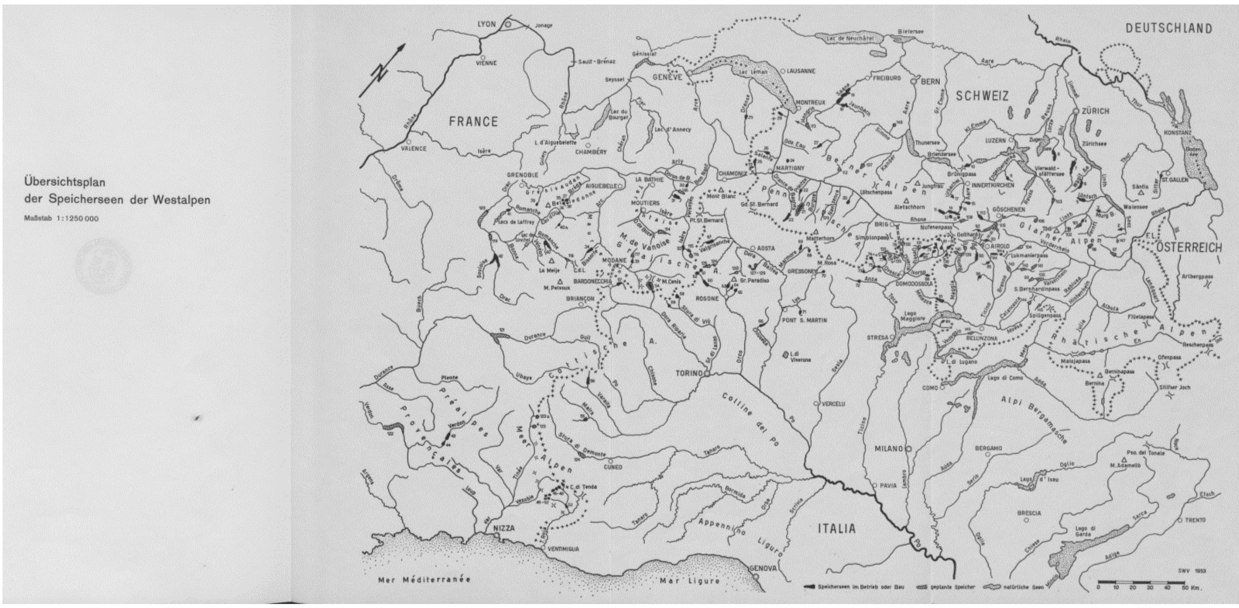

Figure 1. "Overview of the reservoirs of the Western Alps," 1953. Harald Link, *Die Speicherseen der Alpen: Bestand und Planung* (Zurich: Schweizerischer Wasserwirtschaftsverband, 1953).

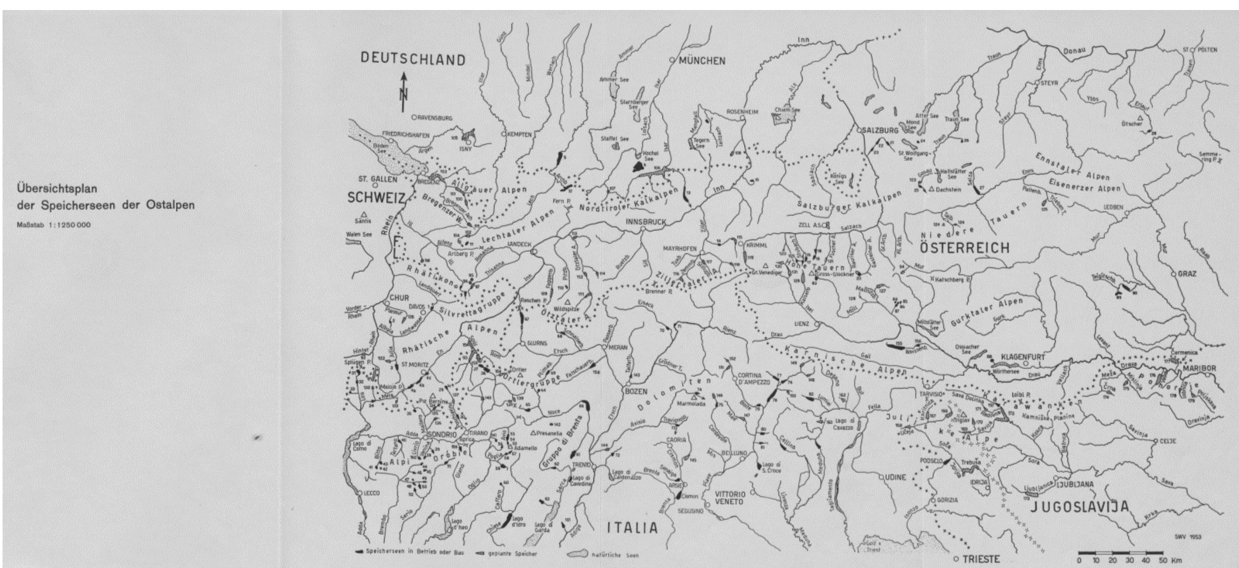

Figure 1. "Overview of the reservoirs of the Eastern Alps," 1953. Link, *Speicherseen*.

In an early 1950s publication for the Swiss Water Management Association, the German engineer Harald Link reflected on a particular feature of the European Alps, the mountains' numerous lakes. "Lakes," he began "are a jewel of every landscape, but especially the high mountains." The Alps, he continued, were rich with lakes of every sort, from the large finger lakes at the mountains' edge, to the smaller lakes of the forest and meadow belt, to the innumerable tiny high-altitude cirque lakes. Alpine lakes attracted crowds of visitors, Link maintained, indeed he judged their appeal to be just as strong as the pull of the highest peaks. Link reported there were some 5,000 lakes in the Alps. Besides a handful that had been created by landslides or mudflows, most owed their existence to ice-age glaciation. Countless Alpine lakes had long ago disappeared, Link explained, thanks to the power of flowing water and some assistance from human hands. Many of these vanished lakes had, as all lakes will eventually, disappeared due to the forces of sedimentation and erosion. Humans, Link intimated, had also played a role in the destruction of Alpine lakes, thanks to their habit of draining them to reclaim agricultural land. As evidence of these developments, Link compared a late-eighteenth-century map of the Alpine region of Tyrol with a current one. The small parcel in the eastern Alps alone counted one hundred fewer lakes.

Link noted that for two generations, however, this trend had reversed itself. Instead of dwindling, the number of new Alpine lakes had increased since the beginning of the twentieth century. Link laid this reversal squarely at the doorstep of humanity. The change had come with the acquisition of a new skill, namely the ability to utilize water power on a grand scale. Technology had helped humans transcend the old-fashioned waterwheels and mills that had previously converted the power of flowing water into useful energy. With the ability to convert this mechanical energy into electricity and transmit this power over long distances, "Water power development pressed everywhere into the mountains, which possessed tremendous, inexhaustible energy in their water-rich rivers and enormous falls." After clarifying their background, Link finally explained the provenance of the new lakes. The new waters had been created because the mountainous Alpine environment provided a unique opportunity to solve a modern version of an energy problem that has dogged humanity for the ages. "Since electricity cannot be stored on a grand scale, rather must be generated at the moment of demand," Link explained, "the necessity emerged to store water in times of abundance, as a carrier of potential energy, for the demands in times of low-flow." Thus Europeans began to "convert natural lakes by draining or damming into reservoirs (*Wasserspeicher*), and to create storage reservoirs by building dams in suitable valleys, thereby enlarging the available water surface area (*Wasserfläche*) and integrating it in a novel manner into the landscape." Storage was necessary because of a fundamental incongruence of the availability of Alpine water and the European energy system's demand for energy. Depending on the altitude and climate, only around ten to twenty-five percent of annual drainage in the Alps flowed during the winter season, the time when demand for electricity in the form of light and heat was greatest. The reservoirs served to redress this disharmony.

Link, a hydraulic engineer, had in fact been intimately involved in the construction of several Alpine reservoirs. Indeed his lacustrine reflections all came in the context of a survey of these new water bodies in the Alps (see figs. 1 and 2). According to his study, around two hundred new reservoirs had been created either by damming existing lakes or submerging previously dry valley floors. These reservoirs existed all across the Alps, about evenly distributed in number between east and west. By 1953 these efforts had resulted in the creation of almost five billion cubic meters of water storage capacity, or about two percent of the entire annual drainage of the Alps. With the exception of a handful of lower-lying irrigation reservoirs at the southern foot of the Alps, these new lakes all functioned as reservoirs of power. When Link revisited his survey of Alpine reservoirs at the outset of the 1970s, he noted, by way of illustrating the grandeur of these achievements, that by 1954 the total volume of material contained in Alpine dams was almost nine times greater than the cubature of the Great Pyramid of Giza.[1]

The changes described by Link were already of a monumental scale, and he had not yet considered their energy consequences. Link was most interested in Alpine reservoirs and did not much discuss the actual electricity produced in the mountains. Others did, and the numbers were equally formidable. According to a 1947 United Nations report the countries of the Alpine massif accounted for about fifty-five percent of the total hydroelectricity in Europe. The same report also estimated that in 1947, water power generated about half of the total electricity supply in Europe, meaning the Alps were responsible for nearly a quarter of the Continent's total. The report, however, also made the point that it was not simply the quantity of hydroelectricity that mattered, but its quality. Some hydroelectric plants could not control the water that flowed over their turbines, and generated electricity more or less ceaselessly whether it was needed or not. Other hydroelectric plants had access to power reservoirs, and could therefore produce to fit the

[1] Harald Link, *Die Speicherseen der Alpen: Bestand und Planung* (Zurich: Schweizerischer Wasserwirtschaftsverband, 1953), 1. The remark about the pyramids appeared in Harald Link "Speicherseen der Alpen/Bassins d'accumulation des Alpes," *Wasser und Energiewirtschaft/Cours d'eau et énergie* 62, No. 9 (1970): 255. In the period from 1955 to 1969 alone, Link estimated that dam cubature was fifteen times greater than the Great Pyramid.

schedule of demand. Thanks to the reservoirs that Link described, the Alps were uniquely rich with the latter sort of hydropower. The report recognized that the importance of hydroelectricity would only expand in the near future, as water power development proceeded throughout Europe in the interests of economic reconstruction. Indeed, even by the time Link's survey appeared six years later, the electrical importance of the Alps had increased.[2]

The UN report did not discuss a further peculiar aspect of Alpine hydroelectricity at the time. The electricity produced by Alpine water power was not used strictly within the mountain limits. Rather Alpine hydro was transported via high tension wires far into the surrounding plains. Indeed, Alpine hydroelectricity was an integral part of the first—and at that time only—efforts to unify disparate national and regional electricity grids into a European network. This idea, which surfaced after the First World War, had its justification in creating an electric interconnection among utilities in continental Europe's main water power resources in Scandinavia and the mountain regions of the Pyrenees, Alps, and Apennines, with the coal fields of central Europe. The momentous first step came in 1930, when a German utility completed a high-voltage link between the water power of the Austrian Alps and the German Ruhr. Further long-distance transmissions of Alpine hydroelectricity foundered first due to economic depression and then later war. But as of the 1947 UN report there were discussions of linking

[2] The energy significance of the Alps would have been even greater than this figure suggests, as the UN report did not account for the considerable hydroelectric production of the German or Yugoslav Alps. Scandinavia produced about twenty percent of Europe's hydroelectricity, and the Danube states twelve percent. See Salzburger Landesarchiv (SLA) Präsidial-Akten 1948/40: "Technischer Vorbericht über die Wasserkraftfragen," (1947), 3.

the water power of the Alps to northwest Europe, from northern Italy to the Netherlands. These visions also eventually became reality.[3]

Taken together, these vignettes provide a snapshot of the Alps in the early postwar period, one that perhaps stands at odds with traditional views of the Alps. From the mid-nineteenth until the mid-twentieth century, Europeans thoroughly transformed unique mountain environments to store hydraulic power on an unprecedented scale, and generate massive quantities of electricity for distribution throughout Europe. The result I argue, was the creation of a new energy landscape which I call "Europe's Battery." Composed of dams, diversions, wires, and towers, Europe's Battery was the largest system for storing and exploiting hydraulic power on the planet. It is the history of this energy landscape that forms the focus of this study. I aim to show how and why Europeans chose to alter the Alpine landscape as they did, as well as some of the consequences of these decisions. The history of Europe's Battery not only sheds light on some important environmental changes in one of the globe's most iconic landscapes, it adds an important wrinkle to a more familiar story of the dominance of fossil fuels in modern European industrial history.

Environmental historians have employed the concept of energy landscapes as a way of emphasizing the connections between energy and the nonhuman environment. The term thus provides one avenue to write the environmental history of energy.[4] In one of the pioneering studies of an energy landscape, Brian Black explained the history of the world's first oil boom in

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[3] Oskar Vas, *Der Anteil Österreichs an der elektrizitäts-wirtschaftlichen Gemeinschaftsplanung in Europa* (Vienna: Springer, 1948), 7.
[4] But not the only one. Since it often deals with natural resources, many scholars already consider energy history as a subset of environmental history. Energy histories with strong focus on the environment include Rolf Peter Sieferle, *The Subterranean Forest: Energy Systems and the Industrial Revolution* (Cambridge: White Horse Press, 2001); James C. Williams, *Energy and the Making of Modern California* (Akron, Ohio: Akron University Press, 1997).

Pennsylvania as a kind of "biotic reaction" that occurred when industrial American society encountered the vast pools of stored energy in the vicinity of the Oil Creek valley. This "Petrolia" landscape is a reminder of the ecological effects of energy production in general, and analysis of the impacts of oil booms in particular.[5] On the other side of the state of Pennsylvania, Christopher F. Jones has recently explored the history of the early-nineteenth century landscapes that he argues underlay the United States' modern addiction to fossil fuels. These landscapes were defined above all by the construction of coal canals that made anthracite affordable for a large portion of the mid-Atlantic states, hastening the transition to an inorganic economy.[6] Other scholars have posited a present-day cityscape in the United States as a sort of energy landscape. An environmental history of Houston and its surroundings suggests that in many ways, the history of the urban agglomeration is indeed the history of an energy landscape.[7] Finally, while Richard White posited the remaking of the Columbia River in the North America as the creation of an "organic machine," his study is in many respects the history of an energy landscape. The most recent model of the Columbia is a machine whose primary purpose is to generate hydroelectricity.[8]

So far, historians have used the term 'energy landscape' primarily in U.S. contexts and none have applied it to water power development in the Alps. Indeed, the story of the modern hydraulic retooling of the Alps remains largely to be told in any conceptual vocabulary. While scholars have recognized and related parts of these iconic mountains' history, few have touched

[5] Brian Black, *Petrolia: The Landscape of America's First Oil Boom* (Baltimore: Johns Hopkins University, 2000).
[6] Christopher F. Jones, "A Landscape of Energy Abundance: Anthracite Coal Canals and the Roots of American Fossil Fuel Dependence, 1820-1860," *Environmental History* 15 (July 2010): 449-484.
[7] Martin V. Melosi and Joseph A. Pratt, *Energy Metropolis: An Environmental History of Houston and the Gulf Coast* (Pittsburgh: University of Pittsburgh Press, 2007).
[8] Richard White, *The Organic Machine: The Remaking of the Columbia River* (New York: Hill and Wang, 1995).

on, let alone focused on, the changes in Alpine hydrology. Some of the broad surveys of Alpine history do indeed mention the importance of hydropower in the Alpine lands, but they do not reflect upon hydropower development in the modification of Alpine waterways, or the broader significance of Alpine hydroelectricity.[9] An exception is the history of the Alpine cultural landscape by the German geographer Werner Bätzing. Bätzing provides a short sketch of part of the role that water power usage played—along with the provisioning of drinking water supplies—in transforming the Alps into Europe's "water tower" ("*Wasserschloss*") in the modern period. While his brief treatment is short on historical details, it stands out for recognizing the different environmental impacts of different methods of harnessing water power.[10] The Alpine environment has been at the center of a rich body of—mostly anthropological—scholarship that has focused on the Alps as a unique ecosystem in which to study the interplay between environment, populations, and communities. Water and energy, however, scarcely play a role in these studies.[11] Historiography on European perceptions of the Alps has thus far not included the perspectives of groups— such as engineers—who not only spied sublime nature in Alpine

[9] The major work on Alpine history is Paul Guichonnet, *Histoire et civilisations des Alpes*, 2 Vols. (Toulouse: Privat, 1980). See also Jon Mathieu, *Geschichte der Alpen 1500-1900: Umwelt, Entwicklung, Gesellschaft*, 2nd ed. (Vienna: Böhlau, 2001). For a discussion of the history of the Alps and transit see Walter Woodburn Hyde, "The Alps in History," *Proceedings of the American Philosophical Society* 75, No. 6 (1935): 431-442.
[10] Werner Bätzing, *Die Alpen: Geschichte und Zukunft einer europäischen Kulturlandschaft*, 3d ed. (Munich: C.H. Beck, 2003), 190-199.
[11] The Alps have long been perceived as a kind of natural laboratory in which to study community and population dynamics. Thomas Malthus, for instance, saw the Swiss mountain environment as a limiting environment, devoting a chapter to the country in his second and later editions of *Essay on Population*. The classic study in this vein is John W. Cole and Eric R. Wolf, *The Hidden Frontier: Ecology and Ethnicity in an Alpine Valley* (New York: Academic Press, 1974). See also Robert McNetting, *Balancing on an Alp: Ecological Change and Continuity in a Swiss Mountain Community* (Cambridge: Cambridge University Press, 1981); Pier Paolo Viazzo, *Upland Communities: Environment, Population and Social Structure in the Alps since the Sixteenth Century* (Cambridge: Cambridge University Press, 1989). An early essay on the unifying cultural effects of the Alpine environment is Robert K. Burns Jr., "The Circum-Alpine Culture Area: A Preliminary View," *Anthropological Quarterly* 36, No. 3 (July 1963): 130-155.

waterfalls, but untapped power as well.[12] Finally, while histories of electrification in the various countries of the Alpine arc have recognized the importance of Alpine water power as an input, they have generally been unconcerned by the changes wrought in the landscape by power generation.[13]

Understanding modern hydropower development in the Alps as the creation of a new energy landscape has the potential to reap new insights into both the environmental history of the Alps and the environmental impacts of energy production. The history of electrification is in part also a history of the environmental change necessary to exploit energy resources, and the story of Europe's Battery composes an important component of this process in Europe. It may be that electricity's most important contribution to modern energy use has been the access it has allowed to previously unused or under-utilized energy sources, particularly flows of natural power. But exploring the environmental foundations of water power usage is particularly useful. Perhaps more than any other type of energy production and distribution, hydropower depends on significant alteration of the landscape, and the imagination to envision how to do so. Only replumbing the land can make the power of falling water useful. Moreover, the landscape changes necessary to generate hydropower also significantly impact the quality of hydro as an energy resource. As will become clear in some of the following case studies, Europeans saw that the methods of harnessing water power determined not only the quantity of useful energy

[12] Jon Mathieu and Simona Boscani Leoni, eds., *Die Alpen!: zur europäischen Wahrnehmungsgeschichte seit der Renaissance/Les Alpes!: pour une histoire de la perception européenne depuis la Renaissance* (Bern: P. Lang, 2005).

[13] On Switzerland see Serge Paquier, *Histoire de l'électricité en Suisse: la dynamique d'un petit pays européen 1875-1939*, 2 Vols. (Geneva: Ed. Passé Présent, 1998); David Gugerli, *Redeströme: Zur Elektrifizierung der Schweiz, 1880-1914* (Zurich: Chronos, 1996). On France *Histoire génerale de l'électricité en France*, 3 Vols. (Paris: Fayard, 1991-1996). On Italy see *Storia dell'industria elettrica in Italia*, 5 Vols. (Bari: Laterza, 1992-1994); On Germany see Wolfram Fischer, *Die Geschichte der Stromversorgung* (Frankfurt/Main: Verl.- und Wirtschaftsges. der Elektrizitätswerke, 1992). No general history of electricity in Austria exists.

created, but the quality as well. In deciding how to engineer the landscape, engineers were constrained only by their imaginations and conventions of economy and the technically feasible (and sometimes not even those). Thus they bitterly debated how one should properly modify the Alpine hydroscape. Compare hydropower's situation to that of coal and oil. Decisions about how to extract these minerals from the earth may impact the bounty of the mine or well, but they have no bearing on their quality as fuels. With water power development, hydraulic engineers must decide (among other things) whether to construct a facility that can store water power for longer periods, or to simply tap into the energy of the immediate flow of the river. Europeans preferred stored water power, as it gave them more flexibility in its employment. However, storage facilities cost considerably more and required greater environmental changes. Landscapes like the Alps, then, provide critical information about historical energy aims. Finally, a more expansive definition of energy landscape that includes the electrical infrastructure created by hydroelectric development also demonstrates the connections between the history of environmental change in the mountains with the economic and social history of wide swaths of Europe as well.

The significance of the Alps as an energy landscape adds to our knowledge of both mountains and water in history. In European history, the Alps have stood out primarily as a barrier to movement. Indeed, the Alps' most memorable role on the European stage has been that of natural antagonist, slowing the movements of both Hannibal and Napoleon. My work suggests the importance of the mountains as a reservoir, in this case of energy. Neither the need for energy storage, nor the role the modern Alps played is entirely new. Societies dependent on seasonal flows of energy have always required storage. Mountain regions the world over have served as landscapes of energy storage in other respects as well. In the past the Alps stored fuel for Europeans in their vast forests. They have also acted as reservoirs of human labor, supplying all manner of seasonal workers. This study also offers a different perspective on water. It surveys water management not on a national basis, or through the lens of a particular river system, but on a broader environmental basis. Alpine water carried potential energy because it was mountain water; the flow regime that made Alpine water power ideal in some respects but problematic in others, was in large part determined by the mountain environment. This is a history of the basins of the upper Rhône, the upper Po, the Alpine Rhine. As such it looks not only at rivers, but waterfalls, torrents, lakes, and sometimes frozen water as well.[14] Finally, a history of hydropower development in the Alps is necessarily one of dam-building too. A history of dam-building in the temperate, humid Alps differs from studies of more familiar dams, such as those of the arid US West for instance, built to fulfill multiple purposes.[15] In the Alps, with few exceptions, dams were about hydropower. And while certain groups expressed a fair amount of militant antagonism towards nature in their desire to dam Alpine waterways, for many engineers this was simply a matter of correcting natural imbalances.[16]

[14] Some recent efforts at reconceptualizing riverine history are Christof Mauch and Thomas Zeller, eds., *Rivers in History: Perspectives on Waterways in Europe and North America* (Pittsburgh: University of Pittsburgh Press, 2008); Mark Cioc, *The Rhine: An Eco-Biography* (Seattle: University of Washington Press, 2002). Recognizing that the hydrology of individual rivers vary greatly according to environmental circumstances, Cioc divides his analysis of "Father Rhine" into sections (Alpine Rhine, high Rhine, upper Rhine, middle Rhine, lower Rhine). Lakes have so far not received as much attention as other surface water. A recent work that focuses on the environmental history of a lake is Harriet Ritvo, *The Dawn of Green: Manchester, Thirlmere, and Modern Environmentalism* (Chicago: University of Chicago Press, 2009).

[15] Donald Worster, *Rivers of Empire: Water, Aridity, and the Growth of the American West* (Oxford: Oxford University Press, 1985); Marc Reisner, *Cadillac Desert: The American West and its Disappearing Water* (New York: Penguin, 1993).

[16] In his volume on hydraulic engineering and the making of the modern German state, historian David Blackbourn finds an adversarial relationship to nature as the common thread connecting over three centuries. See David Blackbourn, *The Conquest of Nature: Water, Landscape, and the Making of Modern Germany* (New York: W.W. Norton, 2006).

The emergence of this mountain battery also changes the way we think about energy and energy history in Europe. By focusing on hydropower, this study adds breadth to a field that has mostly ignored alternative energy use in favor of fossil fuels.[17] In demonstrating the importance of water in west-central Europe in the last two centuries, moreover, it fills in some important gaps left by the global surveys of energy use that represent a significant portion of energy historiography. While these analyses are justified in emphasizing the importance of fossil fuels in the modern period, the history of hydropower development in the Alps is a reminder that their triumph was not a foregone conclusion everywhere.[18] There was a window in time (roughly congruent with the bounds of this study) where hydropower appeared a worthy competitor to coal in some places, including west-central Europe. My study of the Alps, a landscape that bears the marks of thorough rationalization of water power resources, also speaks to a fundamental reality of European energy history. Europe's Battery is a landscape produced by energy scarcity, not abundance. The lack of alternatives drove the efforts to make the most of plentiful water power.[19] Finally, one area where this study makes a new contribution is the environmental history of alternative energy. The making of Europe's Battery is in one sense a case study of the environmental circumstances and modifications that underlay one of the grandest efforts to harness alternative energy in world history.

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[17] Two important works on water power are Theodore Steinberg, *Nature Incorporated: Industrialization and the Waters of New England* (Amherst: University of Massachusetts Press, 1994); and Louis C. Hunter, *Water Power in the Century of the Steam Engine* (Charlottesville: University Press of Virginia, 1979), Vol. 1, Louis C. Hunter *A History of Industrial Power in the United States, 1780-1930*.
[18] Some global surveys of energy are Jean-Claude Debeir et al., *In the Servitude of Power: Energy and Civilization through the Ages* (London: Zed Books, 1991); Vaclav Smil, *Energy in World History* (Boulder: Westview Press, 1994); J.R. McNeill, *Something New Under the Sun: An Environmental History of the Twentieth Century World* (New York: W.W. Norton, 2000), 10-16; Alfred W. Crosby, *Children of the Sun: A History of Humanity's Unappeasable Appetite for Energy* (New York: W.W. Norton, 2006).
[19] For the alternative narrative, see Martin V. Melosi, *Coping with Abundance: Energy and Environment in Industrial America* (New York: Knopf, 1985).

Temporally, this study begins in the mid-nineteenth century. It was at this time that engineers, particularly in the French Alps, inaugurated a water power revolution by tapping into the high-pressure water power of waterfalls. They accomplished the feat with the help of a new prime mover, the turbine, which better withstood pressure than its predecessor the waterwheel. The ability to harness high-pressure water power was the key to the emergence of the entire mountain range as a landscape of potential power. Choosing the mid-nineteenth century as a starting point also demonstrates that modern hydropower use is not simply a product of electrification.

The analysis ends in the postwar period, in 1955, when the Alpine landscape had assumed the characteristics that made it Europe's Battery. At this point Alpine water power was one of the largest producers of electricity in Europe, and this energy was available in places far outside of the Alps. The exploitation of the Alpine environment for storage had by this point assumed large-scale proportions. It was in the postwar years, in the name of European reconstruction, that the fate of the Alps as an energy landscape was sealed.

Closing the analysis in 1955, however, is problematic in some ways. For the development of Alpine hydropower continued throughout the postwar period, and indeed up to this day. In fact, the period from 1955 to 1970 or so witnessed the greatest expansion in dam-building. At the same time, however, the relative importance of Alpine hydropower in the European electricity supply diminished. While the Alps became a battery with greater storage in this later period, its significance flagged slightly with emergence of new electricity sources in nuclear power and natural gas. Thereafter, Europeans no longer looked at alpine hydropower as the energy source of the future.

The spatial limits of my study are a little more amorphous. As geographer Werner Bätzing has pointed out, there are many different ways to define the Alps, all of which depend on who is looking. Bätzing lists no fewer than five definitions, based variously on the perspectives of scientists, tourists, and politicians.[20] It is one of the aims of this study to make the case for a much broader definition of the Alps than traditionally proposed. For the most part, my analysis of the Alpine landscape corresponds to what a hydrologist might consider to be the Alps, that is the streams and lakes whose regimes are governed largely by circumstances peculiar to the mountains. This definition includes the upper stretches of some of the larger rivers that drain out of the Alps, as their flow regimes are still heavily influenced by the mountains. Many of those responsible for creating the Alpine energy landscape also perceived these transitional river stretches to be Alpine in nature. Where my conception of the Alps differs is its inclusion of both the electrical apparatus that transported white coal to regions outside the mountains, and the destinations of Alpine hydropower as well. Transporting white coal to regions with greater electricity demand was a fundamental strategy for developing the mountain energy, as most Europeans believed this power was too great to be utilized in the uplands. Moreover, the quality of Alpine hydropower profoundly affected the provisioning of electricity in grids where it was available. The first major step in extending the Alpine energy landscape occurred in 1930, when a long-distance power linkage brought electrons produced by the power of Alpine water in western Austria to Germany's Ruhr region. By the end of the study, Alpine hydroelectricity had become such a critical component of the Continent's burgeoning electrical networks that the mountains had indeed become a battery for much of west-central Europe.

[20] Bätzing, *Die Alpen*, 21-22.

I have structured my dissertation around the major environmental changes that led to the creation of Europe's Battery. From the perspective of landscape and environment, several key transitions are manifest. The first was the initial harnessing of the power of the Alps' myriad waterfalls, which I discuss in Chapter 2 . The development of the turbine finally made it possible to tap into the high-pressure water power produced by towering cascades. French engineers, harnessing the "high-chute" water power of French Alpine waterfalls immortalized their achievement with the metaphor "white coal." Soon thereafter, the Alpine landscape incorporated different types of hydropower facilities, different means of distributing water power, and greater interventions into Alpine hydrology. All of these novelties were occasioned by the advent of hydroelectricity to the Alps, the subject of Chapter 3. Electricity brought new industries, webs of wires, and greater interventions into the Alpine hydrosphere. With the ability to transmit water power long distances, it made sense to harness and distribute the entire water power of a given site, rather than simply carve out the energy needed for a given pursuit. In the early days of electrification, Europeans still primarily tapped into the power of constantly flowing Alpine water. Around the turn of the twentieth century, voices within the electricity supply community began to argue that finding ways to counter the seasonality of Alpine water flows was critical for expanding the supply of hydroelectricity. Solutions focused mostly on water storage, and as I demonstrate in Chapter 4, this movement to store water initially focused on converting natural lakes into reservoirs. Chapter 5 considers the most important turning point of all in the history of the Alpine energy landscape. The First World War ultimately led to an increase in hydropower development throughout the Alps, and an imperative to more fully rationalize its use. The outbreak of hostilities fomented an immediate intensification of hydropower development in some parts of the Alps, as countries tried desperately make up for fossil fuel shortfalls. By the end of the conflict, waterways throughout the Alps underwent more intense water power development. In Chapter 6 I trace the finishing touches—namely reservoirs and long-distance transmission wires—put on the Alpine energy landscape from the mid-1920s until the early post-World War II period.

Around the globe, the advent of long-distance electric power transmission increased the worth of water power by removing the barrier to its transport. With increased value came intense battles over who should control and benefit from the resource. One of the most important fronts in this battle was the conflict between private and states interests. In the Alps, this was no different. Water laws throughout the region placed control over most water power resources in the hand of the state. While most early hydropower projects in the Alps came at the initiative of private enterprise, the idea quickly emerged that national resources should be controlled by the state to ensure a benefit for all of society. Public hydropower became common in parts of the Alps after the First World War, and the rule after the Second. A history of hydroelectric development in the Alps might very fruitfully center on this question of public versus private ownership. But while the theme appears from time to time in this project, it is not the focus. For as far as the impact on the Alpine environment—a primary focus of this study—is concerned, the public/private dichotomy was not decisive. Private companies, municipalities, states all pursued projects of similar scope and scale at more or less the same time. Even as Switzerland, Austria, and Germany created reservoirs and dam complexes under state auspices in their Alpine regions after the First World War, the private sector completed similar projects in France and Italy. Whether it was private or public enterprise that played the decisive role in the formation of European energy infrastructure, in the case of the structure of Alpine waterways, it did not much matter who was in control.[21]

The Alpine Hydroscape

In the 1907 state catalogue of water resources *The Water Power of Bavaria*, a state official attempted to define for a keenly interested Bavarian public precisely what water power was. He started with an expansive conception. "In the broadest sense" he wrote "water power is the capability to perform work (energy) that is released as soon as a certain amount of water falls from a certain height." Water power could take the form of a raindrop falling from the roof of a house or the action of the tides. The technological sphere, he continued, defined water power in a much narrower fashion. For engineers, the only hydropower that mattered was "useful water power, water power that can be exploited beneficially for humanity."[22]

As another example of falling water, the Bavarian bureaucrat might have also mentioned the continual flow of water from the heights of the Alps that supplied his kingdom with much of its water. Quite apart from any human intervention, enormous amounts of water fell from the peaks of the Alps and flowed down to the plains below, releasing energy and performing work all the way. Some forms of this work were seen as a decided nuisance, such as the damage Alpine waterways caused when they jumped their banks and flooded human works. Others were seen as simply useless or their effects misunderstood. Moving sediment from one place to another might fall into this category. Understanding the environmental basis of Alpine water is useful in understanding why the mountain water was seen as so ideal for power generation in

[21] Robert Millward looks at this question in *Private and Public Enterprise in Europe: Energy, Telecommunications, and Transport, 1830-1990* (Cambridge: Cambridge University Press, 2005).
[22] K. Oberste Baubehörde, *Die Wasserkräfte Bayerns* (Munich: Piloty, 1907), 7.

some respects, and so lacking in others. It is also necessary for comprehending the consequences of human intervention. This requires a brief survey of the history and evolution of the Alpine hydroscape.

First a word about the human history of the Alpine landscape. The first mention of the Alps in European letters stemmed from Herodotus, writing in the fifth century BC. Herodotus wrote of the *Alpis*, which did not refer to a mountain chain, but a tributary of the Danube. About a hundred years later Aristotle called the massif by its earliest known name, the Arcynian Mountains, perhaps alluding to the Hercynian Forest that once covered much of southern Germany. It is in the work of an obscure Alexandrian poet named Lycophron that we first find the term *Salpeis* in the third century BC. The precise meaning of the word remains unknown. The Romans associated it with *albus*, the Latin word for white. In all likelihood the term is Celtic for "lofty", as cognates still appear in Gaelic tongues.[23]

The loftiness that so impressed the Celts was the product of plate tectonics. In fact since the 1960s, the Alps have been used by geologists as a textbook example illustrating the validity of the theory.[24] Scientists believe the folding that created the Alps began some 100 million years ago. At this time, the northward drifting African continental plate collided with the European plate. The impact dramatically shrank the size of the Tethys Sea—the colossal sea that once separated the European and African continents, and whose remnant can be seen in the Mediterranean. It also vaulted the African plate on top of the European, folding together continental crust in the process. This folding took place mostly in the horizontal dimension, creating a low mountain range. It has only been in the last twenty million years that this

[23] Hyde, "The Alps in History," 432.
[24] Heinz Veit, *Die Alpen. Geoökologie und Landschaftsentwicklung* (Stuttgart: Ulmer, 2002), 16.

mountain range was uplifted to resemble the high-alpine peaks we recognize today. The ongoing process of mountain building and the erosive forces of water and ice have for the most part held each other in check, meaning that the Alps were likely never much higher than they are today.[25]

At the height of the last glacial period (22,000 to 20,000 years BP), Scandinavia and northern Europe were completely covered by enormous ice sheets; the Alps, Pyrenees, and the Caucasus sat under smaller ones. This most recent ice age ended between 17,000 and 10,000 years BP. The work of the glaciers expanded and widened valleys and created some of the most important mountain passes in the Alps. The retreat of the glaciers left behind moraines, and transported sediments that aid in the formation of soils and therefore agriculture. The withdrawing ice also created high-altitude cirque lakes and carved out characteristic u-shaped valleys with very steep sides. All of these effects would have important consequences for hydropower development. The valleys would later appear as ideal places to store water. Many of their steep slopes were and remain sites of extreme events such as landslides.[26] But they have also left behind countless so-called "hanging valleys." These hanging valleys are often the site of the spectacular waterfalls that have drawn visitors to the region. As we will see in the next chapter, these falls also contained potential energy, if a means could be found to harness it. Glaciers left over from previous ice ages continue to influence another important factor in the future Alpine energy landscape, mountain hydrology.

[25] The next section draws heavily from Bätzing, *Die Alpen*, 25-43; Heinz Veit, *Die Alpen. Geoökologie und Landschaftsentwicklung* (Stuttgart: Ulmer, 2002), 16-34; and A. Autran, "Introduction to the geology of western and southern Europe," in G. Innes Lumsden, ed., *Geology and the Environment in Western Europe* (Oxford: Clarendon Press, 1994), 9-33.

[26] Bätzing, *Die Alpen*, 30-31.

Hydrologically, the Alps serve as "Europe's Water Tower" ("*Wasserschloss*").[27] The nickname alludes to the fact that several of the continent's most important rivers have their sources in the massif. Alpine water drains via the Rhine into the North Sea, via the Rhône and Po into the Mediterranean, and lastly via the Inn and Danube into the Black Sea. While the Alps compose a relatively small area of these streams' watersheds, they nonetheless contribute a disproportional amount of water to their channels. In the case of the Rhine, the Alps comprise some twenty-three percent of its catchment area, but deliver about half of its total annual discharge. The figures for the Rhône and Po are similar. As such the Alps have an importance that reaches far beyond the borders of its mountain.

Thanks to a host of environmental factors, the Alpine rivers possess an abundance of water that is almost unmatched on the European continent. The mountains function as a "rain catcher" (*Regenfanger*). The lofty Alps drive moist air masses from both the Mediterranean and Atlantic upwards and force them to precipitate their water freight in the form of rain or snow. The mountains as a whole then receive much more precipitation than the rest of Europe. An average of 1,450 millimeters falls on the Alps annually, while western Europe receives about 800. The difference is greater still if one considers all of Europe, which averages only 600 millimeters of precipitation.[28] The high altitude of the Alps also decreases the amount of water lost due to evaporation or transpiration, meaning a higher percentage of its precipitation drains away than in surrounding areas. A large portion of Alpine river drainage basins lie above the tree line. Over half of the watersheds of the Rhine, Rhône, and Inn rest above 2000 meters.

[27] This section based on Veit, *Geoökologie*, 73-76 and Bätzing, *Die Alpen*, 190-191.
[28] Bätzing, *Die Alpen*, 190.

This means that factors of altitude—especially the development of glaciers and frost—play a significant role in influencing the water volume and sediment loads of Alpine watercourses.

Of crucial importance for the ecology—and water power development—of Alpine streams is the seasonal distribution of water flows and the storage of water in lakes and glaciers. This is called a "flow regime." In the Alps, geographers have identified glacial, nival, and nivo-pluvial/pluvio-nival types. In watersheds with glacial flood regimes, a large proportion of the catchment area (greater than thirty percent) is glaciated. Glacial watersheds thus have a high median altitude. The daily and yearly fluctuations in glacial melt give glacial regimes a unique discharge rhythm. Typically, maximum flows occur in the summer months of July and August, when melting glaciers account for approximately sixty percent of all annual discharge. Ninety percent of total discharge takes place from May through September. Accordingly, streamflow in the winter months is low. The catchment areas for strictly nival regimes are devoid of glaciers. Snowmelt begins already in April for lower locations, with the main stage in May and June. The prevalence of substantial summer floods and pronounced winter dryness would prove to be the feature of Alpine hydrology that most concerned energy experts. Between glacial and nival regimes there exist a number of transitional zones which describe a fair portion of Alpine waterways. In contrast to glacial and nival regimes, pluvial discharge patterns post several maxima over the course of the year. The first comes in spring with the snowmelt, and the second in fall due to precipitation. Purely pluvial regimes are rare in the Alps. Only very low-lying tributaries possess strongly pluvial characteristics. Even in the large river valleys, the Alpine snowmelt dominates flow regimes far into the plains. Glaciers currently store about a year's worth of precipitation in their ice fields, and even out the differences between dry and wet years considerably. Some 216,200 million cubic meters of water regularly drain out of the Alps, year in and year out.[29]

While the mountains may appear unmoving and timeless, the defining feature of the Alpine environment is its labile, even volatile natural dynamics. For the Alps are a young chain whose mountain-building process is ongoing.[30] Dynamism characterized Alpine hydrology, especially in the time before hydropower development. From an ecological standpoint, scientists would have characterized undammed Alpine streams as nearly "wild river" ecosystems (*Wildfluss-Ökosysteme*). Alpine waterways continually changed their gradient and velocity, and experienced strong seasonal variations in streamflow and sediment load. During flood periods, the carrying capacity of high-energy Alpine waterways increased. This process constantly created new microenvironments, forcing both flora and fauna to evolve special survival strategies. Certain plants, for instance, acquired flexible stalks that yield to flowing water, and whose growth was stimulated by damage to its shoots. Successful riparian grasses also evolved to be able to quickly populate freshly created sandbanks. Alpine riverbeds, floodplains, and valleys also served as migration corridors for plants and animals traveling both upstream and down. Floodplain environments were (and continue to be) home to some of the greatest biodiversity in Europe.[31]

By no means were the nineteenth-century waterways of the Alps untouched entities. Humans had significantly modified Alpine hydrology for centuries. In the late-nineteenth century Switzerland, for example, a community completely drained the Märjelensee, an upland

[29] Veit, *Geoökologie* ,76-78.
[30] Bätzing, *Die Alpen*, 42.
[31] Veit, *Geoökologie*, 82-83.

lake that had first emerged earlier in the century thanks to glacial advancement. On several occasions, the Märjelensee broke through its glacial dam, flooding the entire Rhône valley from the mouth of the Massa to Lake Geneva. To remove this threat for posterity, locals drilled a drainage tunnel in the lake's empty basin.[32] An example of the types of modifications made to Alpine rivers comes from the French Alpine piedmont, where inhabitants thoroughly rearranged the Isère by the early nineteenth century. The Isère went from being a volatile braided channel to a heavily diked single-channel river, engineered for the purposes of agriculture and flood control in the early nineteenth century. Many would assume that the braided, unpredictable Isère of the early modern period was a waterway untouched by humans. But even the braided Isère system was at least partially the result of human activity. Anthropogenic deforestation teamed with increased Little Ice Age precipitation gave the Isère its multichannel look.[33]

By the mid-nineteenth century, then, the Alps loomed as a continental water tower in the middle of west-central Europe. The landscape, the product of geological forces, served as a reliable delivery system for vast quantities of surface water, even if its deliveries were distributed unevenly throughout the year. Alpine watercourses were one component of a generally high-energy mountain ecosystem. While they might seem "wild" from a present-day perspective, they nevertheless bore the inevitable mark of societies who had long made their home in the Alps. After the mid-nineteenth century, Europeans intervened as never before in the functioning of Alpine hydrology. Over the course of about one hundred years, they thoroughly modified the

[32] Bayerisches Hauptstaatsarchiv München (BayHStAM), Landesamt für Wasserwirtschaft Vorl. Nr. 39: "Niederschrift über die 2. Sitzung des Wasserwirtschaftsrats," (28 May 1910), 50.
[33] On the Isère see Jacky Girel, "River Diking and Reclamation in the Alpine Piedmont: The Case of the Isère," in Christof Mauch and , eds., *Rivers in History: Perspectives on Waterways in Europe and North America* (Pittsburgh: University of Pittsburgh Press, 2008), 78-88.

unique Alpine landscape to transform the mountains into a natural battery, creating new economic and industrial possibilities even as they altered fragile ecosystems. Alpine energy was significant enough that it entangled the mountains in much of the tumult of early-twentieth century Europe. The new shape of the Alpine landscape reveals a good deal about the energy imperatives of this critical time period. And all of it started with a change in the perception of the mountains and their waters.

CHAPTER ONE

WHITE COAL

In 1889, a French engineer named Aristide Bergès (1833-1904) attended the *Exposition Universelle* in Paris to inform the world of a new form of energy he had discovered. The site for this revelation was the gigantic glass-and-iron Galerie des Machines, located across the Champ de Mars from the main attraction of the fair, Gustave Eiffel's tower. Here, the graduate of the École Centrale des Arts et Manufactures and proprietor of a successful paper mill, set up one of the numerous exhibitions on French industry that filled the sprawling display area. Bergès' exhibit consisted of a turbine two meters in diameter, placed above a plaster relief map depicting a small section of the French Alps. On a plaque attached to the turbine, Bergès painted a long inscription that began with the words "exploitation of the WHITE COAL (*HOUILLE BLANCHE*) of the glaciers by the creation of chutes between 500 and 2000 meters in height." By white coal, Bergès meant the water power he had managed to draw from glacial runoff streams at a small town named Lancey near Grenoble. The power derived from the creation of artificial "chutes"—in this case iron pipes—inside of which the brook water plunged several hundred meters in altitude before being conducted to the turbines that provided motive power for Bergès' paper mill. In a pamphlet accompanying the exhibit, Bergès explained that white coal was of course a metaphor. But he had used the word to emphasize that if exploited for their motive power, mountain glaciers could become "riches just as precious as coal for their region and for the state."[1]

While Bergès' white coal referred specifically to the water power he developed from glacial streams, his metaphor about new energy potential could have just as easily been applied to the entire Alps. This chapter tells the story of the emergence of this mountain region as a

[1] Marcel Mirande, *Le Comte de Cavour et la Houille Blanche* (Grenoble, Allier Père & Fils, 1927), 5-6.

white coal landscape. It unfolds in two parts. In the first part, I show how the Alpine hydrosphere, described in the previous chapter, became something close to the ideal environment in which to harness water power. For almost as long as Europeans had been taking advantage of water power, the water-rich Alps had been one of the hydraulic power centers. But around 1850, the massif materialized as an environment with truly unique water power potential. The timing was due to innovations in the technological sphere, particularly the development of the turbine that assumed so prominent a position in Bergès' display. With the advent of the turbine, Europeans finally could avail themselves of a water motor capable of converting enormous pressure into useful energy. Thereafter, Europeans had access to the energy latent in the steep relief of the Alps.

The turbine unlocked the water power potential of the Alps, but this development by itself did not make the Alps a landscape of white coal. This required the intervention of the human imagination. The second part of the story provides the context for what it meant to see white coal in Alpine water towards the end of the nineteenth century. To invoke coal in this time period was to speak about an energy source whose use had wrought dramatic geopolitical transformations. For people like Bergès, who also had a vested economic interest in promoting the development of water resources, equating Alpine water power with coal was particularly savvy marketing. For the Alps and surrounding regions, coal was a scarce resource, and one that many believed held the key to economic prosperity.

Evolution of a Water Power Landscape

The Alps have long been a center of water power usage in Europe. Traditional water power utilization was based on the employment of waterwheels in various types of mills. The Alps, like a number of other regions throughout Europe, possessed environmental characteristics that were well-suited to turning water wheels. But traditional watermills could only ever harness a fraction of the immense flows of power available in the Alps.

The use of water power first began in antiquity, although just when remains unclear. Different scholars suggest an origin in fourth-century BCE India or the Near East around 200 BCE. From this point, water power usage spread throughout the ancient world. Far more certain is the technology that harnessed the power of water for nearly two millennia, from its beginnings until the nineteenth century. The earliest converters—or prime movers—were predominantly water wheels. These came in the two broad varieties, horizontal and vertical waterwheels, each of which operated best under different hydrological conditions. The earliest wheels were utilized in grain mills.[2]

Like nearly all energy on earth, water power is in fact solar power. It is the useful energy that humans are able to harness by intervening in the hydrological cycle. Water power is the product of two primary factors: volume of flow and height of fall (sometimes called head in hydraulic parlance). In the water power equation, a small amount of water with a very high fall can create the same amount of energy as a large amount of water falling a shorter distance. The availability of water power is partly determined by geographic factors, and its utilization is thus regionally limited. Streamflow is influenced by geographic variables such as seasonal rainfall distribution, temperature, humidity, evaporation, air currents, vegetation regime, and geological circumstances.

The Alps possessed many characteristics that made it an ideal setting to harness water power. Chief among these were an abundance of water and a surfeit of slope. The mountains

[2] In contrast to some energy sources there is no dedicated history of water power. The previous section and what follows draws from Terry S. Reynolds, *Stronger than a Hundred Men: A History of the Vertical Water Wheel* (Baltimore: Johns Hopkins University Press, 1983), 9-14, and Vaclav Smil, *Energy in World History* (Boulder: Westview Press, 1994), 103-108.

are rich with water because low transpiration rates—a function of the colder temperatures at higher altitudes—mean that a large portion of the region's abundant precipitation remains surface runoff. Just as important as the quantity, the quality of Alpine water power also facilitated utilization. While Alpine watercourses demonstrated marked differences in streamflow according to season, they generally retained a minimum flow that was available year round. The regularity of Alpine streamflow was in many cases aided by the presence of lakes and glaciers. The great relief of the mountains of course imparted added energy to the water coursing down its slopes, but it was not relief alone that made the Alps ideal for water power. The broken topography of the mountains also ensured more opportunities to concentrate falls than in the lowlands.[3]

As with the emergence of water power usage in general, it is difficult to say when Europeans first began harnessing the power of Alpine water. But by the early medieval period at the latest, mills were an increasingly familiar sight on Alpine waterways. Pockets of southern France and northern Italy took advantage of water power as far back as Roman times. After the collapse of the Empire, the watermill seems to have spread from these bases into the Alpine region. The earliest confirmed mill in Switzerland dates from the sixth century. Southern German legal codes attest to the existence of water power usage in that region during the eighth century; the earliest Austrian watermill seems to have appeared a hundred years later. As with the earliest mills, the primary purpose of these facilities was grain production. The period from the tenth until roughly the sixteenth century CE, however, witnessed a rapid expansion in the applications for water power in the Alpine area. A slew of new uses for water power originated

[3] On the geographical basis of water power see Louis C. Hunter, *Water Power in the Century of the Steam Engine*, Vol. 1 of *A History of Industrial Power in the United States* 1789-1930 (Charlottesville: University of Virginia Press, 1979), 114-139; and Raoul Blanchard, "Geographic Conditions of Water Power Development," *Geographical Review* 14, No. 1(Jan. 1924): 88-90.

in or near the Alpine regions of southeastern France, northern Italy, Switzerland, and southern Germany. In addition to powering the first hemp mills, fulling mills, oil mills, and paper mills, Alpine waterways provided the energy for metallurgical industries such as iron and wire mills, hydraulically operated ore stamps, and metallurgical bellows. In the estimation of one historian, this industrial blossoming made the Alps—alongside a similarly innovative region in northern France—one of the centers of a "Medieval power revolution" based on water power.[4]

To tap into the energy of flowing Alpine water, traditional water power usage required modification of the local environment. Generally speaking, producing water power entailed the impoundment of water and its channeling onto a waterwheel and back into another watercourse. The primary method of impoundment was the construction of a weir across the river—a small dam whose function was not to completely impede flow, but to redirect a portion of water into the millrace, an artificial channel leading to the wheel. Where waterwheels were not installed directly in streams or canals, the millrace often took the form of a wooden flume or chute. After driving the wheel, the water was then led out of the mill into another artificial channel—the tailrace. In most cases, these impoundments and diversions occurred on a relatively small scale. But more serious dams and diversions took place during the medieval period on some larger Alpine streams such as the Lech in Germany, the Durance and Drac in France, and the Ticino in northern Italy. Where conditions permitted, artificial reservoirs known as millponds were also likely employed to regularize to ensure a more consistent water supply.[5]

The power of Alpine water was used outside of mills as well. While navigation never really played much of a role in the Alps, the timber floating and rafting industry have a long and

[4] In his discussion of the diffusion of the vertical water wheel in Europe, Terry S. Reynolds borrows Lynn White's concept of the "Medieval power revolution" where for the first time complex civilization in Europe rested on non-human energy sources such as water power. See Reynolds, *Stronger,* 47-50, 94-95.
[5] Reynolds, *Stronger,* 62-63.

important history. Wood has long been both an important source of fuel and a construction material, and Alpine watercourses offered a convenient means of accessing mountain forests. The tradition of floating individual logs and rafts from the Alps to urban markets is—like water-milling—documented all the way back to antiquity. By the thirteenth century, the Alpine wood export took on such dimensions in some areas that cities were moved to try to stanch the flow. Zurich, for example, issued two decrees limiting timber rafting in its dominions in the late thirteenth century. Later the nineteenth-century iron industry's insatiable demand for wood caused many an Alpine forest to disappear, and prompted renewed concerns about timber rafting from Alpine governments. The Swiss city of Bern, for example, lodged an outright ban on the water transport of timber in 1870. By that time, however, economic changes were in the process of making the industry obsolete anyway. The growth of rail networks enabled access to forests and thus sounded the death knell for this exhausting and at times dangerous type of work. Nevertheless, timber floating and rafting continued on some Alpine waterways until after the First World War.[6]

As a water power landscape, the Alps had something going for it that few other places did. In no other region in Europe was it possible to harness falls as large as those in the Alps. The distinction between high-fall and low-fall water power was not merely a technical detail. High falls were important because they produced high-head water power. Just as there are different sorts of coal with different thermal properties, water power also has different grades and varieties. Broadly speaking, water power facilities come in low and high-head varieties. In the mathematical equation that makes up water power (the product of water quantity and fall), the preponderance of one factor over another would seem to be irrelevant. All else being equal,

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[6] Peter Kaiser, "Das Wasser der Berge – Bedrohung und Nutzen für die Menschen: Notizen für eine Umweltgeschichte," in *La découverte des Alpes. La scoperta delle Alpi. Die Entdeckung der Alpen*, ed. Jean-Francois Bergier and Sandro Guzzi (Basel: Schwabe, 1992), 96-97.

however, high-head water power is generally more desirable. Given a low-head facility and a high-head facility of equal capacity, the latter would be less expensive to equip. The fact that it involved smaller quantities of water meant that many of the components of a high-head hydropower facility could be smaller, and therefore less expensive. High-head facilities required less expansive hydraulic works, water motors, and buildings to house the machinery. High falls were thus the anthracite of the water power world. The importance of high-falls in reducing the costs of developing water power led a professor at an Austrian mining academy to refer to slope as a critical natural resource, no different than iron ore, coal, or petroleum.[7] A little bit of water went a long way in the Alps.

But until the mid nineteenth century or so, much of this potential energy from Alpine peaks lay beyond human grasp. Looking past the issue of accessibility, harnessing high-head water power exceeded the capabilities of traditional water power technology. The waterwheels that generated the power to drive mills could not handle the force of water falling much farther than fifteen meters.[8] This limitation left a lot of unused water power on the table in the Alps.

No natural phenomenon embodied the unused potential energy so much as the plentiful waterfalls that existed throughout the Alps. The Alps, like many mountain regions, are home to an abundance of waterfalls. Plentiful waterfalls in the Alps are the result of two broad sets of conditions native to the mountain region. One group of these chutes derived from a grab bag of geologic phenomena that created steep stretches in the profile of many watercourses. Geologists call these site knickpoints, and they can occur thanks to changes in a channel's bedrock, local tectonic action, changes in stream discharge, or even global change in sea levels. Many waterfalls were also the product of glacial erosion. During ice ages, massive tongues of ice

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[7] Bartel Granig, *Die Wasserkraftnutzung in Österreich und deren geograpischen Grundlagen* (Vienna: Springer, 1925), 1.
[8] Reynolds, *Stronger,* 307.

reached down the mountains, often into the larger main valleys. When the glaciers receded, they left behind mounds of debris known as moraines. Sometimes, these heaps constituted barriers to flowing water that created abrupt slopes. But these moraines sometimes turned watercourses out of their old beds and onto new terrain where the new river's course was almost always punctuated by intermittent falls. It is this phenomenon that is responsible for much of the profile of the Drac River in the French Alps. It also created the Niagara Falls. The most extreme falls, however, were result of the lower erosive power of the ice in the secondary valleys, which left them stranded higher above the newly dug out main valleys. Geomorphologists refer to these higher secondary valleys as hanging valleys, and the heavily glaciated Alps are full of them. Hanging valleys often tower hundreds of meters above the main valley, in some cases reaching over 800 meters in relief. They posed serious obstacles to transportation in valleys. They were also the sites of some of the most impressive waterfalls in the region.[9]

In the eyes of a traditional millwright, a waterfall would have in many ways appeared the ideal site to harness water power. To take greatest advantage of the power of falling water, it is necessary to concentrate the fall at a specific point. This concentration was achieved in two general ways. The first method involved creating a fall solely by obstructing the regular flow of a river. By throwing a barrage or a dam across a river, water could be impounded to create a head between the surface of the captured water and the surface of the water just below the mill. The other method utilized the natural gradient of a longer stretch of a river's course. Using another obstruction, water could be diverted into a headrace canal and led to a suitable point before falling onto the waterwheel. Water power was all the more cost-effective if the natural environment could be relied upon to help create hydraulic head, and waterfalls were the most extreme example of this phenomenon.

[9] Blanchard, "Geographical Conditions," 89; Heinz Veit, *Geoökologie*, 101.

Unlocking the latent power of Alpine water required the development of a new prime mover, a reinvention of the wheel.[10] Movement on this front began with the development of just such an implement in the early nineteenth century. The new device was called the turbine, and it represented in the words of one historian "the first radical improvement of water-driven prime movers since the introduction of the vertical wheel centuries before."[11] Turbines improved on traditional waterwheels in a number of respects. The turbine, unlike the water wheel could operate while submerged, meaning it could utilize every inch of head available. It also converted the power of falling water with greater efficiency than most waterwheels. Most importantly for mountainous areas like the Alps, the turbine could withstand the destructive force of high-pressure water power.

As with many technological innovations, it is no easy task to assign a single inventor responsible for the development of the turbine, the outcome of incremental improvements. But historians generally give credit to the Frenchman Benoît Fourneyron (1802-1867). Fourneyron created his new prime mover in response to a 6,000-franc cash prize offered by the French *Société d'encouragement pour l'industrie nationale* in the early 1820s to the person who could produce a more efficient industrial waterwheel, and especially one that would not cease to function when floodwaters downstream impeded the wheel's forward motion. In 1827, Fourneyron came up with a device that fit the society's bill. Fourneyron's invention was composed of a centrally fixed disk replete with iron compartments that captured the incoming water and guided it to buckets located on an outer wheel—or runner—mounted on a vertical shaft. The name for the device came from the Latin stem meaning to spin or whirl. Throughout the late 1820s and early 1830s, Fourneyron demonstrated the improved efficiency of the turbine

[10] The turn of phrase belongs to David Blackbourn. See *The Conquest of Nature: Water, Landscape, and the Making of Modern Germany* (New York: W.W. Norton, 2006), 7.
[11] Smil, *Energy in World History*,108.

at both experimental and industrial sites. Satisfied that he had fulfilled their contest's requirements, the Society awarded the engineer its grand prize in 1833.[12]

While the turbine would be a boon to nearly all forms of water power usage, the device had special importance for mountain regions. Five years after winning the waterwheel competition, Fourneyron demonstrated this with an installation of one his turbines in the German town of St. Blasien. Located in the mountainous section of the Black Forest region, St. Blasien was home to several waterfalls, including one that measured over one hundred meters in height. Previous attempts to tap into this power had involved the construction of a series of waterwheels situated one above another, but this configuration was unable to take advantage of the entire fall. In their stead, Fourneyron installed one of his new turbines, which was fed water from the fall through an iron conduit. The new prime mover managed to convert approximately 80 percent of the water's kinetic energy into sixty horsepower of usable energy.[13]

The capability of drawing useful energy out of a force of nature such as a waterfall astounded even astute observers at the time. The German engineer Moritz Rühlmann, who visited the facility, recorded his awe in the presence of the turbine:

> On entering the wheel-room, one learns that what had been heard at a distance about this place was not merely mystification, but reality. One then feels seized with astonishment, and wonders, more than in any other place, at the greatness of human ingenuity, which knows how to render subject to it the most fearful power of nature. At every moment the powerful pressure appears likely to burst in pieces the little wheel, and the spiral masses of water issuing from it threaten to destroy the surrounding walls and buildings. Often when I went out of the wheel room, and looked at the enormous height from which the conducting tubes brought down the water to the wheel, the idea forced itself upon me, "that it was impossible," but the idea passed away when I went back into the little room.[14]

[12] Hunter, *Waterpower*, 292-342; Reynolds, *Stronger*, 338-349; Smil, *Energy in World History*, 108; Thomas P. Hughes, *Networks of Power: Electrification in Western Society, 1880-1930* (Baltimore: Johns Hopkins University Press, 1983), 263.
[13] Reynolds, *Stronger*, 342.
[14] Moritz Ruhlman[n], *On Horizontal Water-Wheels, especially Turbines or Whirl-Wheels...*, ed. Robert Kane (Dublin, 1846): 17-18. Quoted in Reynolds, *Stronger*, 342.

By midcentury, the ability to harness high falls had led to the recognition of the awesome potential power slumbering in the Alps. One region where this perception was particularly acute was the Italian state of Piedmont. Piedmont—as its name implies—lay at the foot of the Alps in the northwest Italy. Over the course of the nineteenth century it acquired a particular interest in Alpine water power. At the center of the Italian *Risorgimento*, Piedmont's leaders viewed industrial development as paramount, but the kingdom was decidedly lacking in industrial resources (especially coal). Thanks to the hydropower revolution inaugurated by the turbine, some observers believed Piedmont's industrial luck had changed. For the kingdom dominated the lion share of the western Alps, the highest, wettest, and most glaciated region in the entire massif.

The awesome potential power of Piedmont's mountains was the subject of an alleged 1847 conversation between the Italian statesman Marquis Massimo d'Azeglio (1798-1866), and British politician Richard Cobden (1804-1865). During a visit by Cobden to Piedmont, d'Azeglio supposedly confided his lack of faith in the industrial potential of his country to the Briton. Cobden, whose nation's industrial pedigree presumably lent weight to his opinion, pointed to the snow-covered peaks of the Alps and declared "therewith you can secure the economic future of your beautiful country."[15]

Whatever the veracity of this story, by the mid-1850s the subject of Alpine energy potential indeed preoccupied the highest echelons of Piedmontese government. At this time Count Camillo Benso di Cavour (1810-1861), the future architect of Italian unification, became convinced of a bright future for Alpine water power. Prime minister Cavour voiced his outlook in an 1854 session of Piedmont's "Sub-Alpine" parliament in Turin. In June of that year, Cavour found himself compelled to defend his engagement of an engineer to explore the prospect of

[15] *Elektrotechnische Zeitschrift* 1916, no. 32 (10 August 1916): 431.

transmitting water power overland by means of compressed air. The idea met with astonishment and not a little mockery in the engineering community, but Cavour insisted on the importance of the venture. Finding a way to transport water power beyond the site of its generation would remove one of the primary limitations of hydropower development, and "could do for our country what steam engines have done for England." For, Cavour noted, in "chutes of water" Piedmont possessed "more motive force than England has with all of her steam engines combined." The prime minister's appeals helped win parliamentary support for the compressed-air initiative, even though the technology never became a comprehensive solution to the transport problem of water power (that distinction remained for hydroelectricity, the subject of the following chapter). Nevertheless, hydro-pneumatic power did prove its worth in at least one monumental undertaking. Water-powered pneumatic drills replaced steam-powered ones in the drilling of the Mount Cenis tunnel—the first large-scale "piercing of the Alps"—in the 1860s. Cavour's words also helped the count go down in history as the first visionary to have grasped the new energy potential of the Alps.[16]

"Discovering" White Coal

As French nationalists would later be at pains to emphasize, the true "discovery" of white coal actually took place at the other end of Cavour's Mount Cenis tunnel, in the French province of Dauphiné. It was there in a valley northeast of Grenoble that Aristide Bergès became one of a number of entrepreneurs who exploited ideal environmental conditions to produce high-pressure water power. Beginning in the late 1860s, this group succeeded in harnessing the power of higher chutes than ever before. Bergès proved equally adept at promoting and publicizing the development of Alpine water power resources. After coining the phrase white coal at the

[16] Mirande, *Le comte de Cavour*, 30-31; 33-37. The point of Mirande's essay was indeed to prove that while Cavour had recognized the potential of Alpine water power, the Count never actually uttered the words "white coal". Mirande determined this burst of creativity remained the merit of his countryman, Aristide Bergès.

Exposition Universelle in 1889, both the development of high-chute water power and the term caught on in the Dauphiné. From its beginnings there, white coal would go on to conquer the rest of the Alps and indeed the world as a popular way to describe all water power.

The Dauphiné is a historical region sandwiched between Savoy, the Rhône, and Provence, that occupies a large portion of the westernmost Alps. In the fourteenth century, the Dauphiné passed from the house of Savoy to France, where it has remained ever since. After the French Revolution, the province was divided into the three *départements* that comprise the region to this day: Isère, Drôme, and Hautes-Alpes. Grenoble, location of one of the oldest universities in Europe, was the historic province's capital and the region's foremost city.[17] The province had a history of water power innovation. The first water-powered hemp mills and wood lathes are attributed to the region during the medieval period.[18]

In the 1850s and 1860s, the Grésivaudan valley of the Isère river to the northeast of Grenoble was a center of water power innovation. In the vicinity of Grenoble, the eastern flank of the valley is dominated by the Belledonne, one of the so-called granite massifs that make up some of the highest Alpine peaks including Mont Blanc. Unlike the majority of the Alps, these mountains originated not from the sea, but deep below the earth. Formed some 280 million years ago, the majority of the granite massifs—like icebergs—remain hidden below the surface. Ironically, the granite massifs have reached such towering heights because of their relative lightness. These blobs of igneous material float like buoys upon denser molten rock. When the sedimentary strata that once covered them eroded away, they rose even higher. The peaks of the Belledonne all range between 2500 and 3000 meters above sea level. Some of this area above 2650 meters was glaciated as well. The valley below on the other hand, rested at roughly 300

[17] R. Avezou, *Petite Histoire du Dauphiné* (Grenoble: B. Arthaud, 1946), 8-10; Andrew Beattie, *The Alps: A Cultural History* (Oxford: Oxford University Press, 2006), 40-41.
[18] Reynolds, *Stronger*, 76, 83.

meters above sea level.[19] The great relief of the Grésivaudan lent considerable power to the torrents streaming down the sides of the Belledonne. It was these watercourses that French engineers tapped into using the newly developed turbine, modifying torrents to create higher and higher chutes throughout the 1850s and 60s for the benefit of the lumber industry. In 1867, a sawmill in the town of Brignoud tapped into a 147-meter fall to power its operations.[20]

Two years later, Aristide Bergès tried his hand at high-pressure water power development, transforming the local torrent at a town called Lancey to generate energy for his new paper mill. The stream at Lancey, fed by the runoff from the Freydane glacier, descended from the heights of the Belledonne into the Combe de Lancey—a gorge created by glaciers—before joining the Isère. Later in his life, Bergès would describe the torrent as an "insignificant stream, carrying at most less than a hundred liters per second and managing only with great pain to drive some grist and hemp mills of three or four horsepower each."[21] But with a few modifications, the stream gave life to a thriving industry. Upstream of the Combe, Bergès diverted the waterway into an iron pipe capable of withstanding severe pressure. This penstock then snaked its way to the edge of the gorge, where it plunged down into the canyon where the engineer located his factory. Within the complex, the water of the torrent spun a single turbine—designed by Bergès himself—with the pressure created by the 200 meter difference in elevation between the point of intake and discharge.

Over the years, Bergès intensified his use of the local hydrology, and his factory expanded with the control of ever greater flows of energy. In 1882 he equipped the mill with

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[19] Nicholas and Nina Shoumatoff, *The Alps: Europe's Mountain Heart* (Ann Arbor: University of Michigan Press, 2001), 45; Raoul Blanchard, *Les Alpes françaises* (Paris: Armand Colin, 1952) 35, 146.
[20] Peter Hochgrassl, "Die Wasserkräfte Frankreichs und ihre Nutzung im Rahmen der französischen Elektrizitätswirtschaft," (PhD diss., University of Munich, 1957).
[21] This quote comes from a pamphlet Bergès printed for a water power exhibit he created for the *Exposition Universelle* in 1889. Extracts from the pamphlet are available on the website for the museum honoring Bergès. Maison Bergès Musée de la Houille Blanche, "Extraits d'une Notice parue à l'Exposition Universelle de 1889 http://www.musee-houille-blanche.fr/874-aristide-Bergès.htm (accessed February 5, 2012).

another chute, this one with a head of 500 meters. By the time of his appearance at the Exposition Universelle in 1889, he had added two other conduits, including one with a then unheard of height of 2,000 meters. At this point the turbines in his paper mill generated some 2,000 horsepower.[22] The continual augmentation of the mill's power reflected its economic success, even after Bergès' death in 1904. The harnessing of such great energy for industrial purposes also exercised a powerful influence on the social structure of the rural valley, altering settlement, employment, and agricultural patterns. On the cusp of the 1920s, the compiler of a human geography of the region reported that the factory exerted "a powerful attraction" on the population of the Combe. The majority of the inhabitants of the surrounding hamlets found employment there. According to the author, some workers were attracted by the high wages, and the fact that the work schedule—composed of two half-day shifts—allowed them to continue to cultivate their fields. Other farmers took up residence in Lancey to work the mill and turned their fields over to pasturage to ease their labor burden.[23]

Bergès' white coal and the hydraulic power industry that it helped spark was a strong demonstration of the new power potential of the Alps. With the aid of the turbine, Bergès had succeeded in drawing around 200 times more useful energy out of a relatively small glacial torrent than had been previously possible. As Bergès argued at the Exposition Universelle, France possessed thousands of watercourses like the torrent at Lancey in the Alps (as well as the in Pyrenees and elsewhere, it must be added) that could be made to generate power. Under the new circumstances, Bergès concluded that glaciers were no longer glaciers: "they are mines of

[22] Beginning with the 1882 expansion, Bergès also refitted his turbines with dynamos to generate electrical current.
[23] Suzanne Ténot, "Le massif de Belledonne. Étude de géographie humaine," *Recueil des travaux de l'institut de géographie alpine* 7, Nr. 4 (1919): 626. Found at http://www.musee-houille-blanche.fr/873-le-site-du-musee-de-la-houille-blanche.htm (accessed February 15, 2012).

white coal, and how much more preferable to the other." These were the "unknown riches" that he sought to introduce to the public.[24]

In the twenty years after the birth of white coal at Lancey, French industrialists followed Bergès lead in mining glaciers, extracting some 200,000 horsepower in the process. To reflect on the significance of their achievement (and to lobby for more favorable water-use legislation)

Figure 3. Portrait of Aristide Bergès from the proceedings of the *Congrès de la Houille Blanche,* 1902

many of the industrialists who had promoted white coal development formed an interest group and organized an international White Coal Congress in Grenoble in 1902. The *Syndicat des Propriétaires et Industriels possédent ou exploitant des forces motrices hydrauliques* named the congress in a nod to both Bergès technological and publicity contributions to the field. The Syndicate further honored Bergès' crucial role in the development of white coal by scheduling an excursion—one might even say a pilgrimage—to his path-breaking factory in Lancey. The congress provided ample opportunities for the French to celebrate the energy developments in

[24] Maison Bergès, "Extraits," http://www.musee-houille-blanche.fr/874-aristide-Bergès.htm (accessed February 5, 2012).

the Alps as a triumph over nature and a point of national pride. In the opening speech, the president of the congress argued that harnessing the new power of the Alps had made Grenoble the "uncontested capital of white coal and of the latest rebirth of our national industry." For this reason, the president declared, Grenoble was proud of the role that its "children" had played "in the army marching toward the conquest of the energy of the mountains."[25]

The Geopolitics of White Coal

By the end of the nineteenth century, the Alps had become a landscape of great energy potential. Certain individuals like Bergès, and groups like the Syndicat, also had a vested interest in spreading the gospel that this water was precious white coal. Harnessing the power of the Alps required appropriation of water resources that upset existing social and environmental circumstances. Throughout the Alps, developing water power would always be dependent on a sales pitch, and the one that Bergès devised would remain the most powerful argument for developing the new Alpine energy landscape into the twentieth century. By associating hydraulic power with coal, Bergès sought to connect Alpine water power with the spectacular geopolitical gains made by the transition of certain economies to intense fossil fuel use during the nineteenth century. In Europe, both Great Britain and Prussia-Germany benefited spectacularly from their economies' activation of coal resources. For many contemporaries, it was evident that these states' geopolitical success was based on coal and steam. In few regions could allusions to coal have drummed up more enthusiasm for water power development than the Alps and its surroundings. The geologic forces responsible for distribution of coal resources within Europe had almost uniformly ignored the Alps. In most places, nature had also seen to it that transporting coal to the Alps and its environs would be costly. The recognition that Alpine

[25] Syndicat des propriétaires et industriels possédent ou exploitant des forces motrices hydrauliques pour la réunion du Congrès de la houille blanche, *Compte rendu des travaux du congrès, des visites industrielles et des excursions: Congrès de la houille blanche: Grenoble-Annecy-Chamonix, 7-13 Septembre 1902* (St. Cloud: Belin, 1902), 42.

water power represented a path to the energy prosperity provided by coal would remain a critical part of the story of the transformation of the Alps.

Coal is the residue of forests that existed millions and millions of years ago. It has formed where the remnants of extraordinarily biomass-rich forests accumulated as vegetable matter in low-oxygen aquatic environments such as lakes or coastal swamps. Such conditions limited bacterial activity and thus slowed decomposition. Considering that the intensive burning of fossil fuels is a relatively recent phenomenon, coal use has a much longer history than one might expect. When humans first encountered coal, it was valued foremost for its color and was sometimes even used as jewelry. The origins of coal consumption date back to antiquity, where it was used for iron production under the Han dynasty in China. Around a millennium later, ironmongers and miners in Song dynasty China used coal to launch an industrial revolution almost eight hundred years before the western European version. The Song coal economy placed the Chinese well ahead of any society in the world in this regard. At that time European coal mining was just getting its start in Belgium. Britain, however, soon emerged as the center of European, indeed worldwide coal consumption. Shortages of wood encouraged Britons to switch to coal as a fuel source. By the end of the seventeenth century, coal consumption had progressed to the point in London that diarist John Evelyn could compare the city to the "Suburbs of Hell" among other dismal localities, primarily because of the excess of smoke.[26]

Up until the eighteenth century, coal use in England (and elsewhere) remained a component of traditional energy systems. The main prime movers remained the muscles of humans and animals. Animate power was later augmented by the addition of devices that harnessed the flowing power of wind and water: mills and sailing ships especially. Biomass fuels—wood, charcoal, peat, and animal dung—provided heat for all household and industrial

[26] Crosby, *Children of the Sun*, 61-62; 68-70; Smil, *Energy in World History*,159.

uses. Although these components remained remarkably stable over time, technological innovation greatly improved their efficiency during this time period.

Traditional energy systems were subject to stringent limitations. As historian Rolf Peter Sieferle has demonstrated, one of the primary problems of energy use in this time period-- was that it was dependent upon territory.[27] Societies had to make land use choices that had important effects for the available types of energy. Sieferle breaks these choices down to arable, pasture, and woods. Arable provided the food energy needed to feed a population. Pasture fueled livestock, a source both of food and animate power. Finally, the woods were primary source of thermal energy. Biomass energy production in one area could only be achieved by an increase in the overall territory exploited or at the expense of another type of energy. Transport problems, however, limited the effect of gains in territory.

Inanimate flows of natural power augmented traditional energy systems, but their use was also subject to important limits. The seasonal flows of water and wind power limited energy use to certain parts of the year. Their utilization was also geographically confined and could not be transported. Moreover, wind and solar provided only kinetic energy, not heat. The burning of fossil fuels such as peat and coal skirted the limitations of traditional energy systems, but only temporarily. Both fuels had a limited action radius dictated by high transport costs, and both ran up against problems with extraction. Peat supplies in the Netherlands, where peat helped fuel the tiny state's grand geopolitical successes in the seventeenth century, began to run low by 1700. At roughly the same time, the British coal industry faced a crisis as most readily accessible seams had already been exhausted, and miners struggled to keep the deeper shafts free of water. As previously with wood, a coal shortage loomed.

[27] Sieferle, *Subterranean Forest*, 94-105.

As was the case with water power, the development of a new prime mover had truly revolutionary consequences for coal consumption and human energy use more broadly. The new machine made its debut at the edge of a coal mine in Staffordshire, England in 1712. It was there that Thomas Newcomen, an ironmonger from Dartmouth, began operation of the world's first steam engine. The engine was constructed to drain water from one of England's many deep coal shafts. Using the heat gained from burning massive amounts of coal, the device boiled water to create steam and drive a piston attached to a bulky wooden beam which raised a series of buckets. Newcomen's machine operated with a strength of nearly six horsepower and raised 120 gallons of water per minute.[28]

In the short term, the steam engine saved the British coal industry. In the long term, Newcomen's devices and its successors broke the constraints of traditional energy systems. Thanks to its water-draining abilities, deeper and deeper pits could be dug, opening up virtually unlimited fuel supplies. With the advent of the steam engine, coal could also be used to supply mechanical energy in addition to heat, opening up a plethora of new applications. The new machines could be used anywhere and even installed on ships and locomotives. The result was a positive feedback loop: steam engines permitted unprecedented speed and range of transport, enabling the distribution of more coal for ever more steam engines. By the year 1800, single engines could perform as much work as 200 men. A century later, steam engines had become 30 times as powerful.[29]

The steam engine revolutionized economic possibilities. By tapping the power of the "subterranean forest", the accumulation of hundreds of millions of years of biomass, they liberated vast amounts of energy and freed up land that would otherwise have been devoted to

[28] Crosby, *Children of the Sun*, 71-74.
[29] McNeill, *Something New*, 13.

producing fuel in the form of food or wood.[30] The most dramatic effects of the transition to coal came in Britain. There the new and improved Watt engine revolutionized the textile industry, which exploded with the availability of new power. While Britain had imported 5 million pounds of raw cotton between 1771 and 1775, the number rose to 58 million pounds in 1834 alone. Coal also transformed transportation. 1830 marked the inaugural voyage of the pioneering *Rocket* locomotive on its route from Liverpool to Manchester. By the 1840s, thousands of miles of networked rail systems emerged not only on the British isles, but Europe and North America. Steam power aided a similar expansion of navigation. Fossil fuels made land and sea travel not only quicker and cheaper, they went a long way towards overcoming the seasonality of transport. After steam-powered transport, muddy roads and lack of wind ceased to be the impediments to travel they once were.[31]

These new economic possibilities also reshaped political relationships the world over. On a global scale, the rise of the industrial British economy helped that nation eclipse competitors in India and China. Shifts in the balance of power occurred within Europe as well. On the continent, no state profited more from the new circumstances than Prussia. Much has been made of the significance of Prussian military prowess in its wars of unification against Denmark, Austria, and France. But Prussia also enjoyed the economic benefits of controlling some of Germany's most important coal reserves in the Ruhr basin. The Prussian statesman Otto von Bismarck famously asserted that "blood and iron" would decide the great political questions of his day, and his state had a leg up on at least the latter part of this equation thanks to the coal-rich Ruhr.

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[30] The term comes from a seventeenth century *Sylva Subterranea* tract by the German jurist Johann Philipp Bünting. Sieferle, *Subterranean Forest*, 181-184.
[31] Crosby, *Children of the Sun*, 76-78.

Contemporaries recognized a connection between coal supply and economic might. Perhaps the best known of these observers is the British economist W. Stanley Jevons. Jevons, one of the founders of marginal utility theory, called early attention to the critical economic importance of English coal supplies in his 1865 treatise *The Coal Question*. In it, he demonstrated the importance of coal consumption for the British economy and attempted to ascertain how long supplies could last. Jevons devoted part of his study to an investigation of alternatives to coal. But after considering a list of potential energy sources, he concluded that the British "must not dwell in such a fool's paradise as to imagine we can do without our coal what we do with it."[32]

Coal transformed economic and industrial possibilities where it could be had cheaply. However, like most energy sources, coal was unevenly distributed across the Continent. The hard coal that fueled nineteenth-century industrialization was the product of a process that had begun 300 million years ago, at a time when Europe was located in equatorial climes. Certain lakes and coastal areas that accumulated vegetal material developed the primary seams that would change geopolitical fortunes in the nineteenth century. The offshore deposits proved to be most plentiful, and they extended in a belt from what became Ireland, across Britain and northern Europe to the Silesian fields in Poland. Another major deposit was located in the Asturias region of northern Spain.[33]

As this list indicates, the Alps possess no major pockets of coal. The mountains were not entirely devoid of fossil fuels. The so-called Briançonnais Basin, which runs in an arc extending from northwest Italy through Briançon to the Valais in Switzerland, is a product of the very same geologic forces that endowed Great Britain and northern Europe with its coal stocks.

[32] W.S. Jevons. *The Coal Question* (London: 1865), 145. Quoted in Sieferle, *Subterranean Forest*, 199.
[33] A. Autran, "Introduction," 26.

Nevertheless, the orogeny that created the Alps also considerably deformed these outcroppings, making them very difficult to mine.[34] In addition to scanty local coal supplies, transport conditions made fossil fuels relatively more expensive to procure in Alpine regions than in other areas.

Many saw the absence of coal as crippling for economic development in the Alps in particular. For the Baron von Liebig in turn-of-the-century Munich, all it took was an imaginary trip across western and southern Germany to confirm the correctness of economic geography theories that attributed the development of national industries to the availability of coal above all. If one traveled in their mind's eye from the Rhineland through the Saarland, one saw industrial development "as can only be found in England and the United States of America." The continuation of this trip to the upper-Bavarian high plateau witnessed a "considerable decrease in industrial activity." "The reason," Liebig wrote, "is clear as day. The industrial operations that require and consume coal here in Bavaria are too far away from the site of coal production in the Ruhr. Transport costs increase so substantially with the distance from the site of production, that one pays double the price for coal here in Munich as in the Rhineland." Liebig advocated the development of Bavaria's water power as a means of securing the economic benefits of industry. The baron was particularly interested in industry as an employment opportunity for the "excess population growth" that would otherwise be forced to emigrate from Germany. The German engineer Wilhelm Pressel also expressed similar concern for the economic situation in the Alpine provinces of Austria. Pressel prophesied that the "decline, impoverishment, and emigration" out of the Alps that he perceived could not be slowed by maintaining the current economic order. Humanitarian considerations and state interests demanded an intervention, and fortunately the

[34] B. Kelk, "Natural resources in the geological environment," in G. Innes Lumsden, ed., *Geology and the Environment in Western Europe: A coordinated statement by the Western European Geological Surveys* (Oxford: Clarendon, 1994), 65.

Alps possessed a natural resource that could reverse the downward economic trend: "In the abundantly available, considerable, and what's more perennial watercourses the Austrian Alpine lands have been conferred treasure of great value." It remained only for Austrians to make the minimal commitment necessary to activate this power.[35]

For the French economist Pierre Leroy-Beaulieu, his country's newly valuable water power had the potential not only to improve the economic situation of the Alpine lands, but the entire nation. Leroy-Beaulieu argued that Alpine water power could save the nation in the new century from its recent energy woes. Chief among these was France's lack of coal, which many blamed for a humiliating defeat in battle at the hands of Bismarck's Prussia in 1871. Indeed, this paucity had been exacerbated when France lost much of what little fossil fuels it possessed after coal-rich Prussia annexed Alsace and Lorraine as part of the war's settlement. In light of these energy traumas, Leroy-Beaulieu pinned great hopes on the prospects of Alpine water power. "The richness of France" wrote Leroy-Beaulieu "in chutes of water, in white coal, as this energy that descends from the glaciers is called, could happily compensate in the twentieth century for her poverty in black coal, which harmed her so greatly during the nineteenth."[36]

Conclusion

In the course of the nineteenth century, the Alps emerged as one of Europe's most powerful potential energy landscapes. While the Alps had long been a center of water power use, the mountains became something like the ideal environment for hydropower in the mid-nineteenth century. At this time, the development of the turbine enabled Europeans to harness "white coal", the spectacular hydraulic pressure available in the Alps. Dubbing Alpine water

[35] BayHStAM Landesamt für Wasserwirtschaft,Vorl. Nr. 180: F. Kreuter, "Bericht zur Sitzung im K. Staatsministerium des Innern am 19. Januar 1907," (19 January 1907).
[36] Pierre Leroy-Beaulieu, "La mise en valeur des forces hydro-électriques el les modifications législatives," *Economist français* (14 May 1904), cited in Theodor Köhn, "Einige allgemeine Betrachtungen über den Ausbau von Wasserkräften," *Die Weisse Kohle* 1, no. 2 (25 January 1908): 5.

white coal associated the energy source with the fossil fuel that many held responsible for the most important geopolitical developments in nineteenth-century Europe. The connection of Alpine water power to coal would continue to be a powerful argument for the development of the Alpine energy landscape. Indeed, with the advent of another revolutionary energy technology, the Alps would come to represent white coal for not just for the mountain lands, but an increasingly larger swath of Europe.

CHAPTER TWO

ALTERNATING CURRENTS

In the fall of 1913, the German industrialist Walther Rathenau (1867-1922), like many German leaders, was concerned with the politics of producing and supplying electricity in his country. The director of German General Electric (Allgemeine Elektrizitäts-Gesellschaft, AEG), one of Germany's largest electrical concerns, was part of a group that believed in the idea of a state electricity monopoly, that the generation and distribution of electricity should be the exclusive purview of the German imperial government. Rathenau clarified his monopoly ideas in a memorandum he wrote to the imperial secretary of the interior. He argued that the electricity supply represented a unique opportunity for the German government to establish a "rational monopoly", a field where the state could provide a boost for the national economy by establishing a perpetual source of "welfare". Most of the German public, he acknowledged, viewed monopolies as a form of "command economy" (*Zwangswirtschaft*) that resulted in lower-quality products and arbitrary price increases. While some monopolies indeed brought about such results, Rathenau maintained that an imperial electricity monopoly would be different. In this young and still malleable sector, only the state—not private firms—could establish the rationalization that would drive down generating costs, only the state could ensure fair distribution of electrical energy. By centralizing electricity production in large-scale thermal and hydro plants located directly at the sources, and constructing the infrastructure to distribute this power uniformly across the country, the imperial government could make electricity so cheap as to enable its uniform distribution throughout the Reich. Through rationalization and increases in efficiency, state electricity prices would be far lower than current prices, even with room for steady income for the state.[1]

Though it was not the main point of his memorandum, Rathenau took time at the beginning of his argument to consider the empirical spread of the new energy technology in Europe. In doing so, he noticed something that might seem surprising to present-day observers. In terms of electricity, the Alps stood alongside some of Europe's mightiest coal fields as the most electrified landscapes on the Continent. For Rathenau the matter was simple. In those places where energy was available, electricity flourished. "Countries and regions that possess water power or caloric power areas (*Kraftgebiete*) are presently electrified to a large extent. Today all of Switzerland, all of northern Italy, the Rhineland and Silesia lay under nets of copper..."[2]

While Rathenau did not write about the Alps specifically, it was the mountains of Switzerland and northern Italy that contained the water power generating the electricity coursing through the dense networks of copper he described. His list might have easily included the Alpine portions of Bavaria, Austria, and especially France as well. For these significant "water power areas" had also given rise to extensive electrification. Already by the turn of the twentieth century, the conversion of white coal into hydroelectricity had made the Alps one of the most electrified landscapes in Europe. This chapter looks at this early history of hydro-electrification in the Alps. It shows how Europeans created this electrified landscape by moving from modest beginnings to the harnessing of rivers on a scale that would have pleased Rathenau. From 1880 to 1900, Europeans remade the Alps by tapping into ever larger flows of Alpine power, and

[1] Bundesarchiv (BArch) R 3101/1791: Walther Rathenau, "Denkschrift betr. Ein Reichs-Elektrizitäts-Monopol," (13 November 1913), 1-5.
[2] BArch R 3101/1791: Walther Rathenau, "Denkschrift betr. Ein Reichs-Elektrizitäts-Monopol," (13 November 1913), 2-3.

constructing webs of masts and wires to send this energy ever greater distances from its point of generation.

Isolated Power

The technological systems necessary to generate, distribute, and utilize electrical energy emerged in the latter third of the nineteenth century. Thomas Alva Edison's central station, introduced at the end of the 1870s, became the basis for the networks of electric power familiar today. Edison's central station utilized thermal power to generate electricity and distributed it via copper wires. At the same time as Edison was developing his system, Europeans experimented with using Alpine water power as an energy source to produce electricity. The first Alpine hydroelectric facilities appeared in the early 1880s. Like the Edison central stations, they primarily produced electricity for lighting purposes. Soon thereafter, advances in electrical technology enabled electricity to supply power for a number of industrial purposes, and for transportation as well. By the early 1890s, numerous small hydroelectric plants dotted the Alpine landscape.

Humankind had always been aware of the power of electricity. But the mysterious substance remained largely beyond control until the eighteenth century. Achieving this control required unprecedented technological innovations.[3] An important first step was taken at the time of the French Revolution, when Italian Alessandro Volta used chemical reactions to create a useful battery that dispensed electric current. Several decades later, Michael Faraday determined that electric current could also be created by moving metal between the poles of a magnet. This electromagnetic principal was the basis of electric dynamos or generators that proliferated in the wake of his discovery. From the outset, electricity was used primarily as a source of

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[3] Smil, *Energy in World History*,169.

illumination. Beginning in the 1850s, arc lights turned night into day in theaters and on the façades of public buildings.

Electric energy systems proliferated in the wake of a slew of innovations by the American inventor Thomas Alva Edison. In the 1870s Edison began working on designing a comprehensive system for providing electric light to private customers. His plan, as he announced to the *New York Sun* in October 1878, was to produce electricity from a centrally located generator (a central station as it came to be known) that would then be distributed in underground mains to provide "light to all houses within a circle of half a mile." At the time of his statement, Edison had not yet designed the generator, a practical incandescent lamp, or a system of distribution.[4] But over the course of the next several years, Edison and his team at Menlo Park conceived and developed the necessary components for the first central stations that he would construct in London and New York City in 1882. The technology spread throughout the United States and Europe, partly thanks to its successful demonstration at a number of international fairs and exhibitions.

Others meanwhile experimented with converting water power into electrical energy. The Alps, as a region with substantial water power, was one area of experimentation. The goal here, as elsewhere, was electric light. As in many water power matters, the pioneer seems to have been Switzerland. In 1879 the Swiss hotelier J. Badrutt used water power from a nearby waterfall to power six arc lamps at the Engadiner Kulm resort in the mountain town of St. Moritz.[5] Now tourists attracted to Switzerland by its mountain scenery could also enjoy the most modern lighting amenities, also courtesy of the peaks.

[4] Hughes, *Networks of Power*, 32-33.
[5] Alessandro Botteri Balli, *Wasserkraftwerke der Schweiz: Architektur und Technik* (Zurich: Offizin, 2003), 20.

Within a few years of these first experimental illumination plants, schemes to tap into larger flows of Alpine energy also emerged. Hydro-powered central stations began to appear in the Alps, especially in Switzerland and France. Lausanne became the first city in Europe to boast a central station for electric light. Unlike the more famous specimens in New York and London, Lausanne's was based on hydroelectricity generated through the city's municipal waterworks. Initially it supplied power for a total of twenty light bulbs in a restaurant and two nearby street lamps. Soon thereafter, many of the mountain villages in western Switzerland also utilized their water power resources to install lighting plants.[6] In neighboring France, a number of hydroelectric facilities emerged in the upper-Rhône basin in the early 1880s to provide illumination. The country's first Alpine hydroelectric plant was built on a tributary of the Rhône near Bellegarde in 1882.[7] In contrast to the more familiar story of urban electrification in western societies at this time, early electrification in the Alps was not driven by the demand for new and modern lighting so much as the desire to put sizeable, untapped water power reserves to use. As the prominent Swiss electrical engineer Walter Wyssling later recalled, his compatriots quickly realized that the new technology represented an opportunity to utilize abundant Swiss water power. From the beginning, electrification in his country was hydro-electrification.[8]

The sudden appearance of so modern a technology as electricity in the rural mountain region struck contemporaries. As one Bavarian engineer told a lecture audience in Berlin, "In

[6] There is no history of hydroelectricity in Europe. The following section is pieced together based on regional and national histories of electrification and water power use. Monique Savoy, *Lumières sur la ville: Introduction et promotion de l'életricité en Suisse: l'éclairage lausannois, 1881-1921* (Lausanne: Université de Lausanne, 1988), 5-6; Walter Wyssling, *Die Entwicklung der Schweizerischen Eletktrizitätswerke und ihrer Bestandteile in den ersten 50 Jahren* (Zurich: Schweizerischer Elektrotechnischer Verein, 1946), 18. For a discursive approach to electrification in Switzerland, see Gugerli, *Redeströme*.
[7] Hochgrassl, *Die Wasserkräfte Frankreichs*, 11. For the history of hydraulic engineering on the Rhône see Sara B. Pritchard, *Confluence: The Nature of Technology and the Remaking of the Rhône* (Cambridge: Harvard University Press, 2011). Denis Varaschin details the creation of the Bellegarde central station in an article on the Swiss influence of hydropower development on the French upper Rhône: "Centrales hydrauliques du Haut-Rhône français: De quelques savoir-faire suisses (années 1870-années 1930)," in *L'eau à Genève et dans la région Rhône-Alpes, XIXe-XXe siècles*, ed. Serge Paquier (Paris: L'Harmattan, 2007), 57-85.
[8] Wyssling, *Entwicklung*, 18.

contrast to the pristine nature (*Ursprünglichkeit*) of highland Bavaria, the widespread proliferation of electric incandescence appears as a peculiar phenomenon." The Bavarian chalked it up to the combination of technology and the Bavarian environment, which had endowed the kingdom with cheap energy in the form of white coal.[9] The irony of the juxtaposition of a rural landscape and the trappings of electrical technology in the Alps would be a theme that impressed observers throughout the twentieth century.

As the 1880s wore on, hydroelectricity became a matter of power and not just light in the Alps. With the development of electric motors and other apparatus, hydroelectric facilities that supplied energy for industrial purposes also began to emerge. Hydroelectricity spread in part because it permitted completely new types of industrial processes. But it also displaced traditional water power in existing industries.[10] Hydroelectricity possessed several advantages over traditional water power usage. Electricity can be rapidly converted into light, heat, motion, or chemical potential. The flow of electrons is also easily adjustable, permitting the completion of tasks with unprecedented speed and precision. Furthermore, electricity has none of the negative hygienic characteristics associated with burning fuels and is noiseless at the point of consumption. All of these factors combined to completely transform production and factory conditions. Factories equipped with electricity had no need for the shafts and belts required to transmit mechanical energy. This allowed for improved illumination, ventilation, safety, and a

[9] Kammerer, "Ausnutzung der Wasserläufe im bayerischen Hochlande für elektrische Energieverteilung," *Zeitschrift des Vereines deutscher Ingenieure* 41, no. 30 (24 July 1897): 864.
[10] Although this process did not happen rapidly everywhere. In her study of the Arve River basin in the French Alps, Anne Dalmasso finds that even as hydroelectricity spread rapidly in the region from 1880-1900, it did not immediately extinguish the type of modern hydromechanical production pioneered by Aristide Bergès. A handful of even more traditional mills persisted in the region until the 1950s. See Anne Dalmasso, "D'une hydraulique à l'autre: L'évolution des usages industriels de l'eau dans la vallée de l'Arve de la fin du XVIII siècle au début du XX siècle," in Paquier, *L'eau à Genève*.

reduction in noise. In short, electric power permitted the type of workplace rationalization that appealed to many industrialists.[11]

Many of these early hydroelectric facilities in the Alps were what engineers called isolated plants: power facilities designed and built specifically for the use of one proprietor. Because there were limits on the distance that hydropower could be transmitted economically, isolated hydroelectric plants were located on the same premises or in close proximity to the industrial factories they powered. Companies sought water power sites that would satisfy their own needs and not much more, meaning that isolated plants were relatively small-scale affairs. They were also overwhelmingly private concerns.

One of the most important new uses of Alpine hydropower was aluminum production. Aluminum smelting represented the most important innovation in nonferrous metallurgy since the transition into the fossil fuel era, and cheap Alpine energy made the mountains one of two birthplaces of the global aluminum industry. The electrolytic process developed independently by the American Charles Martin Hall and Frenchman Paul Héroult requires enormous amounts of energy (six times more energy than required for smelting iron).[12] Consequently, the industry was dependent from the beginning on extremely cheap electricity. Charles Martin Hall found the necessary cheap energy in Pittsburgh and his counterpart Héroult in the backyard of Aristide Bergès, the Grésivaudan. In 1886, Héroult began producing aluminum with hydroelectricity at a plant in the town of Froges. Bergès himself linked aluminum production to white coal and predicted a bright future for the new metal: "Coal reduces the iron ore that has forged our civilization and our century, as we see in the poetry, so to speak, of the Eiffel Tower; it doesn't have anything on aluminum. Whereas white coal or the economic force of electricity reduces

[11] Smil, *Energy in World History*, 194-195.
[12] Smil, *Energy in World History*, 181.

alumina and bestows upon us aluminum, whose name the new century will bear if it can be gained at a reasonable price." Aluminum, Bergès noted, had many astounding qualities. It was "a metal light as glass, nearly as resilient as iron, also nearly as rustproof as silver." It would reduce the weight for construction materials, transforming how vehicles and weapons were made, and opening the skies to navigation. Aluminum was "certainly the secret of the future" as long as it could be delivered at a good price. Bergès argued that only electricity—generated through water power—had the capability to do that.[13]

France pioneered aluminum production, but soon companies throughout the Alps eyed the new industrial potential of mountain water. In 1889, the Aluminium-Industrie AG (AIAG) exploited the power of one of the High Rhine's many falls at Neuhausen to procure cheap energy necessary for Europe's first significant aluminum plant. AIAG and the Rhine helped Switzerland become the first European country to mass produce aluminum, which it sold primarily to Germany. There, west German firms turned the aluminum into flatware that it sold mostly in the United States (Swiss consumers apparently wanted nothing to do with eating utensils made out of mud). A spike in aluminum demand around the turn of the twentieth century occasioned AIAG to further tap into the power of the High Rhine. The company was one of the primary customers of the new Rheinfelden dam. When it went online in 1898, the Rheinfelden power plant was the largest in all of Europe.[14]

Turning hydropower into aluminum was not only good business. Proponents also argued that aluminum production represented the most efficient use of white coal available. The Swiss engineer Walter Wyssling explained that the electro-chemical industry—particularly

[13] Maison Bergès, "Extraits," http://www.musee-houille-blanche.fr/874-aristide-Bergès.htm (accessed February 5, 2012).
[14] Luitgard Marschall, *Aluminium—Metall der Moderne* (Munich: Oekom, 2008), 69-83; Wyssling, *Entwicklung*, 215; Cioc, *The Rhine*, 131-132.

aluminum production—was crucially important for water management in his country. The existence of this branch, which could adjust its energy demands to the available water power, and use this existing power more or less around the clock, meant that even the somewhat irregularly flowing Swiss waterways could be utilized economically. Aluminum products could be stored more or less indefinitely. In a sense, a hydroelectric plant that turned falling water into a warehouse full of aluminum stored the value of constantly flowing water in a way that facilities which generated current for less constant loads—such as illumination—could not.[15] Nowadays, economists even conceptualize aluminum production as an "indirect" export of hydropower.

Sending Power Overland

During the 1880s, Europeans took advantage of cheap and easily accessible Alpine water power to generate a considerable amount of electricity for a variety of new applications. But the true boom in hydroelectric development came with the development of a new means of generating and transmitting electric power over long distances. This was the alternating current (AC) system, which eventually entered into the infamous "battle of the systems" with Thomas Edison's direct current scheme. The alternating current system emerged from a desire to improve upon the direct current system's most glaring weakness: the prohibitive costs of electric transmission. Even as the first hydroplants were appearing throughout the Alps, an international group of engineers set to work on this problem, and in the event initiated an alternating current system that competed alongside Edison's direct current. The demonstration of the ability of alternating current to transmit power effectively at a distance of nearly 200 kilometers at the Frankfurt Electrical Engineering Exhibition in 1891 persuaded most energy experts of that system's superiority.

[15] Wyssling, *Entwicklung*, 215.

The Frankfurt demonstration was also very much a part of the story of the hydro-electrification of the Alps. A closer look at this event and the developments leading up to it reveals that the motivation to tap into unused Alpine water power drove many of the innovators who made it possible. They recognized the expensiveness of transmitting electrical energy as a major obstacle to the development of Alpine hydropower, as many of the most lucrative sites were remote from centers of consumption. This reality is clearest in the early career of the Bavarian engineer Oskar von Miller, who played a major role in the 1891 experiment that won most of the electrical world for alternating current. The Alpine energy landscape spurred developments in electrical engineering, and consequently changed because of them. With the new ability to transmit electrical energy at distance, the waterways of the Alps became all the more tempting sources of power.

Thomas Edison's electric power systems astounded the world after their introduction, but the system was not without its flaws. As historian Thomas P. Hughes has argued, the high-cost and general difficulty of transmitting direct-current electricity long distances was one of the major "reverse salients" that limited the early growth of Edison's system. The problem, as Edison early recognized, was that the large current required to power anything on a large scale would require such great amounts of expensive copper wiring that investment in such a system no longer made financial sense. "In other words, an apparently remote consideration (the amount of copper used for conductors), was really the commercial crux of the problem." Indeed, even in his boldest statements concerning the effectiveness of his central stations in the early 1880s, Edison spoke only of a half-mile radius.[16]

Throughout the early 1880s, electrical engineers worked on the problem of electrical transmission. Thomas P. Hughes credits the Franco-English team of Lucien Gaulard and John

[16] Hughes, *Networks of Power,* 33, 83.

D. Gibbs with having developed the system which provided the starting point for all other alternating current schemes. Their main achievement was the development of a transformer capable of increasing the voltage of alternating current to levels that enabled cost-effective overland transmission. Subsequent inventors and companies improved upon Gaulard and Gibbs' designs. These included the American William Stanley who developed transformers for the Westinghouse company and helped turn that firm into Edison's major competitor . By the end of the decade, several installations in both the United States and Europe demonstrated the suitability of alternating current for transmitting power long distances. Fearing their competition, direct current advocates resorted to "nontechnical compensatory responses," using political power to try to stifle the technical advantage of the AC proponents. These included the electrocution of animals with alternating current to prove the danger of that technology. The electrocution of living organisms, however, did not halt the momentum of alternating current.[17] On the contrary, the success of a power transmission experiment organized by Oskar von Miller for the Frankfurt Electrical Engineering Exposition cemented the superiority of alternating current in the minds of most in the electricity field. On August 24, 1891, Miller and a group of engineers from several important electricity firms managed to transmit water power some 170 kilometers from a plant on the Neckar River in southern Germany using high-voltage AC. For the electrical world this signalled the end of the "battle of the systems."[18]

The development of long-distance electric power transmission and its triumphal display at Frankfurt was also an integral part of the evolution of the Alps as an electric landscape. The incremental improvements in electrical engineering technology that culminated with the

[17] The electrocutions proved unsuccessful in currying anti-AC legislation but succeeded in convincing the state of New York that alternating current could be used in executions. The first criminal was legally executed with alternating current in 1890. Hughes, *Networks of Power*, 107-108.
[18] For a detailed history of the development of the alternating current system and the subsequent "battle of the systems" see Hughes, *Networks of Power*, 83-139.

Frankfurt transmission were in large part driven by persons with an explicit interest in making remote Alpine water power more economical. Large urban centers on the outskirts of the mountains in particular sought to find ways to make white coal available in their environs. Others recognized that the Alps were far too remote from transportation routes, markets, and dense populations to ever fully utilize the water power resources of the mountains. Only a means to transmit this power overland would permit rational use of this immense power. For people like Giuseppe Colombo, it was clear that developing this ability carried revolutionary potential in the field of energy, and consequently the political one too. As the one-time finance minister of Italy and board member of the Italian Edison company (Società Edison) predicted:

> The transmission of electricity over long distances represents a fact of such extraordinary significance for Italy that even the most powerful imagination would have difficulty foreseeing all the possibilities. It is something that could alter completely the face of the nation, that could one day carry the nation to the ranks of the best endowed countries in terms of natural resources and industry...When countries that had previously grown rich on coal run out of it will then be the turn of nations with rich sources of flowing water.[19]

One early example of the connection between innovation in alternating current technology and the Alps stems from the Piedmont. Recognizing that direct current systems would not help make the region's abundant white coal available in the towns and factories of the northwest Italian plains, the city of Turin organized an international exhibition and competition for the most effective system of long-distance transmission in 1884. The winners of the 10,000 franc grand prize were Gaulard and Gibbs, who used the occasion to test out their new technology. Installing their new transformers along a nearly 100-kilometer circuit, the pair succeeded in providing illumination at the exhibition buildings, the Turin rail station, and several other train stations on the rail route into the Savoy Alps.[20]

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[19] Quoted in McNeill, *Something New*,175.
[20] Hughes, *Networks of Power*, 94.

At roughly the same time on the northern slope of the Alps, a young Bavarian engineer named Oskar von Miller (1855-1934) was also beginning to engage with the problem of hydroelectric power transmission. Miller was born the tenth son of Ferdinand von Miller, a bronze founder and sculptor for the Bavarian royal dynasty and member of an old and esteemed Munich family. Miller capitalized on good educational opportunities to join the engineering profession. After attending secondary modern school (*Realgymnasium*) and the technical university in Munich, Miller began apprenticeship as an engineer in the Bavarian state service. His initial activities centered on projecting new railway routes, and Miller's entrance into the field of electrical engineering owed a great deal to chance. On a Sunday morning in 1881, as Miller was following a Bavarian bourgeois tradition and enjoying some sausages and a pint at a local haunt, the director of the Bavarian state railways read aloud a newspaper article about an electricity exposition in Paris and suggested that the event would be something for the young civil engineer. Miller took the remark seriously and determined to be present in Paris. By the afternoon he had already received the approval of his father. Getting permission to take leave of his duties from the Bavarian state proved more difficult. During a series of hard negotiations, Miller eventually suggested that a trip to Paris would provide an opportunity to evaluate the potential of using Bavarian water power to generate electricity. With the task of investigating the potential for combining the new technology with the harnessing of water power, the state of Bavaria granted Miller a three-and-a-half month hiatus from government service.[21]

In the topic of water power, Miller had hit on a subject that resonated with his superiors. The kingdom of Bavaria possessed the greatest water power supplies in all of Germany, with the bulk of this energy being located in the southern part of the state where water flowed out of the Alps towards the upper Danube River. Bavarians had been exploiting this water power since the

[21] Wilhelm Füßl, *Oskar von Miller 1855-1934: eine Biographie* (Munich: Beck, 2005), 40-41.

medieval period for mining and metallurgy, forges, and mills of various kinds.[22] But traditional water power had not enabled the state to industrialize to the same degree as other German regions. In hydroelectricity, the state saw a means to improve its economic situation. In September 1881 Miller departed for Paris in the role of Bavarian Commissar.

The Paris International Electrical Exhibition in 1881 is remembered as one of the key events in the history of electrical engineering. It marked the introduction of the Edison central station to European audiences. Edison did not attend the exhibit himself, but his 200-horsepower generator, which powered some 1,200 lamps hanging from the ceiling and in the stairwell, dominated the fairgrounds.[23] Years later, Miller described the impression left by the exhibition as "overwhelming." The greatest commotion, he recalled, was caused by the one Edison bulb that could be lit and extinguished with the flip of a switch. Hundreds of people stood in line to do just that.[24] Many of the fair's nearly one million visitors during its three-month span left convinced of the superiority of the Edison system.[25] Among them was the German mechanical engineer Emil Rathenau, who determined to acquire an Edison franchise. This formed the basis of the German Edison Company (the forerunner to AEG) which would go on to become one of the world's largest electrical firms.[26]

Miller recounted his immediate impressions of the exhibition in a report nearly fifty pages long that he filed with the royal Bavarian interior ministry. For his study of the new field

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[22] Ludwig Strobel, "Bayerische Geschichte im Donauraum, Wasserbau und Wasserwirtschaft im Lande Bayern—Historische Abrisse, Entwicklungslinien und Wechselbeziehungen" in *Geschichtliche Entwicklung der Wasserwirtschaft und des Wasserbaus in Bayern,* Bayerisches Landesamt für Wasserwirtschaft, Vol. 1 (Munich: 1981), 41-42.
[23] Hughes, *Networks of Power*, 50.
[24] Oskar von Miller, "Erinnerungen an die Internationale Elektrizitäts-Ausstellung im Glaspalast zu München im Jahre 1882," in *Abhandlungen und Berichte des Deutschen Museums,* 4, no. 6 (1932): 154, quoted in Anne-Kartin Ziesak, "Am Vorabend des elektrischen Säkulum. Die Zeit der Ausstellungen 1882-1891," in *Unbedingt modern sein. Elektrizität und Zeitgeist um 1900*, ed. Rolf Spilker (Osnabruck: Rasch, 2001), 26.
[25] Ziesak, "Am Vorabend," 27.
[26] For a company sponsored history of the AEG, see Peter Strunk, *Die AEG: Aufstieg und Niedergang einer Industrielegende* (Berlin: Nicolai, 1999).

of electrical engineering, Miller took advantage of the plentiful opportunities offered by the exhibition. In the exhibit's well-equipped reading room Miller availed himself of international electrical journals and works on electricity. Miller was most enthusiastic about the fair's "extremely interesting" congress proceedings, "where the most famous scholars and electricians of the world" traded their viewpoints and experiences. There were also discussions and scientific presentations where professors and technicians explained then demonstrated the machines and apparatuses that populated the exhibits. Of course, there was the exhibition itself, where Miller could view the practical application of the things he had read and heard about. Finally, the hoopla was not limited to the fairgrounds. Numerous experiments and demonstrations with illumination, power transmission, and telecommunication took place at the exhibition's galas and operas, as well as throughout the city. [27]

Soaking in all of this information, the young engineer summarized those achievements in electrical technologies that were closely related to civil engineering and water power, in order to justify his leave from state service. The engineer reported that hydraulic motors drove dynamos just as well as either gas or steam engines.[28] More importantly, the medium of electricity also held the promise of transmitting flows of natural energy—like water—over long distances. The Paris exhibition was also the site of the first comprehensive attempts to transport power over longer distances, largely thanks to the effort of the French engineer Marcel Deprez (1843-1918). There, he demonstrated that electricity could perform useful work at a distance of 1,800 meters from its point of generation, no small feat for the time. Nevertheless, Deprez's bold predictions

[27] The original of the report can be found in the Deutsches Museum Archive (DMA), NL 114/Vorl. Nr. 324. In 1932, on occasion of the fiftieth anniversary of the International Electrical Engineering Exhibition in Munich the Bavarian minister of the interior presented Miller with a reproduction of the original which can be found in the library of the Deutsches Museum. Oscar von Miller, *Reise-Bericht des Ingenieur Praktikanten Oscar v. Miller, Theil I*.
[28] Miller, *Reise-Bericht*, 45-46.

about the future of electric power transmission probably raised more excitement than his actual demonstration. Deprez claimed it would be possible to transmit a useful amount of power a distance of 50 kilometers with high-voltage direct current. The assertion encountered hefty skepticism, if not downright antagonism.[29]

Miller, for one, believed in the potential of electric transmission, and its ability to help harness water power. He reported that electric current was well-suited to transmit the energy of "large, often worthless natural forces" like waterfalls, tides, and wind in cases when the costs of generation and transmission were lower than those necessary to provide equivalent steam power. In practice, this meant that the source of natural power would have to be twice as large, since half of the energy would be lost in the transmission. Nevertheless, Miller was confident that this calculus would soon change in favor of the competition to steam. In the conclusion of his report, Miller predicted that the immediate future would certainly bring progress, "if not in the almost perfected electric illumination, at least in the field of power transmission and the accumulation (*Ansammlung*) of electric current." The final sentence of his report Miller devoted to a plea. "May this new area of technology also be supported in every manner in Bavaria, so that the people may enjoy the advantages that the application of electrical current offers, so that the state can benefit from the capital that it possesses in its unused water power."[30]

Miller's closing summation represents perhaps the earliest formation of what his biographer refers to as the engineer's concept of "social electricity." While many of Miller's colleagues were interested in electricity as a technological problem, Miller went a step further and continually considered how it could be employed towards certain social goals. Eventually Miller came to believe that by making electricity available to everyone—not just well-to-do

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[29] Richard Rühlmann, "Marcel Deprez' Versuche über elektrische Kraftübertragung," *Zeitschrift des Vereines deutscher Ingenieure* 29, no. 50 (12 December 1885): 981.
[30] Miller, *Reise-Bericht*, 42; 45-47.

urbanites—disadvantaged social groups could draw economic benefits. Miller argued that especially farmers, artisans and tradesmen might once again find prosperity in the industrial-age economic order with access to electricity. As Miller saw it, in order to obtain the necessary "electricity for all" it would be necessary to activate latent natural forces as well. As he later put it: "the mission of electrical engineering was not at all fulfilled by the manifold applications of electricity; it was necessary to exploit the powers utilized to generate electricity more economically and above all to strive, with the help of electricity, to employ new energy sources , that until now have remained either incompletely exploited or not at all."[31] For Bavarians, as for others throughout central Europe, the most abundant source of accessible natural power existed in the Alps. Solving the transmission problem was the key to the problem of provisioning social electricity, and Miller made it a crucial goal of his early career.[32]

The year following the Paris fair, Miller continued his efforts to unlock the power of the mountains. In 1882, the Bavarian organized his own international electric exhibition in his hometown of Munich. As the high-point of the exhibit, Miller offered his colleague Marcel Deprez the opportunity to prove his controversial claims about long-distance power transmission. With financing from the Baron Alfons Rothschild, Deprez and Miller set up a transmission line running some 60 kilometers from the village of Miesbach in the foothills of the Bavarian Alps to Munich. The high-voltage direct current flowing through the line was supposed to power a small pump that would create a two-meter high waterfall at the fairgrounds. Set amidst a smattering of conifers on the edge of a rocky cascade, the waterfall symbolized the role that electricity would play in making the remote energy of mountain water power (ironically the generator in Miesbach was coupled to a steam engine). The Miesbach transmission pushed the outer limits and neither

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[31] Oskar von Miller, *Die Naturkräfte im Dienste der Elektrotechnik* (Leipzig: F.C.W. Vogel, 1902), 3.

[32] For the development of Miller's "social electricity" concept see Füßl, *Miller*, 140-164.

Miller nor Deprez were certain of success. When at the appointed time the waterfall indeed began to flow, Deprez, who had travelled from France to attend, joyously hugged Miller. Nevertheless, the experiment was not a complete success. Various components broke down, meaning the exhibit operated only for a very short time. The efficiency of transmission, moreover, was abysmal. While the experiment demonstrated that power transmission was theoretically possible, much work remained before the technology could be used to transport power economically.

Expert opinion on the significance of Miller and Deprez' experiment was correspondingly ambiguous. Among the impressed, however, was Friedrich Engels, who interpreted the event as path breaking. Immediately after the exhibition Engels penned his colleague Karl Marx to inform him of the great significance of the transmission. Several months later in a letter to the German socialist Eduard Bernstein, Engels described the feat as an "electrical engineering revolution" and speculated that electric power transmission would liberate industry from geographic limits and enable the harnessing of even the remotest water power, leading to the abolition of the gulf between the city and the country.[33] Several years after the Munich exhibition, the Frenchman Deprez retired to another part of the Alps to continue work on the transmission problem. The city of Grenoble invited the engineer to come to the Dauphiné and experiment with the transmission of the abundant water power in the valleys surrounding the capital. Here Deprez managed to deliver nearly seventy percent of the ten horsepower generated by a water turbine a distance of fourteen kilometers.[34]

[33] Füßl, *Miller*, 52-58. According to the Swiss engineer Walter Wyssling, the Miesbach transmission convinced Swiss engineers that electric power transmission was the key to helping Swiss industry utilize the country's water power. Wyssling, *Die Entwicklung*, chapter 7.
[34] Rühlmann, "Marcel Deprez' Versuche," 981.

Miller's most conspicuous effort in developing power transmission technology came with the key role he played in the organization of the Frankfurt Electrical Engineering exposition that persuaded most electrical experts of the superiority of alternating current.[35] As technical director of the exhibition, Miller had the greatest hand in designing the event, and the power transmission that sealed its epoch-making reputation among his colleagues in the electrical world. In 1890, the city of Frankfurt enlisted the aid of Miller in the expo that had been conceived as a means to help the city decide what type of electricity to use in the municipal utility it sought to build. The idea to build a municipal electric plant in Frankfurt dated back to the time of Miller's 1882 exhibition in Munich. As the years passed the question became one of the most important European fronts in the battle of the systems. Unable to decide between direct or alternating current, city representatives decided to hold an international exhibition where proponents of the various systems could compete with one another to demonstrate their superiority. Miller came recommended as a man with the know-how to pull off such an undertaking.

As the exposition was intended to help the city of Frankfurt choose an electrical system, displaying the various generating and distribution characteristics of the electrical systems stood in the forefront. As in Munich, Miller sought to make a bold long-distance transmission the highlight of the exhibition. Since that time transmission technology had matured a great deal. Instead of direct current, Miller opted for a new type of cutting-edge alternating current called polyphase. This time, he chose a route that nearly tripled the distance of the earlier demonstration. From a hydroelectric plant on the Neckar River in southern Germany, polyphase current at a voltage of as much as 25,000 volts would be transmitted 170 kilometers north to the fairgrounds in Frankfurt. To emphasize the connection Miller saw between water and electricity, mountains and power, the electricity would once again power an artificial waterfall (in addition

[35] Füßl, *Miller*, 105-140.

to one-thousand lamps). Besides the German electrical trust AEG, a smaller Swiss firm called Oerlikon, responsible for one of the first long-distance transmissions of Alpine water power in Switzerland, provided the electrical equipment. After months of preparation, on the evening of August 24, 1891, Miller and his associates completed the transmission line. Observers at the exhibition jubilantly confirmed that "the electricity is in Frankfurt". In contrast to Munich, the power transmission functioned nearly flawlessly, and managed to transport hundreds of horsepower with impressive efficiency. While historians today recognize the Frankfurt demonstration as the outcome of continual technical development, contemporaries almost unanimously interpreted it as a crucial turning point in the history of electricity supply. Thoroughly convinced, the city fathers of Frankfurt chose alternating current for their burg.

Frankfurt also marked a turning point in the evolution of the Alpine energy landscape. After 1891, European interventions into Alpine hydrology increased dramatically. In place of small-scale modifications of waterways to generate power for isolated plants came a willingness to more drastically rearrange the Alpine hydrosphere to liberate larger amounts of energy. Electric power transmission changed attitudes on Alpine water power. With the ability to transmit hydroelectricity beyond the waterways where it was produced, it now made sense to find large water power sites and exploit them as completely as possible. Oskar von Miller had a hand in designing a fair share of such facilities throughout central Europe, including one of the first in his homeland of Bavaria.

Putting the Isar to Work

The Isar River is an international river and southern tributary of the Danube. From its source at nearly 1,800 meters above sea level in the Karwendel range of the Austrian Alps it quickly reaches the border with the German state of Bavaria, flowing first through the Kochel mountains and the pre-Alpine hill and moorland. Within this region the river punches through several moraines left by glaciers long ago, descending rapidly and cutting down into a narrow valley to the south of the Bavarian capital of Munich. After leaving the city the Isar finds its way to the Danube in a far more leisurely fashion. All told, the Isar drains some 9,000 square kilometers. In its upper stretches in particular, sections of the Isar channel are characterized by the kind of abrupt descents ideal to take advantage of water power. There, in the pre-Alps south of Munich, the power of the river was harnessed to create the Isar Works—the most powerful hydropower plant in Bavaria before the turn of the twentieth century and one of Germany's and central Europe's first "overland" power stations.

The upper Isar valley was scoured out by a succession of glaciers that at times reached from the Karwendel far into the plains below. Like most glaciers, the Isar glaciers carried rocks and debris picked up along the way which it then dumped off in terminal moraines. Successive belts of these moraines from different ice ages mark the Isar valley as it flows through the pre-Alpine hill and moor landscape. As the glacier from the last ice age began to recede about 30,000 years ago, it left behind a series of lakes dammed in by moraines. Since then, the Isar has managed to cut through these obstructions and drain the lakes.[36] The river's descent picks up in these geological transition zones, creating ideal conditions for water power. Up until the late-nineteenth century, Bavarians made partial use of the Isar energy in this stretch of the river. A catalogue compiled by the Bavarian state after the turn of the twentieth century lists twelve different mills on the upper Isar that predate the 1890s, including one that was constructed in "time immemorial" (*in unvordenklicher Zeit*). These facilities delivered power mostly to mills,

[36] Bayerisches Landesamt für Wasserwirtschaft, *Flusslandschaft Isar von der Landesgrenze bis Landshut: Leitbilder, Entwicklungsziele, Maßnahmenhinweise*, 2nd ed., (Munich: Hannes Lindner, 2002), 14.

especially sawmills. But the upper Isar also drove two factories (one made pulp and paper, the other brushes) and a monastery mill.[37]

At the close of the 1870s, the power potential of one stretch of the river in particular caught the attention of a pair of entrepreneurs from Munich. Jakob Heilmann, an engineer, and Wilhelm Peter von Finck had their eye on the Isar between the Bavarian towns of Höllriegelskreuth and Pullach to the south of the capital. Near Höllriegelskreuth, the river cut through the lower moraine as it left the pre-Alpine region, plunging sixteen meters over a distance of only four kilometers. Here, the Isar flowed audibly, "rushing forth as mountain water between its steep banks."[38] With the available fall and hydrological circumstances of the Isar, it would be possible to harness up to 6,000 horsepower. In the 1870s, however, only a mechanical harnessing of this power would have been possible, in an industrial facility in the immediate vicinity.[39] For several years, Heilmann and Finck dropped the idea of developing the upper Isar power further. The developments in the field of electrical engineering during the 1880s, however, opened up new prospects for the project. With the ability to transmit water power via electricity, the entrepreneurs would not have to settle for developing and using the power in the backwater of the upper Isar. They could instead deliver the current to Munich, where a much larger market of potential light and power users existed. In 1889, Heilmann and Finck requested a concession from the Bavarian state to develop the water power of the upper Isar by damming the river at Höllriegelskreuth. They quickly received the go-ahead, and construction on the dam began that winter.

Impressed by the results of Miller's Frankfurt transmission, Heilmann and Finck determined to expand the scope of their project. They would develop the entire available energy

[37] K. Oberste Baubehörde, *Die Wasserkräfte Bayerns*, 253-254.
[38] Kammerer, "Ausnutzung," 866.
[39] "Die Isarwerke bei München, Geschichte, Bau, Betrieb," *Weisse Kohle*, 215.

of 6,000 horsepower. Although they had initially planned on exploiting the power in one twelve-meter fall, the pair resolved to develop the energy in multiple stages. While such a plan increased overall costs for machinery and facilities, it had the advantage that the complex could be expanded as demand increased.[40] This was essentially a hedge to determine if the new technology would prove feasible, and it speaks to the uncertainty that persisted about the future prospects of electricity. Heilmann and Finck obtained Miller's services to design the electrical part of the facility. Miller, of course chose to equip the plants with polyphase current. In 1893, construction on the dam finished; a year later the first 2,000-horsepower hydroplant at Höllriegelskreuth came online as the property of the newly formed Isar Works, LLC. In 1904, the Isar Works completed a second hydropower station at Pullach with double the capacity of the first facility.

In remaking one stretch of the Isar, Heilmann and Finck created a considerable amount of useful industrial energy. By way of comparison, the Isar Works tapped into over half of the power that had been available to the mill centers of Lowell, Lawrence, and Manchester on the lower Merrimack in the United States.[41] The Niagara Falls power station, one of the largest and certainly the most renowned hydroelectric plant in the world at the time, generated some 15,000 horsepower—a little over two times more than the Isar Works. Unlike the Isar Works, however, the Niagara power was mostly limited to the immediate vicinity of the plant. Until 1910, when the Ontario provincial hydroelectric utility constructed a line reaching through the province and into Toronto, only one transmission line ran to Buffalo with a comparatively small capacity of 1,000 horsepower.[42]

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[40] Kammerer, "Ausnutzung," 866.
[41] Smil, *Energy in World History,* 108.
[42] Hughes, *Networks of Power,* 265.

The Isar Works provided light for a number of localities in a wide area, and the outline of its distribution network had a fundamental impact on the location of industry in the upper Bavaria region. At the outset, Heilmann and Finck had believed the Isar Works would deliver light and power to the city of Munich. In exchange for the right to sell their electricity in Munich, the Isar Works also offered the city the right to purchase the facility at cost (plus a "modest" bonus) or to purchase a sizeable stake in the concern. Rebuffed by the magistrates, the Isar Works sought to create a market for its electricity. Towards this end they decided to create two industrial zones from the ground up. In these areas, the company would provide ideal conditions for factories and industries to establish themselves. The Isar Works purchased two plots of land—one near the first central station in Höllriegelskreuth and the other on the Obersendling field in the Munich suburb of Thalkirchen—totaling two hundred hectares together. Both zones had access to the German rail network. Heilmann and Finck argued that particularly the larger industrial zone of Obersendling outside of Munich would benefit the city by providing a suitable space for inner-city industries to relocate. The entrepreneurs argued that "hemmed in" factory owners could make a profit by exchanging their expensive inner-city real estate for the cheaper land of the countryside. The relocation would be a boon to the city as well, as the reduction in smoke and soot would improve hygienic conditions. By the close of the first decade of the twentieth century, the Isar Works supplied thirty different communities with light. The Obersendling industrial zone counted 34 different industrial facilities. Its occupants included several raw material processing facilities, machine tool and motor factories, cement and asphalt production facilities, soap and perfume manufacturers, a specialty paper factory, shoe factories, a lithographic art facility, and a cotton factory. Some 2,000 souls who made their livelihoods in these various industries called Obersendling home as well. Among these residents were many of the owners of the factories, who built villas on what many considered a lovely piece of land on the banks of the river. All told, the Isar Works supplied power for 70 large industrial facilities, 100 small ones, 9 medical institutions, and 11 public facilities.[43]

Harnessing the power of the upper Isar required the construction of a dam, but not in the manner of some of the more well known dams on larger rivers. The Isar Works are a special type of "run-of-river" dam. While they raise the water level upstream, run-of-river dams have no (or minimal) means of storing this water. They tap into instantaneous flows of water, and their electric power generation is proportional to the flow of the stream at a given time. The primary purpose of the dam at Höllriegelskreuth was not to create hydraulic head. Rather, the point of the low concrete barrier that spanned the upper Isar—referred to as a weir—was to impound the stream and divert a portion into a headrace canal whose course led to the turbines and dynamos that turned water into electricity. In the case of the Isar Works, this canal measured nearly six kilometers in length. Whenever the flow of the Isar was high enough, whatever water that was not required by the hydropower plant flowed over the weir into the river's previous channel. This was generally the case outside of the winter months in non-drought conditions. In the period after the emergence of hydroelectricity in the Alps, this combination of weirs and headrace canals was quite common for run-of-river plants. While run-of-river dams are considered less ecologically damaging than storage dams, they still require far-reaching modifications of the riverine environment.[44]

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[43] BayHStAM MF 67744: Cassimir, *Vorträge des kgl. Direktionrates Dr. Cassimir "Über die Ausnützung der Wasserkräfte im Auslande und deren Entwicklung nach der technischen, wirtschaftlichen und rechtlichen Seite", ferner "Über den Stand der Ausnützung der Wasserkräfte in Bayern und unter Berücksichtigung des Programmes der Verkehrsverwaltung gehalten am 20. und 27. November 1909 und am 23. April 1910 in den Ministerialbesprechungen des k. Bayerischen Staatsministeriums für Verkehrsangelegenheiten* (Munich: Carl Gerber, 1910), 26; "Die Isarwerke," 278.

[44] Patrick McCully, *Silenced Rivers: The Ecology and Politics of Large Dams* (London: Zed Books, 1996), 11-12. In some cases, the distinction between run-of-river and storage dam is more difficult to draw than with the Isar Works.

This was certainly the case with the Isar Works, whose environmental impacts were manifold. The power facility drastically changed the river's hydrology, disrupting life on the Isar for both humans and other organisms. In the late-nineteenth century, the upper Isar would have come close to fitting the type of the "wild river" (*Wildfluss,* see introduction) ecosystem characterized by strong seasonal dynamics; the Isar Works altered these drastically. One set of consequences came as a result of the change in flow regime. The stretch of the Isar exploited for its power saw its flow volume permanently reduced in order to pay tribute to the hydroplant. In the winter, the river could be reduced to a trickle. The Isar dam also impeded upstream and downstream flows of material and organisms that characterize all rivers. The construction of the weir at Höllriegelskreuth provides insight into the impacts that most concerned the planners at the time. In addition to the six sluices that fed the headrace were two other gates that could be opened periodically to flush out the heavy gravel load (*Kies*) that the Isar, like all mountain rivers, normally carried but was forced to drop when it met the new barrier in its way. In the absence of its usual sediment load, the lighter Isar was freed up to dig deeper into its old bed below the weir. Additional openings in the weir accommodated a flume for timber rafts to pass through, and a ladder to aid fish in their migration upstream. The existence of a headrace canal—a second Isar running parallel to the old river's west bank—also completely altered the floodplain ecology. In many ways the old Isar itself came to resemble a canal. As one of the conditions attached to the concession to utilize the upper Isar, the Bavarian state also charged the Isar Works with correcting the section of the old Isar channel from which the water was diverted. Along this nearly six-kilometer stretch, engineers regulated the Isar so that its water levels would henceforth fluctuate in a much narrower band than before.[45] The removal of natural retention spaces and the reduction in flooding also permanently changed the river habitat. The slowing of

[45] "Die Isarwerke," 216.

stream velocity, and the altering of ground water levels—two other prominent environmental effects of run-of-river dams, may also have affected the Isar's ecology.[46]

The nature of the Isar Works influenced power production in myriad ways as well. One of the most disruptive was the appearance of ice in the power canals in the wintertime. As one engineer explained it, the steep gradient of Alpine rivers all but prevented them from icing over. Thus, a sudden breakup of river ice during a thaw (*Eisgang*), sending a violent rush of ice and water—was not a problem as in the rivers of the plains.[47] Ice formation in the power canals, on the other hand, was a constant danger on the coldest winter days. Power canals were purposely built to flow sluggishly until the moment they fell onto the turbines, and ice often appeared along the edges and at the bottom of the slower headrace water. If this ice were to freeze permanently, it could result in an extended period where the turbines were out of operation. In order to prevent this eventuality, the Isar Works were compelled to keep strict watch over the canal. For this purpose, a hut was built before the power stations to house two-man watch teams with two-hour shifts. When a team spotted ice, the Isar Works' operators opened the floodgates, sacrificing water for power generation purposes in order to shoot the ice downstream. At such times power production could drop to a meager several hundred horsepower. In some years, ice days were extremely frequent. In the winter of 1900/1901, for example, the Isar Works recorded eighty-nine ice days. Ice obligated the Isar Works to keep large, and expensive steam engines in reserve (6,000 horsepower).[48] While some Europeans openly recognized issues such as ice when

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[46] Veit, *Die Alpen*, 211-212. Eventually, the hydropower development on the Isar south of Munich encountered opposition from the nascent Bavarian nature protection movement in the form of the Isar Valley Association. Formed in 1902 in protest against the Isar Valley Association opposed the developments on aesthetic grounds. See Reinhard Falter, "Achtzig Jahre "Wasserkrieg": Das Walchensee-Kraftwerk," in *Von der Bittschrift zur Platzbesetzung: Konflikte um techn. Großprojekte;Laufenburg, Walchensee, Wyhl, Wackersdorf*, ed. Ulrich Linse (Berlin: Dietz, 1988), 73-74; Raymond H. Dominick, *The Environmental Movement in Germany: Prophets & Pioneers, 1871-1971* (Bloomington: Indiana University Press, 1991), 47-49.

[47] Kammerer, "Ausnutzung," 865.

[48] Kammerer, "Ausnutzung," 865; "Die Isarwerke," 216, 260, 278.

discussing hydroelectricity, drawbacks to the new power source tended to be downplayed by those most enthusiastic about the prospects of the new energy source.

The Meaning of Hydroelectricity

The advent of hydroelectricity prompted many Europeans to reflect on the significance and meaning of the new energy source. Observers who recognized only the positive aspects of hydropower seem to have been in a strong majority. Some of the greatest enthusiasts had a vested interest in the development of water power resources. The general excitement about hydroelectricity was at once a consequence of the perceived successes of early hydropower development, and a spur to its continued expansion.

Like Giuseppe Colombo, many believed that hydroelectricity would completely reshape geopolitical fortunes, giving countries with water power resources powerful new advantages. In his *Foundations of the Nineteenth Century*, Houston Stewart Chamberlain strayed briefly from his racist treatise to document—in a footnote—his belief that "poor Switzerland" was about to become one of the richest industrial states in the world, "because she can convert her monstrous amount of water power into electricity almost free of charge."[49] Theodor Köhn, author of one of the first German engineering handbooks on water power utilization, shared Chamberlain's conviction: "As wealth in coal strongly favored the industrial development of England, Germany, America, and Belgium in the nineteenth century, in the twentieth century the lands rich with water power will…be able to benefit greatly in the contest of nations."[50]

Chamberlain of course exaggerated the low cost of harnessing Alpine water power, but not by much. As the rector of the technical university in the southwestern German city of

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[49] Houston Stewart Chamberlain, *Die Grundlagen des neunzehnten Jahrhunderts*, 14th ed. (Munich: F. Bruckmann, 1922), 2:595.
[50] Theodor Köhn, "Einige allgemeine Betrachtungen über den Ausbau von Wasserkräften," *Die Weisse Kohle* 1, no. 2 (25 January 1908): 5.

Karlsruhe noted, "the unit-price of energy is of course the decisive factor in the comparative evaluation of energy sources," and cheapest water power bested the cheapest coal in this respect. By the rector's calculations, even the best thermal plants located directly at the seams and running around the clock could not deliver a horsepower-hour of energy for less than one or two *pfennig*, and most of the time the unit price was two to three times larger than this. The best high-pressure water power plants (located in the Alps), on the other hand, could produce power for a third of the price of the best coal stations. More expensive low-pressure facilities (like the Isar Works) were also cheaper than thermal power stations. These differences in cost added up to huge economic savings in power plants producing several million horsepower-hours annually, savings which the university official believed might finally put the water-rich mountain lands at an industrial advantage. For him, proof of cheap hydro's effects lay in the "tremendous economic boom" experienced by regions such as Switzerland, eastern France and northern Italy. For the rector it was indisputable that these developments were primarily a result of the harnessing of the water power of their Alpine rivers."[51]

One of the most prominent arguments in favor of water power was its comparative renewability. In a 1908 article entitled "The Mightiness of White Coal" an engineer from Saxony outlined how this characteristic made water power superior to coal. Although coal supplies seemed inexhaustible to many, the Saxon believed that increased demand would in fact expedite their depletion. White coal, on the other hand, did not suffer from this problem. "As long as the sun continues to radiate its power onto the earth," the engineer explained, "it constantly raises water from the endless seas to the peaks of the mountains, where the water flows once again to the sea in an eternal cycle." Whereas coal seams all came with a more or

[51] Th. Rehbock, "Der wirtschaftliche Wert der binnenländischen Wasserkräfte, unter besonderer Berücksichtigung des Großherzogtums Baden," *Die Weisse Kohle* 1, no. 3 (10 February 1908): 3-4.

less calculable expiration date, white coal did not. White coal, the engineer pronounced "does not lie buried in the mysterious depths of the earth's womb, it renews itself daily before our eyes, and we can observe the processes that drive this cycle and learn to predict their effects."[52] Using water power was economically preferable to burning coal, because the former was a case of adding value to natural resources while the latter represented their destruction.

In a unique form of this argument, the German chemist Wilhelm Ostwald contended that using hydroelectricity instead of coal represented not just economic prudence, but a more advanced stage of cultural development. Ostwald was the originator of the "energetic theory of culture" in which he argued that all societal endeavors were in reality efforts to increase the amount of usable energy, either by finding new sources of power, or harnessing existing ones more efficiently. This meant that the "character" of the dominant energy source exercised a strong influence on the character of a corresponding time period. For the most part, he was not very impressed with the moral qualities of his own era. While the intensive use of fossil fuel resources had permitted unprecedented development in his lifetime, Ostwald was doubtful of the wisdom of carbon-based economies. For him, exploiting fossil fuels was akin to stumbling into an "unexpected inheritance" that had allowed humanity to turn away from a "sustainable economy" (*dauerhafte Wirtschaft*) and live profligately. He regarded increases in energy efficiency on the other hand as both cultural progress, and morally preferable because squeezing more out of existing power sources was a means to avoid the struggle and competition to find new ones. The move from petroleum to gas lamps was an improvement in efficiency and therefore a step forward. The same applied to using water power to generate electricity. Water power use was also preferable to coal because it was renewable and more aesthetically pleasing than burning fossil fuels. Ostwald's attempt to explain cultural developments from a natural

[52] Kretzschmar, "Die Mächtigkeit der weißen Kohle," *Die Weisse Kohle* 1, no. 11 (10 June 1908): 125.

science perspective met with disapproval from many corners, including the sociologist Max Weber, who believed making sense of historical processes was the purview of the nascent social sciences. And while most hydroelectric enthusiasts likely did not conceive of the harnessing of Alpine water power in a world-historical framework, they nonetheless shared his belief in the superiority of renewable energy.[53]

Europeans also pondered hydroelectricity's social and industrial consequences. One oft-heard refrain had it that water power was in several respects a more independent source of energy than coal. A supplement to the *Münchener Allgemeine Zeitung* in 1899 explained how hydroelectricity empowered industrialists in Bavaria, and presumably the rest of the coal-poor Alps:

> In our time of strikes and trusts, there is substantial value in the independence of a source of power. According to experience, coal prices and correspondingly the production costs of steam power are subject to quite considerable fluctuations. The industrialist who works with steam eats his bread from the hands of the mine owners and the railway administrations. Every misfortune which befalls them, befalls him as well. If the miners strike, or if the mine operation is interrupted, so might the factory shortly close. If the miners win a wage increase, if the freight prices are pushed up, if the owners of the coal mines want higher profits—it is always the industrialist who pays in the end.[54]

If Bavarians switched to hydroelectricity, they would no longer be beholden to the whims of the Ruhr coal syndicate, the workers who produced the coal, or the railways and navigation companies responsible for transportation (and their workers' unions too). From this point of view, hydroelectricity was one tool to dismantle the growing political power of the working class.[55]

[53] Wilhelm Ostwald, *Energetische Grundlagen der Kulturwissenschaft* (Leipzig: Werner Klinkhardt, 1909), 13, 25; Sieferle, *Subterranean Forest*, ix.

[54] Cited in K. Oberste Baubehörde, *Die Wasserkräfte Bayerns*, 37-38.

[55] This question of the connection between energy systems and political power has been explored by Bruce Podobnik, *Global Energy Shifts: Fostering Sustainability in a Turbulent Age* (Philadelphia: Temple University Press, 2006); Timothy Mitchell, *Carbon Democracy: Political Power in the Age of Oil* (London: Verson, 2011).

Others believed hydroelectricity would have important social impacts by bolstering the diminished prospects of artisans and craftsmen in the age of industrialization.[56] Oskar von Miller, the proponent of "social electricity", expounded such views in an 1890 letter to his wife Marie. In the letter, Miller recounted a meeting with Wilhelm Peter von Finck, the co-founder of the Isar Works. Miller explained that he wanted to see a company formed that would loan electric motors and other necessary equipment to craftsmen for a rental fee or by sharing in the worker's increased profits. Not only would this system lead to an "eminent turnaround" for artisanal industry, but it would dampen some of the social strife that he saw as a consequence of German industrialization. Miller described to Finck "how good and timely it would be, if the factories were disaggregated and installed in the craftsmen domiciles again, where no quarrels about eight-hour working time and employment of women and children could take place." According to Miller, Finck appeared enthusiastic about the idea, if only because it seemed to be a good business idea as well. To further win Finck's favor, Miller also recommended using the Isar water power as the basis for a storage battery factory in Höllriegelskreuth, and even intimated the people who would be well-disposed to such an undertaking. Still Miller did not have much hope that his plan would soon be put in action. As he wrote his wife, "A lot of water will flow down the Isar until this, one of my favorite plans, is fulfilled."[57]

The increased value of water power also raised questions about who should have the power over its disposal. In all Alpine countries, the question of whether the state should develop water power resources, or the private sector (often categorized simply as "industry") generated serious debate. As early as the 1880s, movements to nationalize water power resources emerged

[56] In France, for example, the distribution of electricity into the homes of craftsmen was intended to rescue the artisanal textile industry. Philanthropic associations also formed to assist artisans in acquiring electric equipment for their trades. See BayHStAM MF 67744: Cassimir, *Vorträge*, 8.
[57] Füssl, *Oskar von Miller*, 144.

in the Alps, particularly in Switzerland, Austria, and the German state of Baden. The discussions reveal much about Europeans' attitudes towards water, energy, and the role of the state in economic life.[58]

One of the first strong movements to nationalize water power emerged in Switzerland. The formation of an association in favor of nationalizing Swiss water power, the "Freiland" Society, in 1888 marked a beginning of the societal discussions about nationalization there. In nationalization, the "Freiland" Society saw the best means of overcoming the negative effects of Switzerland's byzantine water law landscape. The Swiss confederation's twenty-two cantons (and three half-cantons) had a hodge-podge of different forms of water legislation that complicated the harnessing of water power, especially in the (very frequent) cases where a particular water power project involved more than one canton. In 1891, the Freiland Society petitioned the Swiss federal council to codify the nationalization of water power into the federal constitution. The Society called for federal ownership of all unutilized power in Switzerland, and federal regulation of all transmission of said power via, electricity or compressed air. According to their petition, the federation should have the authority to organize the water power monopoly and dispense with its profits as it saw fit.

The group justified its stance on a number of grounds. The transfer of natural sources of energy from private to public property, it argued, would redress social imbalances, reduce economic crises, and lead to a more just distribution of the benefits of industry. Nationalization was all the more justified in the case of water resources, which were already a public good (except where private enterprises had obtained concessions to utilize them). The "Freiland" Society emphasized the decisive importance for water power in Switzerland, a country with no

[58] This discussion of nationalization is based on the chapter on water power nationalization in K. Oberste Baubehörde, *Die Wasserkräfte Bayerns,* 54-64.

coal supplies, and the risks entailed by allowing it to fall in the hands of "profit-addicted private speculators, tribute-demanding high-finance, or the stock exchange." Switzerland's water power wealth should instead "remain preserved for all time for all Swiss." The proponents of nationalization believed that only the intervention of the federal state could ensure that Swiss natural prosperity—by which they meant the spectacular slopes of its Alpine waterways—would be properly utilized. Without state intervention, the "Freiland" Society predicted the continued fleecing of cantons and municipalities by the private sector, who would gain control "piece by piece" of the country's waterfalls. In the place of uniform, well-thought out water power projects, the country would reap nothing more than the "atrophied crumbling" of the natural falls. In the end, it would be the industrious Swiss folk (*gewerbetreibende Volk*) that would suffer the most, paying "taxes to private owners for every motor load, every electric light bulb."[59]

In 1895 the federal council rejected the Freiland Society's petition, citing a series of private expert testimony. The council agreed with one engineer who insisted that since water power use always had to adapt itself to peculiar local circumstances, the private utilization of water power was actually a boon for many areas. From this perspective, only the "energy and prudence of the entrepreneur" could create the necessary market for the goods produced by water power. It also supported the somewhat confusing arguments of one report that warned that state development of remaining water power was a potentially risky business proposition before doubting that the government would be able to raise the capital necessary to exploit the water power of all Swiss waterways anyway. This report also departed from the dubious notion that the state would develop its many million horsepower all at once, and so artificially expand national industrial production with no hope of finding a market. Another expert opinion advised that the complicated field of water power use did not lend itself to a state monopoly in the

[59] K. Oberste Baubehörde, *Die Wasserkräfte Bayerns*, 59-60.

manner of the postal service and telecommunication. Even Switzerland's recent nationalization of the railways took place only after that sector had outlived its initial "growing pains." In the final instance, the federal council stood by the principle "the state should not speculate", as the monopolization of water power would mean "a constraint on the healthy development of native industry."[60]

In Austria, the premier professional association for engineers and architects came out against the nationalization of water power in 1897. In response to a legislative initiative in the Upper Austrian provincial diet, the Austrian Engineers and Architects Association composed a report in which they argued against monopolization as an obstacle to hydropower development. Tapping into this energy, the report stated, was merely a means to an end, namely the promotion of the commonwealth through industrial development and job creation. Similar to the Swiss federal council, the association believed in the centrality of entrepreneurs in this process, and rejected saddling them with any tax or fee that might hamper their activities. "If we want to raise labor and industry," the statement insisted, "we ought not tax tools, or the steam and water power that drives the motor." This does not mean that the group recognized no role for the state. On the contrary, they demanded generous public support to ensure a thorough harnessing of all available water power. The association welcomed tax breaks, subsidies, and help with expropriating property necessary to construct a hydropower project if necessary. But the Austrian engineers and architects sought to uphold the sanctity of private property enshrined in the granting of water power concessions.[61]

[60] K. Oberste Baubehörde, *Die Wasserkräfte Bayerns*, 60-61.
[61] K. Oberste Baubehörde, *Die Wasserkräfte Bayerns*, 56-57.

Locating Alpine Water Power

Around the turn of the twentieth century, the first systematic attempts to quantify and systematize water power in the Alpine lands began to emerge. Such prognoses were made possible by the emergence of state hydrological services towards the end of the nineteenth century. In many cases, states created these agencies expressly to garner hydrological data to facilitate the development of Alpine water power.

Perhaps unsurprisingly, one of the first attempts to determine the available water power of a larger swath of the Alps stemmed from the pen of Oskar von Miller. On the occasion of the forty-fourth annual assembly of the Association of German Engineers, Miller wrote an article in which he calculated the water power streaming down the northern slope of the Alps. By this he meant the water power of the Rhine and Danube basins. Miller focused on this area, because he believed it should be of interest to his audience of German engineers. Not only would German engineers be directly and indirectly involved in the development of this water power (some of the most lucrative in all of Europe), but this energy also lay in Germany and its neighbor states of Austria and Switzerland—states whose industrial and economic futures were "tightly chained to Germany." Miller acknowledged that opinions varied widely on precisely how much additional water power resided in these rivers, if any at all. But he was confident that his scientific approach, buttressed by hydrological observations, would lend clarity to the issue. Miller also distinguished total available "raw" water power, and the portion of this total water power that could technically be exploited. The Bavarian reckoned that his home state possessed almost two million raw horsepower, of which 700,000 might be harnessed. For the Rhine and Danube watershed in Switzerland and Austria, Miller deduced figures of six million raw horsepower, of which about half were potentially usable. In Bavaria and the remainder of the north slope, no more than twelve percent of this energy had already been exploited. Miller concluded that the continued development of Alpine water power would have to unfold in the context of systematic explorations like his own. But he believed that technological preconditions to utilizing this water power had been fulfilled, and he hoped that his engineering colleagues would take to the task of developing the energy of the Alpine area so that "in the future the competition in the various fields of industry will be possible for even these coal-poor lands."[62]

Most of the systematic attempts to estimate available water power in the Alps relied on hydrological data gathered by newly created state agencies that had emerged all across the Alps. These state organizations generally focused on their own territories, however, and around the turn of the twentieth century no uniform survey of Alpine water power existed. Miller, for example, based his treatise on the findings of the Royal Bavarian Hydrotechnical Bureau. Founded in 1899, the Bureau published annual yearbooks that explained its observation methodology and displayed its results. Judging from the foreword to the Hydrotechnical Bureau's first annual yearbook, the impetus behind the formation of the hydrological service was a mixture of a desire to enhance knowledge about the kingdom's water and a somewhat adversarial attitude towards water. The Bavarian state thirsted for knowledge about the gradients of its waterways and their drainage characteristics. This information would enable the determination of the range of flood levels. Another realm of inquiry was the influence of various parts of a catchment area on the streamflow of major rivers and their tributaries. Armed with these data, the state hoped to solve urgent hydrological problems. Chief among these were the rectification of state waterways, the use of water power, flood control, navigation, and torrent control. In justifying the existence of the Bureau, the agency's first director explained that the "increased needs of modern times" demanded that Bavarians "no longer simply accept the

[62] Oskar von Miller, *Die Wasserkräfte am Nordabhange der Alpen* (Berlin 1903), 1-4.

mighty natural force of water as it manifests itself, rather that we track its origins and follow its development in order to gain the knowledge to create a point of departure for all undertakings aimed at the utilization or battling (*Bekämpfung*) of water's power."[63] Over the course of the twentieth century, as the water power question became the most important water management question in Alpine lands, the shaping of the Alpine energy landscape called for and became ever more dependent on hydrological data.

Miller's work highlighted a problem that he and his colleagues were having in trying to convert the rivers of the Alps into the millions of horsepower they imagined: the flows of this energy were not constant. The amount of horsepower available in the waterways of the northern Alps fluctuated along with seasonal streamflows. The summer melt meant increased potential power in the mountains; winters were the opposite. Anyone trying to quantify Alpine water power (or construct a hydropower plant) had to choose a stream level as a baseline for their projections. Early on, most chose to make low flow the baseline. This was certainly the safest option. Miller, however, was convinced such calculations were too conservative, and preferred to base his water power reckoning on the so-called "median water volume", or the amount of water that is available for at least nine months or 270 days. What to outsiders might have appeared to be the dry details of an opaque professional dispute, was in fact a critical problem that would have important consequences for the future of Alpine water. Indeed it would soon become one of the most important issues for Miller's Bavarian homeland.

Conclusion

One of the most significant technological innovations in the waning years of the nineteenth century was the emergence of electric power systems in the industrial world. The

[63] Bayern, Hydrotechnisches Büro, *Jahrbuch des K. Bayer. Hydrotechnisches Burös, Abteilung der Obersten Baubehörde im K. Staatsministerium des Innern* (Munich: Wolf, 1899), 1: foreword.

rural, rustic Alps quickly became one of the most electrified landscapes in Europe, and the globe. Europeans first harnessed cheap Alpine water power to brighten the night with electric illumination. As electrical technology developed, Alpine water power was applied toward new industrial ends such as the production of aluminum. The ability of electricity to transmit power held the key to solving an age-old problem with natural flows of energy like water power: getting it in the right place. The problem of getting Alpine water power into the centers of consumption became one major impetus for the innovations in electrical engineering responsible for permitting long-distance power transmission. The advent of long-distance transmission encouraged the harnessing of greater power than ever before, and networks to distribute this power overland spread far and wide.

By 1900, the Alpine hydroelectric landscape had assumed substantial proportions. In Switzerland, almost 150 different hydroelectric plants were producing nearly 150,000 horsepower at the turn of the twentieth century. The majority of these facilities were small operations, as only one-third had a capacity greater than 500 kilowatts.[64] In the Austrian half of the Habsburg Monarchy, the fin-de-siècle period witnessed the construction of six large hydroelectric plants.[65] Perhaps the busiest of all countries in matters of Alpine energy was Italy. Twenty years after the construction of Italy's first hydroelectric plant in 1885, the country was Europe's leading producer of hydropower, with the majority of this energy coming from its Alpine watercourses. Nowhere was this power more important, as it underwrote Italy's rise to the status of a European power.[66]

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[64] Walter Wyssling, *Entwicklung*, 151-152; .
[65] BayHStAM MF 67744: Cassimir, *Vorträge*, 22.
[66] See the discussion of Italian hydroelectric development in James Sievert, *The Origins of Nature Conservation in Italy* (Bern: Peter Lang, 2000), 86-90. Cf. McNeill, *Something New*, 174-176.

At this point in time, people like Oskar von Miller envisioned the future evolution of the Alpine energy landscape as a simple continuation of previous trends. But the year 1900 marked an important turning point in hydroelectric development. Before 1900, Europeans had taken advantage of the Alpine environment to tap into continuous flows of energy. After 1900 they exploited mountain nature in order to store white coal.

CHAPTER THREE

POOLS OF POWER

Figure 2. Bavaria's Walchenseewerk, Deutsches Museum Archive

According to an old legend, the depths of the Bavarian lake Walchensee are prowled by a giant monster with the ability to unleash frightful power. Located some 100 kilometers to the south of Munich, the Walchensee is one of Bavaria's many beautiful mountain lakes. Surrounded on all sides by the limestone peaks of the Kochel mountains—the last northern outliers of the eastern Alp—the lake sits perched two hundred meters above the hilly pre-Alps, held back only by a kilometer-thick wall of rock known as the Kesselberg. As the old legend has it, should the wickedness and sinfulness of the capital city increase to an unbearable level, the monster would smash through the Kesselberg with its giant tail, draining the lake and sending a flood surge devastating all of the towns of the Loisach and Isar valleys below—including the immoral capital. This nightmare preoccupied not a few of Munich's inhabitants. Up until the year 1783, a mass held in hope of averting such a disaster was given every three days in the city.[1] On a still winter afternoon in 1924, a host of high-ranking Bavarian politicians and engineers purposely brought about what the populace had previously feared for so long, albeit in a more controlled manner.

In January of that year, the Bavarian state began operation of the Walchenseewerk, a gigantic hydropower plant that utilized the lake as a high-pressure power reservoir. Henceforth, water from the nearby upper Isar river would be diverted from its normal course into the Walchensee, where it would flow through its rock barrier and plunge toward the plains below—within the confines of a tunnel and several large penstocks. The force of this water would not lay waste to the valleys below, but generate electrical current destined for all corners of the state. The energy produced by the Walchensee had been given a special task in Bavaria's electricity supply. The power of the lake was to be fed into the Bayernwerk—a high-voltage electricity grid constructed to make the Walchensee's unique power available throughout Bavaria. To take advantage of the Walchensee's ability to store water power, Bavarians had thoroughly rearranged the region's hydrology.

The Walchenseewerk was hardly unique. From the 1890s until the 1930s, dozens of Alpine lakes were transformed into vessels for storing water power. Until the larger dam-projects of the mid-1920s, many of these lakes were components of the most important power facilities in their respective countries. In France, in addition to the Lac du Crozet, the high-Alpine lakes Lac de Caillaouas and Lac de la Girotte in Savoy, all underwent extensive regulations to improve the efficiency of existing waterpower plants.[2] The Brusio power plants in southern Switzerland harnessed the storage power of a handful of lakes to generate 50,000

[1]Falter, "Achtzig Jahre," 66.
[2] K. Oberste Baubehörde, *Die Wasserkräfte Bayerns*, 119-121.

horsepower of electricity as of 1910—a very substantial amount for this time period. Much of this energy provided traction for two Swiss railways. About 20,000 kilowatts were reserved for export to the thriving cotton industry to the north of Milan.[3] Directly to the southeast in Italy, a high-pressure work connected to the Lago d'Arno in the Adamello range exploited two stages of around 1400 meters to generate 20,000 horsepower. The Adamello Works also fed their power to Milan and its surroundings. In Austria, the state's highest capacity electric utility until the postwar period came online in 1927, and harnessed the waters of the Achensee. The Achenseewerk provided power for the Austrian Federal Railways and exported a sizeable amount of electricity to neighboring Germany.[4] This chapter explores the motivations behind the movement to use Alpine lakes as reservoirs and looks at the case of the Walchensee in greater depth.

The Mood of the Water

The significance of lakes for the energy supply emerged as the engineering community came to the consensus that the future development of the Alpine energy landscape rested on the ability to find ways to store water. They viewed storage as the best way to solve the primary problems with hydroelectric power, all of which stemmed from the basic reality that electricity is extremely difficult to store. This fact proved a particular challenge to those interested in using water power to supply electricity at a time before the existence of expansive, interregional electricity grids fed by a mix of energy sources. For Europeans had very little control over the availability of water power. It flowed more or less steadily both day and night, heedless of changes in demand. It fluctuated according to season, and sometimes came in quantities either

[3] "Das Wasserkraft-Elektrizitätswerk Robbia der Kraftwerke Brusio," *Zeitschrift des Vereines deutscher Ingenieure* 54, no. 50 (10 December 1910): 2115.
[4] Ludwig Mühlhofer and Carl Reindl, *Das Achenseekraftwerk der Tiroler Wasserkraftwerke AG* (Munich: Wasserkraft und Wasserwirtschaft, 1928).

too large (flood) or too small (drought). These natural characteristics of flowing water provoked a litany of complaints about hydroelectric energy wherever it was employed. Under these circumstances, lakes appeared as ready-made reservoirs.

Hydroelectricity, for all of its advantages discussed in the previous chapter, was in many respects a less than ideal energy source for twentieth-century Europeans. Many of its perceived negative characteristics began and ended with the fact that electricity was (and still is) nearly impossible to store, especially on a large scale. Although batteries that could store sizeable charges had already been developed by the late nineteenth century, these operated inefficiently and were prohibitively expensive. For the most part, electricity must be used in the instant it is generated, or it will be lost to the ages.

This fact was a particular problem for the development of water power at the time. The flow of coal into a boiler lay more or less under the control of a plant operator. This was not the case with water power. While a relatively constant amount of water cascaded down the slopes of the Alps each year, discharge varied greatly according to season. During the winter, Alpine watercourses ran low as a large portion of precipitation remained motionless as snow and ice. Beginning with the spring melt, streams swelled. During the drier period in the late summer, flows could once again dwindle.

The "inconstancy" of water power, as many at the time referred to the seasonal fluctuations in streamflow, and its impacts on hydropower exploitation became a topic of debate among hydraulic and electrical engineers around the turn of the twentieth century. One of the most intense disputes centered on a critical matter that confronted engineers at the very outset of hydropower planning. As Oskar von Miller discussed in (see chapter 3) his consideration of the water power on the north slope of the Alps, fluctuating water levels—and therefore power –

prompted the question at what capacity should one design and equip a hydropower plant? The answer to this fundamental question determined the scale of the hydraulic intervention and the amount of electrical equipment, quantities which proved difficult to alter once chosen. Should one opt to exploit a watercourse's low flow, the amount available year round? This would help ensure that the plant rarely experienced power shortfalls. But it also meant allowing any additional water throughout the year to flow to the sea unutilized. Miller advocated exploiting a considerably larger portion of streamflow, fully aware that some electrical equipment might be forced to sit idle at times. Of course, the precondition for this decision making was precise knowledge of hydrological regimes, and this was almost universally lacking. In the United States, the practice at the time was to design a hydroplant to utilize the lowest available amount that had been observed in a recent period of time, typically ten years.[5]

Artur Budau, a professor at the technical university in Vienna, detailed how the inconstancy of water power challenged the profitability of hydropower plants, making it a less suitable energy source than coal. Professor Budau noted that a heap of coal in his courtyard provided the "lord of the factory" (*Fabriksherr*) with the assurance of energy for months. By contrast, the prime mover water had the disagreeable characteristic that its presence varied greatly. Receiving permission to impound water was difficult, because this often injured the claims of other riparian owners. "Here the lord of the factory is dependent on the mood of the water. The temporary surplus that accompanies the flood is completely worthless for him. The times of water shortage, on the other hand, are oppressively felt. It is mainly this circumstance that so unfavorably influences the profitability of water power plants today, as one usually builds his facility for that water volume which is safely available the whole year through. The potential

[5] K. Oberste Baubehörde, *Die Wasserkräfte Bayerns*, 18.

bonus is foregone, since one would have no means to dispose of it."[6] Although Budau did not mention it, the timing of Alpine floods was also problematic from an energy standpoint. At the turn of the twentieth century, when loads for illumination predominated, the demand for electricity was greatest precisely during the time of year when Alpine water power was least available. As days became shorter and light more necessary, Alpine rivers ran at their lowest levels.

To be sure, there were perfectly reasonable measures available to hydropower plant operators to ameliorate these problems. One of the most obvious was to have auxiliary thermal power available to make up for any shortfalls. While many complained about the expense of keeping such equipment on hand, no less an authority than Oskar von Miller dismissed this viewpoint out of hand: "Steam reserves are not so terrible, as the lay person often assumes, rather it is a good thing that we have the ability in our age to procure such extraordinarily cheap steam reserves—namely through steam turbines—because that makes it possible to exploit the mean flow and let the steam auxiliary run for short time."[7] Still, even Miller could not deny that retaining underutilized steam engines negatively affected a hydroplant's bottom line. When addressed to those who sought to completely substitute water power for coal, however, arguments like Miller's about the harmlessness of steam reserves fell on deaf ears.

The inconstancy of human demands for electricity also stymied efforts to efficiently use available water power. Even in the rural Alps, the rhythms of modern industrial society largely governed the demand for current. One of the greatest fluctuations in energy consumption occurred on a weekly basis, namely the transition from the work week to the weekend. On

[6] Artur Budau, "Über hydraulische Akkumulierungsanlagen bei Kraftwerken," *Zeitschrift des österreichischen Ingenieure- und Architekten Vereines*, no. 11 (13 March 1908): 169.
[7] BayHStAM Landesamt für Wasserwirtschaft, Vorl. Nr. 180: "Niederschrift über di am Samstag, den 19. Januar 1907 im K. Staatsministerium des Innern stattgehabte Besprechung über die Ausnützung der staatlichen Wasserkräfte," 30.

weekends, demand for electricity tended to drop as factories and workplaces closed. To keep from laying their plants correspondingly still, cagey plant operators sought to balance the load by finding customers who required weekend electricity. One of the most peculiarly Alpine of these clients were churches, who installed electric heaters. In Switzerland, at least, the presence of electric heat in churches was quite widespread. The pioneering place of worship was most likely Linthal, which began warming its pious with electric heat in 1904.[8]

Inconstant flows of water, and inconstant patterns of demand were both intractable problems for hydroplant operators. One potential resolution to both issues that was never discussed was the possibility of adapting energy use to reflect the availability of white coal. Indeed, seasonal adaptations like these had been the rule for much of human history. For 10,000 years, farmers had adjusted the rhythms of their work years and days to the unsteady rhythms of energy delivered by the sun. It is conceivable that Europeans might have attempted adjusting their societies to more closely match the flows of available power. Conceivable indeed, but very improbable in a world where fossil fuels like coal offered almost complete independence of earlier geographic and seasonal restrictions on energy use. By the late nineteenth century, Europeans had grown accustomed to the convenience of coal. What had been practical for farmers proved less so for factory owners and workers. Instead of adapting their lifestyles, Europeans resolved to adapt the environment of the Alps to fit their needs.

If storing electricity was an impossibility, storing water power was not. The Alpine environment provided plentiful opportunities to store water, none more attractive than the region's many lakes. In some respects, the exploitation of water power had benefitted from the storage capabilities of lakes from the outset. Indeed, lakes regulate downstream flows quite independently of any human interventions, improving conditions for water power exploitation.

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[8] Wyssling, *Entwicklung*, 509.

Many Alpine lakes had also undergone extensive rectifications during the nineteenth century, bringing control of their water levels increasingly under human control. Thus many of the earliest large run-of-river hydroelectric plants were located in the downstream vicinity of some of the larger Alpine finger lakes such as Geneva, Constance, and Como. In the 1890s, some pioneering engineers even anticipated future developments by converting small, high-altitude Alpine lakes into reservoirs of high-pressure water power. Aristide Bergès, for example, equipped his paper mill at Lancey with a high-pressure reservoir in the form of the Lac du Crozet.

But the trend that began at the turn of the twentieth century went much further. At this time, engineers advocated greater hydrological modifications of lakes in order to convert them into larger and more effective reservoirs. In many cases, this entailed measures to substantially increase a natural lake's storage capacity by damming its previous outlet, and expanding its catchment area through diversions. The most valuable energy resources proved to be higher-lying lakes most frequently found in the region's interior. Engineers quickly recognized that with a few modifications, such lakes could be converted into basins of high-pressure water power. This meant that relatively small amounts of water, drained from the lake and utilized to generate electricity, could create considerable power. Unlike the earliest hydroelectric plants in the Alps, these high-pressure plants could utilize water only when needed and allow surplus to accumulate the rest of the time. By storing water in existing basins, moreover, the disruptions to water use rights caused by other types of reservoirs could be avoided. For comparatively little cost then, engineers could turn Alpine lakes into the type of dams that would have required substantial outlays anywhere else.[9] Engineers began to scour the mountains for lakes that rested near precipitous falls.

Equipping hydropower plants with storage capabilities, many argued, would negate the problems emanating from fluctuating water levels in Alpine rivers, allowing for more rational energy exploitation. Professor Budau at Vienna couched the function of reservoirs in terms of making water power a more perfect substitute for coal, and thus a critical means for maintaining European *Kultur*. "What will become of us in Europe," he asked "when our coal supplies are exhausted? Then our industries—such as the blossoming iron industry, the chemical industry etc., the innumerable machine factories—will disappear and plant themselves in those parts of the earth whose coal supplies are still unaffected." For this reason, he stated the mantra "'spare the coal' should hover before (*vorschweben*) all those who care about our culture. For the time being, the best means for this is probably a sound exploitation of water power, namely the connection of the same with storage facilities (*Akkumulierungsanlagen*)."[10]

The energy importance of lake reservoirs ensured that they played an important role in one of the most significant moments in the history of electrification. A crucial juncture in the development of the electricity grids we recognize today, was the advent of interconnection—the linking of two different electric power stations. Electrical engineers in the Alps rapidly recognized the advantages to be gained by connecting high-pressure lake power plants with hydropower stations with no access to reservoirs. This created a kind of virtual storage that allowed the benefits of Alpine lakes to be spread around. The idea to interconnect the power of lakes and streams originated at the Swiss company *Motor AG*, which first constructed a 65-

[9] Oskar Vas, ed., *Grundlagen und Entwicklung der Energiewirtschaft Österreichs: Offizieller Bericht des österreichischen Nationalkomitees der Weltkraftkonferenz* (Vienna: Julius Springer, 1930), 21.
[10] Budau, "Über hydraulische Akkumulierungsanlagen," 190. Budau, like many German-speakers, thought in terms of European "culture" rather than "civilization", a term they deemed too closely related to French revolutionary ideals.

kilometer link between a power station on Lake Biel and one on the Kander River near Spiez in 1903. Five years later, *Motor* completed a much larger interconnection of the Beznau hydroplant on the Aare River with the Löntsch Works, the largest lake turned power reservoir in Switzerland on the Klöntalersee.[11] The 75-kilometer high-voltage link between the two plants enabled the constantly running power of Aare to be almost completely harnessed—the type of rational exploitation sought by Professor Budau.

Despite claims that lakes were natural basins ready to be exploited, turning Alpine lakes into hydroelectric reservoirs was not a simple proposition. In fact, this conversion literally required moving mountains and bending rivers. Generally, three environmental modifications needed to occur before a mountain lake could become a high-capacity hydroelectric reservoir. The first piece of engineering entailed the moving of mountains to create a concentrated fall from the lake to the powerhouse. The solution which found widespread application was to drill a tunnel from a point on the lake's floor through the mountain wall holding the lake back from a valley below. There, on the other side, a surge chamber was usually constructed to mitigate momentary changes in water pressure. From this point, water was fed into one or more iron pipes—or less commonly into an underground shaft—to the turbines below. In effect, this method created a new outflow for the lake. Drilling through mountainsides, moreover, created a much more concentrated fall, and therefore increased the amount of power that could be generated.

It was the bending of rivers into the new reservoir that carried with it the most extensive environmental alterations. Alpine lakes represented excellent storage opportunities but left something to be desired in the amount of water they held. By their nature, high-Alpine lakes

[11] Patrick Kupper and Tobias Wildi, *Motor-Columbus: From 1895 to 2006* (Baden-Dätwill: buag, 2006), 4-5; Wyssling, *Entwicklung*, 313.

drained relatively small areas and thus received precious little recharge. Any power plant that processed more water than annually flowed into the lake would drain the lake over time. For remote lakes with few recreational uses this was not necessarily a problem. However, many Alpine lakes were inhabited or served as popular tourist destinations. In both cases, there would be resistance to the permanent lowering of lake levels. To avoid such problems, and in the interests of maximum power output, engineers sought to divert watercourses into these new reservoirs where they could. This often involved the rerouting of torrents from neighboring valleys, again by drilling tunnels through the mountains separating them. At lower altitudes it could also mean the diversion of larger rivers. Finally, to insure that all of the additional water routed to a lake remained there, that lake's previous drainage point had to be blocked off. How this was achieved also depended on the type of lake in question. Usually this meant damming a smaller stream that had earlier drained the lake.

Hydroelectricity Gaining Traction

Inconstancy of water was not the sole problem that concerned engineers pondering the development of Alpine hydropower. How to use white coal to provide electric traction for main gauge railroads also emerged as a hotly debated subject. The primary motivation for this examination emanated from Alpine state governments, who saw traction as a means of putting public resources to work for the public good, as well as an opportunity to improve their countries' balance sheets at the expense of coal suppliers.

For almost as long as rail travel has existed, there have been efforts to move trains using electricity. In fact, some of the earliest applications of electric motors were used in this attempt. In 1839, Robert Davidson used an onboard battery to move a five-ton locomotive at a speed of 6 ½ kilometers per hour along a flat stretch of the Glasgow-Edinburgh line using electric current from a battery. Forty years later at a Berlin exhibition, Georg von Siemens powered a street car with electricity delivered to it from a cable set up near the track. In the wake of this demonstration, the 1880s saw the rapid expansion of electric tramways and narrow-gauge railways. Electric traction quickly proved superior to steam locomotives not only on streetcar lines, but also on suburban passenger trains with heavy traffic. Subways only became possible with the advent of electric traction. Especially in the United States, the so-called interurban lines connecting cities proliferated.[12] In the Alps, narrow-gauge mountain railways also found widespread use. The success of these enterprises encouraged further experimentation with introducing electric traction on main lines. The electrification of the Burgdorf-Thun railroad in Switzerland using water power in 1898 gave hope to those who sought to apply white coal to this end. These hopes were improved in 1902 when previously steam-driven rail travel was switched to water power just across the Swiss border in Italy around lakes Lugano and Como north of Milan.[13]

Endeavors toward electrification entered a new stage when at the outset of the twentieth century states began seriously to consider introducing electric traction on mainline public roads. The Alps were one center of this activity (another was Scandinavia), thanks to the widespread desire to use hydro to power state railways. The first formal attempt came in 1904 with the establishment of the Swiss Study Commission for the Electric Operation of the Railways (*Schweizerische Studienkommission für elektrischen Bahnbetrieb*). This commission was composed of members of the Swiss Electrical Engineering Association, the Swiss Federal

[12] For a discussion of interurbans see David E. Nye, *Electrifying America: Social Meanings of a New Technology, 1880-1940* (Cambridge: MIT Press, 1990), 119-122.
[13] Emil Huber-Stockar, *Elektrifizierung der Schweizerischen Bundesbahnen bis Ende 1928. Neujahrsblatt der Naturforschenden Gesellschaft in Zürich auf das Jahr 1929* (Zurich: Beer, 1929), 8.

Railways, and the country's Railroad Office.[14] In Bavaria, the state's engagement with alternative power for its trains began when its transport minister asked Oskar von Miller to study the possibility of electrifying several routes that ran along the Alps in the southern portion of the kingdom.[15] Across the border in Austria, the imperial government commissioned a Water Power Cadastre in 1906. While the cadastre was to catalogue all potential water power sites, one of its explicit goals was to determine whether hydroelectricity could be used to power any of Austria's Alpine railroads. That same year an Italian law stipulated that by 1911, 320 kilometers of rail had to be electrified, with the energy supplied almost completely from water power.[16]

Electrifying the mainline railways in the Alps could be justified on several counts. Technologically, electric traction offered advantages over steam, some that were particularly significant in mountainous areas like the Alps. One advantage of electric traction in regions with steep gradients was that it enabled downhill-traveling trains to generate electricity which could then directly be used to power the train uphill.[17] In reference to the electrified Arlberg line in western Austria, a brochure from the state's federal railways explained: "The principle advantages of electric traction over steam-power are known to be the increased efficiency and utility of the electric locomotives, the absence of any necessity of carrying coal and water and therefore of stations for loading such, the possibility to increase the profitable load carried by the train, increased speed and shortening of intervals, escape from smoke and soot, reduction of expenditure for administration and upkeep."[18] Elimination of the "plague of smoke" was frequently cited as a benefit of electric traction.[19] Doing so on scenic mountain railways like the

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[14] Huber-Stockar, *Elektrifizierung*, 9.
[15] BayHStAM VARCH 8691: Letter Oskar von Miller to Frauendorfer (6 November 1903).
[16] K. Oberste Baubehörde, *Die Wasserkräfte Bayerns*, 111, 144.
[17] Miller, *Die Naturkräfte*, 6.
[18] Austrian Federal Railways, *Over the Arlberg by Electricity. On the Occasion of the Opening of the Electric Traffic on the Line Innsbruck-Bludenz in Spring 1925* (Vienna: Christoph Reisser, 1925), 15-16.
[19] BayHStAM MF 67742: Attachment to "Bericht der Generaldirektion," (12 October 1905), 1.

Arlberg "that traverse such beautiful and fascinating regions was particularly important, seeing that in the numerous long tunnels the heavy smoke from the steam engine was most annoying to travelers."[20]

But the greatest motivation to conserve coal was the hope on the part of states for an improvement in both their immediate financial situation and their long-term economic security. As the secretary of the Swiss exploratory commission emphasized: "The main importance for Switzerland lies much more on the economic side, in the application of its water power instead of coal imports from abroad."[21] At the time, railroads were one of the primary consumers of coal and Alpine states made considerable outlays to procure the fuel. The expense by itself might have been bearable, but many state governments—and military officials—bristled that their transportation networks operated at the mercy of coal suppliers. Worries about dependence on syndicates abounded, whether or not the coal came from abroad. One German economist, for instance, called the cartelization of the German coal industry "the sword of Damocles hanging over our economic life" and lamented that "the price politics of the coal syndicate drives the coal prices ever higher."[22] Other Alpine districts in countries without coal stocks experienced perhaps even more acute pressures, and the desire for economic independence from coal imports would increase dramatically after the First World War's disruptions to fossil fuel supplies and the generalized coal crisis they unleashed.

The first order of business for groups systematically studying the question of using water power to provide electric traction was to determine the nature of railway energy

[20] Austrian Federal Railways, *Over the Arlberg*, 15-16.
[21] Walter Wyssling, ed., "Der Kraftbedarf für elektrischen Bahnbetrieb," Vol. 1 *Mitteilungen der Schweizerischen Studienkommission für elektrischen Betrieb* (Zurich: Rascher & Cie.), 1.
[22] C. Hartl, *Bayern auf dem Weg zum Industriestaat: Eine vergleichende volkswirtschaftliche Studie über die Ausnützung der bayer. Wassekräfte, sowie über Staats- und Privatbetrieb in den Industrien der schwarzen und der weißen Kohle. Zugleich ein Beitrag zur Kartellfrage* (Munich: Max Steinebach, 1911), 38.

requirements. They quickly realized that using water power to provide electric traction for mainline railways was a more difficult proposition than previous pursuits. The problem lay primarily in the unique daily pattern of energy demand for main gauge railways, which differed considerably from other types of loads. The typical daily demand for electricity around 1900 was driven by the need for illumination. Portrayed graphically, this curve hovered at a low point throughout the early morning hours, rose slightly as the workday began, and then returned to the minimum until the early evening. At this point, the demand rapidly reached a peak that lasted several hours before descending Mainline railways posted a much different curve. During the day, with myriad trains stopping and starting continuously, the demand for energy oscillated constantly between minimum and maximum demand. With a series of jagged peaks, its energy curve looked in some ways like a stylized representation of the Alps themselves. As with the mountains, the spikes in energy use for trains could also reach tremendous heights. The Swiss study commission calculated that hydropower plants would have to be able to handle "formidable fluctuations" in demand, with maxima up to five or ten times greater than the average load.[23] Water power, as it had been harnessed up until this point, was not capable of cost-effectively meeting these spikes in demand.

Storing high-pressure water power in lakes also emerged as the preferred solution to the problem of using white coal to power trains. When train traffic ceased during the nighttime hours, water could be stored in a lake until it was needed in the daytime. Governments across the Alps deduced that exploiting the power of lakes would be critical for the success of any electrification projects. The Swiss commission charged with studying waterpower for electric traction concluded: "Only such waterpower can be considered that is permitted by accumulation

[23] Wyssling, "Der Kraftbedarf," 22.

in lakes."[24] The Commission advocated that some of Switzerland's most promising lake-reservoirs "that due to their nature are especially suitable for electric traction, must be cautiously set aside and safeguarded for their timely use." Other states followed this lead.[25] State governments wanted to ensure that these singular power sources did not fall into the hands of private entrepreneurs.

The Walchenseewerk

None of these lake plants, however, attained the significance for their societies as the conversion of Lake Walchensee did for Bavaria. Up until the turn of the twentieth century, Bavaria's Lake Walchensee led a relatively undistinguished existence. Linguists believe the lake takes its name from *Wälsche*, denoting a Ladin (Rhaeto-Romanic dialect) speaking population that inhabited the lake's shores for some seven hundred years, from the sixth to the thirteenth century CE. The lake remained relatively undeveloped until the nineteenth century. Until that time, only a nearby monastery used its waters to breed fish. In the same year that Columbus made landfall in the Americas, the first road leading up to the Walchensee was constructed as part of a shortcut on the route between Munich and Innsbruck. Though this road was continually expanded and improved, it remained the main transportation development in the area until the close of the nineteenth century, when the lake was integrated into Germany's burgeoning networks of railways. In 1898, the initiation of regular train service to Kochel—the town just below Lake Walchensee to the north and situated plausibly enough on Lake Kochelsee—improved access to Lake Walchensee. With the trains came tourists and nature enthusiasts, drawn by the lake's fjord-like qualities and stunning color. Artists were especially attracted to the landscapes of the area. The expressionist painter Franz Marc had a house in Kochel, and

[24] Wyssling, "Der Kraftbedarf," 23.
[25] Wyssling, "Der Kraftbedarf," 24.

painted the Walchensee and its surroundings. In 1918 the impressionist Lovis Corinth moved to the shores of the Walchensee and produced a series of portraits of the lake.[26] By the turn of the twentieth century, Lake Walchensee was home to several small towns and villas. Most locals earned their living either in the tourist industry, or in the fishing or timber trades.

The idea to convert the lake into high-pressure power reservoir first emerged in the summer of 1904. In July of that year, the Upper Bavarian district government received a request for a concession to build a hydroelectric power station on the shores of Lake Kochelsee. The author of the request was Rudolf Schmick, a hydraulic engineer from the south German state of Hesse who had spent considerable time siting waterpower plants in Switzerland. According to the project's designs, the power plant in Kochel would utilize the higher-lying Lake Walchensee as a power reservoir, generating a constant 20,000 horsepower of electrical energy. Later, if there was demand for additional power, Schmick's plan provisioned for the construction of an additional hydroplant on the shores of the Walchensee. The energy was to be sold for industrial and lighting purposes to consumers in the plant's immediate vicinity.

Making a power reservoir out of the Walchensee required substantial environmental modifications. In the first place, it was necessary to modify the lake's outflow so that it led to the turbines in Kochel. At the time the Walchensee did not flow into the Kochelsee. Rather water from the Walchensee was carried via a small creek called the Jachen into the Isar River. Schmick's plan created a new outlet for the Walchensee by drilling a tunnel from the lake floor through the kilometer-thick Kesselberg that separated it from the lower lake. At the end of this tunnel, Walchensee water would collect in a surge tank located on the slope above Kochel, and then plunge inside several penstocks to the turbines in the powerhouse below. Further adjustments were required to enable the Walchensee to accumulate water. Schmick's project

[26] Falter, "Achtzig Jahre," 63, 66.

called for the damming of the Walchensee's previous outlet. This step enabled the lake to store the additional water that Schmick sought in order to keep the Walchensee filled close to its prevailing levels and augment the power plant's capacity. Supplementary water was found in the upper stretches of the nearby Isar River. From a weir near the town of Wallgau a portion of the river would be diverted from its bed into the neighboring valley, a basin which led to the Walchensee.

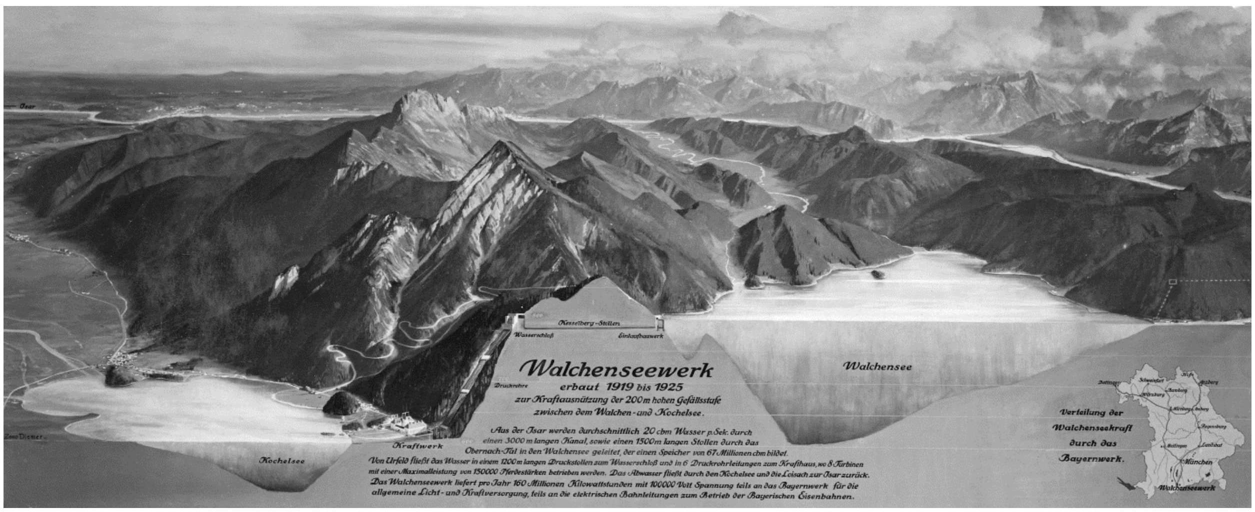

Figure 3. Cross-Section of the Walchenseewerk, Deutsches Museum Archive

The Walchensee's function as a reservoir was dependent on two sets of requirements: those of the lake's inhabitants and those of electricity plant. On the one hand, Schmick's project sought to avoid drastic changes in the lake's level in order to appease locals. One of the driving reasons behind the Isar diversion was to allow generous electricity generation while keeping the Walchensee more or less filled as it was. On the other hand, Schmick envisioned the Kochel plant generating a constant 20,000 horsepower day in and day out. This required that a constant ten cubic meters of water per second flow over the plant's turbines. For the majority of the year, this amount of water was readily available for diversion from the Isar. However, during the winter months, the Isar’s flow often fell too low. Schmick therefore planned to divert an additional portion of the Isar during the summer months, when the river was running at its highest. This supplemental water would be stored in the Walchensee until the winter. This additional water would raise the lake level by about a meter at the end of the summer. Over the course of the colder months, the power plant would slowly drain the lake's level once again. Schmick's project only made moderate use of the storage capacity of the Walchensee.

From the outset, the Bavarian state's reactions to Schmick's project were overwhelmingly enthusiastic. In fact, the only dissenting voices came from local authorities that worried about the plan's considerable environmental impacts. Officials in the Ministry of the Interior, the department that dealt with hydraulic engineering projects, were far more positive. As the head of the Bavarian Supreme Construction Service (*Oberste Baubehörde*) noted in his evaluation of Schmick's project: "from the first glance it is clear that its realization would be of outstanding economic importance –not only for the city of Munich, but the entire land." "When one considers" he continued, "that even the water power of the Lech River of only 12,600 horsepower (not including the 5,000 HP of the Gersthofen power station) make Augsburg an industrial site of the highest rank, the possibility of exploiting 20,000 horsepower from the Isar with the help of the Walchensee opens the prospect of a previously unthinkable industrial development for Munich, in which the broadest circles would share."[27] A colleague at the state's hydrographic service agreed, exclaiming that the project "is so obviously grand, that further words about it are not to be wasted. In all of Bavaria we will probably not find one single site which nature has so favorably created for the exploitation of water power on a grand scale." Above all, he meant that the Walchensee's unique environmental constellation permitted the generation of large amounts of electricity extremely cheaply. The author explained that the cost

[27] BayHStAM MF 67742: "Wasserkraftgewinnung durch Überleitung der Isar in den Walchensee und Erbauung eines Elektrizitätswerk in Kochel," (3 January 1905).

to generate one horsepower for one hour in large coal-fired plants was at least 3 1/2 Marks. In the Kochel plant the same amount of power would cost a half Mark at most. Additionally, the geographic location of the site was also advantageous. The location of the Walchensee made it possible for electricity to be transmitted to the eastern, western, and southern borders of Bavaria, and potentially Munich with ease and with relatively small transmission losses. The director of the hydrographic service was impressed with Schmick's plan and believed it could be carried out as submitted. The bureaucrat also believed it obvious that the Walchensee power should be employed in the service of the Bavarian state railroads.[28]

In other corridors of Bavarian government, the prospect of using Walchensee power for electric railways caused a stir. Bavaria, like other Alpine states, had been considering the problem of substituting water power for coal in train propulsion since the turn of the twentieth century. Powering the state's railways required massive coal imports. In fact, state railroads were one of the largest energy users in the kingdom, burning nearly a quarter of total coal imports in their boilers at a cost of fourteen million marks annually.[29] Since locomotives were dependent on hard coal, the Bavarian railways were largely dependent on the price policies of the Ruhr coal syndicate, to the consternation of Bavarian leaders. Along with improvements in electrical engineering came the realization that the state possessed an energy source which could potentially be substituted for coal. In 1903, Bavaria's first Minister for Transport Affairs inaugurated the state's electrification efforts when he approached Oskar von Miller privately with the request to help study the feasibility of using Bavarian water power to introduce electric traction on the state railways. Miller recommended compiling a list of the available large

[28] BayHStAM Landesamt für Wasserwirtschaft Vorl. Nr. 188: Hensel, "Gutachten des Hydrotechnischen Bureaus," (February 10, 1905).
[29] Fritz Blaich, *Die Energie Politik Bayerns, 1900-1921* (Kallmünz/Opf: Lassleben, 1981), 141.

waterpower sites in the kingdom.[30] A survey completed by the hydrological service found that most of the suitable waterpower was to be found in Bavaria's alpine watercourses. At the time it occurred to neither the hydrologists nor Miller that the Walchensee could be utilized in the manner proposed by Schmick.[31]

Before the state was clear about its own electrification requirements, it hesitated to make a decision on the Walchensee concession. In the months that the state was studying its electrification needs, two occurrences would have a great impact on its policymaking. The first came in the form of a journal article, published by someone with rich experience in matters hydroelectric. One year after Schmick submitted his project, in July 1905, Ludwig Fischer-Reinau, a German engineer living in Switzerland, launched a public campaign that shed light on the enormous potential of Bavaria's hydroelectric power. Fischer-Reinau's first salvo arrived in the form of a journal article published in the trade journal *The German Engineering Times* (*Deutsche Bauzeitung*) entitled "The Water Power of the Bavarian Alps." His essay was so well received in Bavaria that he was invited to give several lectures in the capital of Munich.[32] In both platforms, Fischer-Reinau introduced Bavaria to the energy value of Alpine lakes and their usefulness in introducing electric traction. He did so with soaring rhetoric.

For Fischer-Reinau, the harnessing of the power of mountain lakes was part of an international task of epochal importance. He began his article with the declaration that "the high mountains of the Alps build a mighty frontier rampart (*Grenzwall*) in the heart of Europe, to which the peculiarity and above all the temporal disparity in the development of the intellectual

[30] BayHStaM VARCH 8691: Oskar von Miller to Frauendorfer (6 November 1903).
[31] See BayHStaM Landesamt für Wasserwirtschaft Vorl. Nr. 27: Study by Hydrotechnisches Bureau (5 February 1904).
[32] Ironically, the Bavarian government had rejected an earlier request by Fischer-Reinau for hydrological data on Bavarian Alpine rivers for his article, referring him instead to Oskar von Miller's essay on the water power of the northern slope of the Alps. See the correspondence between Fischer-Reinau and Hensel in BayHStaM Landesamt für Wasserwirtschaft Vorl. Nr. 27. Both the article and lecture were reprinted in L. Fischer-Reinau, *Die Wasserkräfte der bayerischen Alpen* (Munich: Süddeutsche Verlags-Anstalt, 1906).

and economic lives of the peoples who live at its feet should be ascribed." This state of affairs, Fischer-Reinau believed, naturally created a constant "push for equilibrium" between the peoples of the Alps and the surrounding regions. Only in the modern period, with the help of "monstrous sums of technical work and jingling coins," had Europeans succeeded in breaking through the wall from both sides with the construction of Alpine railroads. And even as these works were hailed as feats of modern technology, the drive to build still more continued unabated. Hand in hand with these endeavors to attain new *ways* of modern communication were efforts to achieve new *means* of modern travel. It was this search for new means of transport that, according to Fischer-Reinau, had led "to the recognition of the task, whose resolution stands in equal importance to the opening up of new transport routes: the task of exploiting the water power of the Alps."[33] As it happened, lakes provided the solution to both problems.

Taking advantage of the storage capabilities of high-Alpine lakes simply represented the most rational means of water power exploitation. Step-by-step Fischer-Reinau laid out the logic of using high-altitude lakes as power reservoirs. To start with, he echoed the arguments that high-pressure water power was superior to low-pressure. The Swiss engineer also noted the incongruence in the schedules of water availability and energy demand. Bavarians needed electricity most in the summertime, when demand for traction loads was highest, and in the winter to provide illumination. Alpine waterways, on the other hand, provided power according to a different rhythm. Not including the fluctuations caused by extraordinary precipitation, the ratio between flood and low flow could reach 100 to 1, and sometimes even higher. "Indeed," Fischer-Reinau claimed, "the volume of water is lowest precisely when the demand for energy is highest, in the cold winter months and on dry summer days." For Fischer-Reinau, it was the duty of engineers to effect a "balancing out". "With the incorporation of existing lakes," he

[33] Fischer-Reinau, *Wasserkräfte der bayerischen Alpen*, 3.

continued, "a large portion of Bavaria's Alpine water power will receive effective accumulators that can even out the differences between water flow and consumption through relatively small variations in their water levels." For these reasons, Fischer-Reinau concluded that for high-pressure water power works, the exploitation of available lakes was to be the "unconditional aim".[34]

That this water power should then be used to provide electric traction for the Bavarian state railways was also a simple matter for Fischer-Reinau. Powering trains represented the most difficult task for electric power plants because of the considerable fluctuations in demand. "But," Fischer-Reinau argued, "precisely the hydraulic power of the Bavarian Alps is capable of meeting these challenges, because the incorporation of reservoirs provide never-failing batteries."[35] Using Bavaria's hydropower for traction also made sense because skepticism about the future of electricity still existed. Traction loads represented an already existing market for electric current. In light of this reality, Fischer-Reinau declared that Bavaria's mountain lakes were "a precious gift of a benevolent nature" and admonished his audience to do their part so that they would be used "for the benefit of the people."[36]

Fischer-Reinau's arguments about the calling of Bavaria's Alpine lakes had a dramatic impact on the state's thinking about the Walchensee project. They prompted an immediate internal investigation of the suitability of Bavaria's Alpine lakes as power reservoirs.[37] In October 1905, the Royal Bavarian Railway concluded its study of the feasibility of using Bavarian water power for electric traction. The railway administration that only a year earlier had been searching for conventional, run-of-the-river sites on Bavarian rivers was now singing a

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[34] Fischer-Reinau, *Wasserkräfte der bayerischen Alpen*, 4-5.
[35] Fischer-Reinau, *Wasserkräfte der bayerischen Alpen*, 9.
[36] Fischer-Reinau, *Wasserkräfte der bayerischen Alpen*, 23-24
[37] BayHStAM Landesamt für Wasserwirtschaft Vorl. Nr. 27: Oberste Baubehörde to Hydrotechnisches Bureau (11 July 1906).

different tune. It declared it "obvious" that in all plans to utilize Bavarian hydroelectricity to power the railways that "attention must above all rest on the mountain lakes as natural batteries (*Akkumulatoren*), and it is only a question of special studies to determine in what manner and scope the mountain rivers and lakes can be drawn upon to produce electric energy."[38]

One thing the railway agency was certain about was the importance of the Walchensee. In a special evaluation of the project, it reiterated the importance of electrification for the Bavarian state and the decisive role that the Walchensee had to play in this endeavor. The railway authority explained that conserving coal supplies was one of the most important duties , and believed that posterity would be thankful for sparing these stores of energy and warmth. But, it noted that coal consumption at the present time was anything but economical. The smoke and soot caused by ovens, factories, and locomotives represented only a fraction of the inefficient use of coal supplies. To arrest the wasteful consumption of this precious resource, the report declared, was the "calling" of flowing water. For one thing, flowing water provided a far more energy-efficient medium of transportation than roads or rails. But also the power of flowing water could be harnessed on railroads and canals, and perhaps ever for trackless electric motors. "If any land, then Bavaria—so poor in stocks of mineral coal—has the greatest interest to make use of the energy in its mountain waterways, and place electric power instead of coal, hereby minimizing the very substantial outlays for the purchase of foreign coal and improving both the industrial competitiveness and the financial performance of its railways, which suffer from their significant distance from coal stocks."[39] It concluded that it could not give its approval for a concession to exploit any large water power site in state possession until it was completely clear that the energy was not needed for electric traction. This stance applied

[38] BayHStAM MF 67742: "Bericht der Generaldirektion der K.B. Staatseisenbahnen vom 12. Oktober 1905," 1.
[39] BayHStAM MF 67742: "Bericht der Generaldirektion," 1.

especially to the Walchensee, which the administration believed promised large amounts of particularly cheap electricity. The railway administration declared that the Walchenseewerk must be carried out by the Bavarian state, and in the wake of the railway administration's report, the kingdom's engineers retired to draw up their own project.

The railway administration's evaluation of the Walchensee plan considered not only Schmick's project, but another Walchensee scheme that had emerged shortly after the first project. Beginning in the winter of 1905, a retired Prussian army officer named Fedor Maria von Donat had been giving his own lectures on the Walchensee power, and his ideas were resonating with the public. The major had actually approached the Bavarian government shortly after the submission of Schmick's project with his own plan for a Walchensee power plant. According to Donat, the idea to exploit the Walchensee for energy purposes occurred to him during a sojourn on another Alpine lake, the Achensee, just across the Bavarian border in the Austrian province of Tyrol. In the course of his stay, Donat worked out a plan to utilize the Achensee as a power reservoir that he submitted to the Tyrolean provincial government.[40] While working out the details of this project, Donat noticed the difference in elevation between the nearby Walchensee and Kochelsee on a topographic map, and quickly drew up a similar project. Donat sought to generate power on a scale far greater than Schmick. Indeed, his scheme would produce a minimum of 92,000 constant horsepower, with a temporary maximum output of 150,000. "The result," Donat boasted, "is power exploitation not yet achieved in Europe, or even

[40] See Mühlhofer and Reindl, *Das Achenseekraftwerk*. In 1927, the Achensee began serving as a reservoir for a hydropower plant. Donat had a long history of advocating large-scale engineering projects. In the 1890s, he promoted a scheme to drain the Pontine Marshes in Italy.

on Niagara Falls."[41] Donat suggested the electricity could be used to power Bavaria's state-owned railways.

Donat's scheme was similar to Schmick's, but with several notable differences. Donat, like Schmick, sought to exploit the sizeable difference between the Walchensee and the Kochelsee by tunneling through the mountain separating them. Moreover, Donat had also resolved to divert water from the Isar river basin to increase the capacity of his plant. Donat, however, sought to capture not just a portion of the river's flow, but the entire runoff of the upper Isar basin. To do this, he advocated constructing a dam wall across the Isar Valley. Behind the barrage, a new lake would emerge—the Isarsee as Donat dubbed it. The major also planned to impound the Riss—the upper Isar's largest tributary—within the Isarsee. Despite the state's dismissive stance towards Donat's extreme project, the major persisted in trying to acquire a concession.

To win support for his Isar dam, Donat took his ideas public, where he criticized Schmick's Walchensee project as too cowardly and conservative. The Bavarian press gleefully characterized the disagreement between Donat and Schmick as a "battle for the Isar" (*Kampf um die Isar*). In a broadside entitled "The Power of the Isar", Donat argued that the river's waterpower could solve most of Bavaria's energy problems, from the powering of its railways, to the fixation of nitrogen, to the provision of cheap electricity for the state's artisans. "Generally, we have no idea how inhumanly rich Bavaria is, and that thanks only to the exploitation of the Isar. It is said, that the Isar carries golden sand, and that it is just somewhat costly to fish it out: Here you have the gold in thick—thick—really thick clumps!"[42] Donat further explained the shortcomings of Schmick's plan: "one must always remember that each cubic meter that flows

[41] Fedor Maria von Donat, *Die Kraft der Isar, eine Quelle des Reichtums für Staat und Volk* (Munich: J. Lindauer, 1906), 4.
[42] Donat, *Die Kraft der Isar*, 22.

[unused down the Isar] equals a loss of 2825 horsepower...such a crippling of the glorious waterpower of the Kingdom would be an inexcusable crime against the Bavarian state and commonwealth."[43]

The Bavarian government rejected the idea of damming the upper Isar. State objections were of a primarily technical nature. In early January 1905, the Bavarian state construction authority's evaluation of Donat's Isar dam concluded the plan was "not worth discussion." The report questioned Donat's understanding of the morphology of mountain rivers, stating that while the Major lived in the mountains "he seems not to have acquainted himself with the main characteristic of all mountain watercourses, namely their excessive sediment loads." The high sediment load of the upper Isar, according to the report, meant any dam there would fill up in a relatively short time period. The author of the report noted that Donat had acquainted himself with the publications of Otto Intze, the grand master of German dam-building, but did not consider that Intze's monumental works in Silesia and Westphalia had not been built on waterways with heavy sediment loads. With a noticeable touch of defensiveness, the report declared that if not for the sedimentation problem "then numerous dams for the purpose of water storage would have been built long ago."[44]

While Donat's Isar dam failed to gain support, his activities nevertheless had important impacts on planning for the Walchensee project. The Prussian major's success with the Bavarian public especially encouraged state engineers to increase the dimensions of their Walchensee project. Although they had admired the Schmick project from the start, their final plan far exceeded it in scope and scale. The new conception was expressed in a memorandum entitled *The Waterpower of Bavaria* that was published in October 1907. In it, the Bavarian state

[43] Donat, *Die Kraft der Isar*, 27.
[44] BayHStAM VARCH 10543: Oberste Baubehörde Evaluation (31 January 1905).

outlined its plans to utilize the kingdom's waterpower and revealed the details of its Walchensee project. The memorandum announced that the "moment of waterpower exploitation" had arrived on the world historical stage, and its advent heralded a new chapter in the age-old relationship between humans and water. Although water power was being exploited considerably in Bavaria and elsewhere, existing facilities had been constructed under different circumstances. In recent times, the continual climb of coal prices made the possession of water power resources ever more valuable. The signs of this new perspective were to be found not just in Europe but across the globe. In Egypt, for example, the new economic circumstances necessitated the destruction of the Temples of Philae that were to be drowned behind the first Aswan dam.[45] Accordingly, the state Walchensee project went far beyond the scale of Schmick's project. Seizing on Donat's idea of diverting the additional water of the Riss as well, the state project was slated to produce a maximum of 56,000 horsepower, nearly triple the capacity of Schmick's project. Furthermore, the state planned to make much greater use of the Walchensee's storage capabilities. Over the course of a year, the state project would cause the level of the Walchensee to fluctuate twenty meters.[46]

Even as the state was working out the details of its project, the question of whether the Walchenseewerk could be used to electrify the state railways was thrown into doubt. The German imperial leadership was not nearly as sanguine about the prospects of electric traction. The greatest objections came from Germany's military establishment. For the General Staff especially, railroads were key to the national defense. The principal problem of electrification as they saw it was its effect on German mobilization for war. Electric trains were bound to their transmission wires, and thus would not be able to operate in enemy territory. Furthermore,

[45] K. Oberste Baubehörde, *Die Wasserkräfte Bayerns*, II.
[46] K. Oberste Baubehörde, *Die Wasserkräfte Bayerns*, 501

military leaders worried about electric railways' vulnerability to enemy sabotage. In comparison to steam locomotives that carried their fuel with them, electric trains were dependent on electric generation in central stations, and distribution via high-voltage wires. Both were considered prime targets of enemy disruption. During a series of negotiations with imperial leadership in 1906, the Bavarian government was informed that the General Staff did not object to electrification of its railways under the condition that the Bavarian state held steam locomotives in reserve. Keeping the auxiliary engines would be costly, however, thus negating the fiscal justifications for electrification.[47] The Bavarian government eventually received approval to implement electric traction on rail lines of little strategic value, especially the railroads south of Munich heading into the mountains. If these routes proved their reliability over a several year period, then it would be permissible to electrify a main line, most likely the east-west route from Lake Constance through Munich and terminating in Salzburg.[48] Nevertheless, the military's objections ensured that a much smaller portion of the electricity generated on Kochelsee would be used by the state. The question of what to do with the excess electricity was one that would plague proponents of the project for years to come.

With the release of the memorandum outlining the future of the Walchensee, the first determined resistance to the project also emerged. Opponents seized on the substantial environmental impacts of the project. These fell into three broad categories: the consequences of the Walchenseewerk for the Isar Valley, the influences on the lake itself, and the results for the Loisach Valley, the river that received additional water from the Isar once it had been processed in the power plant. Objection to the project from the inhabitants of the Loisach Valley were

[47] BayHStAM Landesamt für Wasserwirtschaft Vorl. Nr. 27: "Niederschrift über die am Montag, den 5. März 1906 im K. Staatsministerium des Innern stattgehabte Besprechung über die Ausnützung der staatlichen Wasserkräfte," 7
[48] BayHStAM Landesamt für Wasserwirtschaft Vorl. Nr. 27: "Niederschrift über die am Mittwoch, den 31. Oktober 1906 im Staatsministerium des Innern stattgehabte Besprechung über die Ausnützung der staatlichen Wasserkräfte," 22.

relatively few, since most viewed the additional water as an advantage. Although the Loisach required costly regulations to be able to receive the additional water, this was not a reason to reject the project. Resistance to the changes in the Isar Valley and the Walchensee, on the other hand, was intense. The Walchenseewerk necessitated the diversion of considerable amounts of water from the upper Isar Valley. For a stretch of over fifty kilometers, a substantial portion of the Isar would be removed from its bed. From autumn until the spring melt, this section of the river would run completely dry, with disastrous results for local flora and fauna. The removal of this water would also affect livelihoods. While agriculture did not have an important role in this region, the timber rafting trade did. The Isar and its tributaries were the only transport route for the valley's considerable wood resources. In the years before the emergence of the Walchensee plan, an average of 77,000 cubic meters of timber had been floated annually down the Isar to Munich. A study found that any disruption of upper-Isar rafting decreased the price the region's forest owners could gain for their goods.[49]

The river diversion also worried the inhabitants of riparian communities along the upper Isar. Chief among them was the bath town of Tölz. Hotel owners and other participants in the tourist industry declared that a diminishing of the Isar would seriously endanger the town's position as a popular tourist destination. In addition to concerns about the aesthetic impacts to the Isar, townspeople wondered whether the lack of water could lead to hygienic problems. For Tölz, like most river communities, had charged the Isar with removing its wastewater. The diversion also raised questions about the legality of separating settlement from the waterways. As the Bavarian state conservation agency put it "important settlements, that in any event owe their emergence mostly to their respective waterways have a right to the same. One cannot take

[49] BayHStAM Landesamt für Wasserwirtschaft Vorl. Nr. 39: Wasserwirtschaftsrat protocol (28 May 1910), 20.

the Isar from Munich, the Main from Wurzburg, the Rhine from Cologne."[50] Ultimately, the majority of Tölz's residents accepted the importance of the Walchenseewerk and did not challenge the state's right to build it. Their primary concern was to ensure that the town was left an adequate water supply. They demanded a reduction in the amount of Isar water that would be diverted, and insisted that Riss stream be left alone. Thanks to their numbers, their voices were difficult to ignore.

Historians have documented how the Walchenseewerk gave impetus to burgeoning nature conservation movements in Germany. Thus far, scholarly attention has mostly been devoted to the significance of the Walchensee opposition for the institutional history of the German environmental movement. Less interest has been paid to the actual nature that conservationists sought to protect. In the case of the Walchenseewerk, the principal question concerned the value and function of Alpine lakes. Conservationist objections to the project reveal that they were concerned above all with the aesthetic importance of Bavaria's Alpine lakes. One aspect they focused on was the lake's color. Bavarian nature protectors argued that the lake's unique turquoise color would be ruined by sediment carried in the Isar. Their most stringent objection, however, was to the enormous alterations of the lake's level caused by power generation. As the leader of conservationist opposition explained, the state's plan meant the destruction of the Walchensee.

> The Walchensee, a king among the Upper Bavarian lakes, shall be degraded to a reservoir (*Talsperre*), whose ebb and flow will not recur in daily, but only in annual cycles, and therefore will not enable the sorrowful, 16 meter high bare spots, which will be visible for three-quarters of the year, to cover themselves with plants. This would no longer be an intervention but an irresponsible assault against a unique memorial to the Creation.[51]

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[50] BayHStAM VARCH 10547, Landesausschuss für Naturpflege to Königliches Staatsministerium des Innern (21 September 1909).
[51] Schmidt, "Das Schicksal und die Zukunft des Walchensees und der Isar" *Münchner Neueste Nachrichten,* December 5, 1907.

The arguments of conservationists did not persuade most Bavarians of the plan's folly. But for many conservationists, this had not been the point. Most did not reject the idea of Walchensee hydropower out of hand. They simply bristled at the scale of the state's project (and its impacts on the lake especially). But they did succeed in injecting questions about the intrinsic value of nature into a discussion that had primarily revolved around technological and economical considerations. Their protests also helped pull the state back from its plans to execute a larger scale project. First, they gained state assurances that the Walchensee would not be drained any lower than six meters below its current level. Conservationists' critiques of the official state project were also one major reason that in 1907 the Bavarian government decided to hold a contest to elicit new Walchensee ideas. Internal discussions make clear that state officials greeted a public competition as a means of relieving some of the critical pressure it was feeling in response to its published project. The contest, some hoped, would deflect some criticism about the government's "one-sidedness", and perhaps even result in a few useful new ideas. Others anticipated a certain "reassurance" for the state engineers who had drawn up the project, who hoped to have their ideas confirmed by a broad swath of their colleagues. Both the appearance of impartiality and competence would be especially valuable "for a government that must always be concerned about cover."[52] As a nod to the nature protection movement, the contest instructions insisted that all entries appropriately consider the landscape. An international prize jury met in July 1909 to crown the winner. Among the over thirty entrants, the titles of some submissions such as "No Dam," and "Power and Natural Beauty" make clear that the message about nature protection had been received by some. The eventual winner, entitled "Simple and Safe," was a far more modest proposal than the original state project, and

[52] BayHStAM MF 67742: "Niederschrift über die am Samstag, den 19. October 1907 im K. Staatsministerium des Innern stattgehabte Besprechung über die Ausnützung der staatlichen Wasserkräfte," 36-37.

the jury especially appreciated its less intense use of the lake as a reservoir.[53] The state incorporated many of "Simple and Safe's" suggestions into an adapted Walchensee project. From the conclusion of this contest, nature protection ceased to play such an important role in the development of the Walchensee plan.

The controversy over the Walchensee project did not remain circumscribed within Bavarian borders. As with many of the larger hydro-schemes in the transnational mountain range, the project assumed international dimensions as well. For one thing, the diversion of water from the upper Isar into the Walchensee promised to disrupt the timber trade, affecting the forest holdings of both the Grand Duchy of Luxemburg and Austria. The latter country in particular was one of the largest forest owners in the region.[54] Furthermore, a number of the watercourses involved in the various projects belonged to watersheds that extended into the Austrian crownland of Tyrol. Proposed hydraulic modifications to several of these waterways threatened to alter flow conditions on both sides of the border. To incorporate the waters of the Riss, the upper Isar's largest tributary, Major Donat called for impounding the stream with a dam whose reservoir would reach into Austria. Conversely, Austrian plans to make a reservoir out of one of their own lakes, the Achensee menaced Bavaria's designs. In order to increase the capacity of the planned Achenseewerk, Austrian engineers intended to divert several torrents that would have otherwise flowed into the upper Isar basin. News of Achensee project in 1906 set off a panic among Bavarian supporters of the Walchenseewerk, and the Bavarian press announced the breakout of a "water war" between the two allies.

The water war alerted Bavarian government officials for the first time to the precarious nature of much of the state's waterpower, and got them thinking about the relationship between

[53] For records on the competition, see the file BayHStAM VARCH 10545.
[54] BayHStAM MWi 2880: K. Staatsministerium der Finanzen Ministerial Forstabteilung to K. Staatsministerium des K. Hauses und des Äußern (1 October 1917).

international politics and nature. In response to the plans for the Achenseewerk, the Bavarian state hydrological agency undertook a study of the water power in its border rivers, to determine if any domestic hydraulic measures could potentially threaten Austrian plans, and thus strengthen Bavaria's hand in negotiations. The state discovered that it had little leverage in this area, as the headwaters of most of the rivers in southern Bavaria lay in the Austrian Alps.[55] In negotiations with Austria, Bavarian diplomats appealed to conventions of international law that maintained individual states could only claim exclusive rights of disposition over so called "national rivers" that resided completely within national borders. Otherwise, according to international law, no state could alter the natural circumstances that nature itself had created. "An individual state may not treat as special property" explained a German international law text marshaled by the Bavarians, "what nature gave to all states."[56] Austrian diplomats rejected Bavaria's arguments, revealing in a top secret communiqué that not least considerations of the military security of the Austro-Hungarian monarchy required such a stance. According to Austria's foreign minister Graf Aehrenthal, any such concession, "even to such a close friend" as Bavaria, could open the monarchy to political difficulties. Geography had made Austria the upstream power to all of its neighbors with the exception of Switzerland, and a concession to Bavaria might be viewed unfavorably with its remaining neighbors.[57] Here Graf Aehrenthal clearly implied that water might become yet another front in the nationalities conflicts plaguing the Habsburg Monarchy. Eventually, the issue was settled amicably. But these incidents demonstrate the instrumental role that political borders could play in influencing the development of Alpine hydroelectricity.

[55] BayHStAM,Landesamt für Wasserwirtschaft Vorl. Nr. 27: Staatsministerium des Innern to Hydrotechnisches Bureau (9 October 1906); Staatsministerium des Innern to Hydrotechnisches Bureau (10 December 1906).
[56] BayHStAM VARCH 8827: Letter Koenigl. Bayerisches Staatsministerium des Koenigl. Hauses u. des Aeussern (2 April 1908). While formulating their appeal to international law, Bavarian diplomats made inquires of both Prussia and Switzerland to determine whether either state had made similar appeals in reference to international waterways.
[57] BayHStAM MA 93011: Letter K.u.K. Oesterr.-Ungar. Gesandtschaft (19 July 1911).

At this point, after over five years of public debate, the question of the Walchensee began to assume ever more explicit political importance. In early 1912, the Bavarian regent Luitpold declined to reappoint the Liberal prime minister Clemens von Podewils-Dürniz, opting instead for the conservative Catholic Center politician (and future chancellor of Germany) Georg von Hertling. The change marked an important caesura in Bavarian political history, as the monarch broke with a long tradition of supporting Liberal ministers. Luitpold expected Hertling to help circle the wagons against the growing left in Bavaria, and the increasing calls for parliamentarization. There is evidence that the departure of Podewils—who had headed the government since 1903—was related to the Walchensee question. Indeed, this was one of the many inflammatory arguments made in a controversial brochure anonymously published in 1912. Entitled *Down with the Hertling Ministry or an attack on the Bavarian wasp nest*, the pamphlet's author accused the Podewils government of criminally delaying the Walchensee project due to its partiality to private electricity trusts.[58] The author gave the new Hertling government all of eight days to act on the Walchensee issue before launching another attack.

The mystery pamphleteer would be disappointed, for the spring of 1912 marked the apogee of another source of resistance to the Walchensee project. While the lower chamber of the Bavarian diet had thus far readily released the necessary funds for the Walchensee project, the upper chamber had always been stingier. Although the upper chamber counted members like Oskar von Miller who completely supported a state role in developing the Walchensee power, it also housed a contingent far more skeptical of the large project and state involvement in the

[58] Wigulì Kreitmayr II, *Ministerium Hertling Weg oder ein Angriff auf's Bayerische Wespennest. Eine hochpolitische Lektüre aus einer kleinen Zauberstube* (Munich: F. Bosch, 1912). Years later, a leading Bavarian social democrat would also attribute Podewils's dismissal to the mishandling of the Walchensee question, but for the opposite reason: that his support for a public Walchensee Works showed too much affinity for "state socialism." See E. Auer, *Das Bayernwerk und sein Zusammenhang mit dem Walchenseewerke* (Stuttgart: J.H.W. Dietz, [1918?]), 3.

Bavarian economy. This group of patricians, led by Wilhelm von Finck, the founder of the Isar Works, used the debates about the financing of railway electrification and the Walchensee as a platform to undermine the state Walchensee project. In addition to worries about their own private economic interests, their arguments ran the gamut from suspicion of the new technology, worries about state finances, concerns about the role of government in the economy, and fears about environmental consequences. Indeed, many pointed to the extraordinarily dry year of 1911 and wondered how it would have impacted an upper Isar depleted of its water by the Walchensee project. All of these misgivings came to head with the interpellation of Ernst von Moy, who asked the state if it truly believed it could develop and utilize the Walchensee power for electric traction. The interpellation provoked a reconsideration within the Bavarian state about the feasibility of their Walchensee plan.[59] The immediate fallout was an admission that the financial benefits of rail electrification did not look as positive as initially believed.[60] The government resolved to shift responsibility for the project from the transport to the interior ministry. The move received the blessing of the diet in the spring of 1914, but the future of the Walchensee remained very much in doubt.

The advent of the First World War brought a new sense of urgency to the project's supporters. In October 1914, Oskar von Miller volunteered the services of his engineering bureau to the state for the duration of the war, to ensure that the Walchensee project did not fall by the wayside. When the war continued past the autumn of 1914 and it became clear that there was no decision in sight, Miller seized the initiative to harness the power of the Walchensee for a plan he had been developing for several years. In October 1915, Miller submitted a new plan to

[59] On the debates in the upper chamber see Bernhard Löffler, *Die bayerische Kammerder Reichsräte 1848 bis 1918: Grundlagen, Zusammensetzung, Politik* (Munich: C.H. Beck, 1996).
[60] K. Bayerisches Staatsministerium für Verkehrsangelegenheiten, *Bericht über den Stand der der Staatseisenbahnverwaltung vorbehaltenen staatlichen Wasserkräfte* (Munich, C. Wolf & Sohn, 1914).

the Ministry of the Interior to use the Walchenseewerk in a scheme to supply all of Bavaria with electricity. Miller had been considering this possibility since at least 1910, when it was becoming clear that the future of electric traction in Bavaria was in doubt. Now Miller believed that the Walchensee should be used to make electricity cheaper and accessible in all of Bavaria. Miller proposed building a state-wide high-voltage electricity grid—the Bayernwerk—to interconnect existing power plants and consumers. The Bayernwerk would purchase electricity from existing power plants and sell it to electrical utilities for further distribution throughout the kingdom. Miller envisioned the grid being financed by the state, overland stations, municipal utilities, and those firms constructing the grid. Miller argued that the Bayernwerk would lower the costs of generating and transporting electricity. The state, he argued, should be interested in the Bayernwerk because it would be making a "major contribution toward securing significant advantages for nascent industry and agriculture after the war." Miller estimated a combined length of around 1200 kilometers for the high-voltage lines.[61]

The purpose of the Bayernwerk was to interconnect the unique Walchensee power with the rest of the kingdom's electric utilities, and most importantly, its hydroelectric plants. Miller explained: "the remaining public and private waterpower could be substantially better exploited, if their transmission succeeded along with the distribution of the Walchensee power across the entire land, and the steam reserves required to supplement this waterpower could be removed from all these works."[62] According to Miller's calculations, harnessing the Walchensee power through Bayernwerk would allow Bavaria to substitute water power for 130,000,000 kilowatt hours of steam power. Supplying Bavarian electricity with the Bayernwerk would result in a

[61] BayHStAM MF 67746: Oskar von Miller to Staatsministerium des Innern (15 October 1915), 15
[62] BayHStAM MF 67746: Oskar von Miller to Staatsministerium des Innern (15 October 1915), 10

reduction of costs by some 20%, a savings of over four million marks.[63] The Bayernwerk thus allowed the various sources of electrical energy to perform specific new functions. Within its framework, the Walchensee would act as the reserve power for all of the Bayernwerk's utilities, and the remaining water power plants would pick up the base load.

Miller's pitch about the Bayernwerk benefiting Bavarian industrialization was well-received thanks to the changing political climate in Bavaria during the First World War. For decades, some Bavarian observers had worried that their state was being left behind economically by more dynamic regions in Germany, particularly Prussia. But before the First World War, powerful political interests—above all the majority Catholic *Zentrum* (Center) Party were wary of industrialization. They argued this sort of economic growth brought with it debilitating social turmoil. Economic developments during the First World War began to convince even Zentrum politicians that without state intervention, Bavaria would fall irreversibly behind other lands. A sense of bitterness prevailed that the lion's share of the imperial government's economic aid went to heavily industrialized German states while Bavarians shouldered the costs. In fact, Bavarian politicians had also tried to secure subsidies to promote key war industries on Bavarian soil as well. In 1916 the Bavarian state government tried to raise the interest of the War Materials Section (*Kriegsrohstoffabteilung*, or KRA) in harnessing Bavarian waterpower to produce the nitrates so desperately needed for the war effort. The KRA was the central organ created within the War Ministry to control the procurement and distribution of all war-related resources. Ultimately, the KRA decided that the nitrate plants would be built near the lignite mines of east Germany, as the waterpower plants could not be

[63] BayHStAM MF 67746: Oskar von Miller to Staatsministerium des Innern (15 October 1915), 36.

erected quickly enough.[64] This was a severe economic blow, and by 1917, *Zentrum* leaders were calling on the Bavarian state government to support their new policy of "industrial advancement." Their highest priority was swift development of Bavarian waterpower, and thus Miller's Bayernwerk plan. With the weight of the *Zentrum* behind it, Miller's Bayernwerk proposal was passed by the diet in June 1918.[65]

Even after the political upheavals of November 1918, Bavarian politicians remained committed to building the *Bayernwerk*. For one thing, the state's energy situation had become still more acute following the war. Coal was so scarce in Germany that its provisioning was controlled by an imperial coal commission. Furthermore, the conflict had disrupted the provision of coal from both the Ruhr and Bohemia, Bavaria's two largest prewar sources. Under these circumstances, developing Bavarian waterpower seemed a wise policy move in uncertain times. Additionally, the large-scale construction projects were welcomed for the jobs they created in the period of transition. Construction of the Walchenseewerk began shortly after the end of hostilities in December 1918. To expedite the process, the state granted special executive powers to Oskar von Miller in January 1919.[66] Building was hampered by the considerable upheavals that rocked Bavaria and Germany in the postwar period, including revolution and runaway inflation. The latter reached such enormous proportions in 1923, that one Munich satirical magazine quipped that the state was so eager to complete the Walchenseewerk because it needed the electricity to run its money-printing machines.[67] While Miller had originally envisioned both the Walchenseewerk and Bayernwerk as joint public and private ventures, both projects were ultimately financed by state-owned corporations.

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[64] BayHStAM MWi 2880: "Niederschrift über eine Besprechung in der Kriegsrohstoff-Abteilung in Berlin am 29. April 1916."
[65] Blaich, *Die Energiepolitik Bayerns*, 144-146.
[66] BayHStAM MF 67748: Staatsminister des Innern to Oskar von Miller (22 January 1919).
[67] "Vom Tage" *Simplicissimus* 27, Nr. 49 (March 5 1923): 687.

In January 1924, the Walchenseewerk began feeding electricity into the Bayernwerk. The majority of its electricity was not reserved for electric traction, but was spread around the state for the purposes of industry and agriculture. The final dimensions of the facility had also changed from the plans of Donat and Schmick. Prewar opposition to the Walchenseewerk succeeded in limiting both the size of the Isar diversion, and the depth to which the lake could be lowered. However, to enable the Walchenseewerk to provide reserve power for all of the Bayernwerk's utilities, the maximum capacity of the plant had been increased to 124 megawatts. On the occasion of the opening of the power plant, Walchensee power was stepped-up to 100,000 Volts, and transported to the Bavarian industrial center of Nuremberg, 350 kilometers to the north in the Franconian plain. A Bavarian newspaper columnist attempted to capture the significance of the moment. "South Bavarian hydroelectricity has unlocked our north Bavarian, especially Franconian industrial zone as a new, inexhaustible (*unversieglich*) energy source. A fast bond of the commonality (*Gemeinsamkeit*) of Bavarian economic striving therewith wraps itself around Bavaria's land from mountain to valley, from the Alps down to the Main.[68] Thanks to the power of the Walchensee and other Alpine lakes, the reach of the Alps in Europe had just become a little larger.

Conclusion

After the turn of the twentieth century, lakes across the Alps emerged as valuable energy commodities. The difficulties of storing electricity made acute problems out of the inconstancy of white coal and the demands of the humans that sought to put it to work. Engineers found a unique solution to this problem in the form of Alpine lakes. Energy experts saw lakes as extremely valuable power resources. So valuable, indeed, that one French engineer believed

[68] "Walchenseekraft in Nordbayern: Inbetriebsetzung des Walchenseekraftwerks und Bayernwerks," *Bayerische Staatszeitung*, 28 January 1924.

lake-turned-power-reservoirs deserved their own special designation. His suggestion of "blue coal" (*Houille bleu*) failed to catch on but the practice of converting lakes into reservoirs did.[69] All in all, 131 Alpine lakes were converted into reservoirs by the year 1970, with the lion's share falling in the period before 1954. The refitted lakes accounted for 40% of total reservoirs in the Alps. Moreover, they provided a considerable percentage of the total storage capacity throughout the chain. In the Eastern Alps, lakes-turned-reservoirs made up 32%, while in the Western Alps they supplied 16% of the available storage capacity.[70]

In Bavaria, the fate of one such lake became one of the central political and social questions of the state's first few decades of the twentieth century. The Walchensee emerged as the state's most important water energy resource, and subsequently became the focus of intense debates about the state's role in the economy, the proper usage of Bavaria's water power, and the natural value of mountain lakes. The belief that the Walchensee—and its storage capabilities—represented a unique source of power led to the conclusion that it must also be exploited to special ends. Ultimately, Bavarian planners envisioned the Walchensee as the auxiliary power for a state-wide electricity grid whose scale placed their still rural state at the cutting-edge of worldwide electrification.

[69] *Congrès*, 223.
[70] Harald Link, "Bassins d'Accumulation," 251; 253

CHAPTER FOUR

EMERGENCY POWER

The October 1914 issue of the *Zeitschrift für die gesamte Wasserwirtschaft* (*Journal for Total Water Management*) contained a special message for its readers from its editor, Dr. Georg Adam. Adam explained that the "circumstances brought about by the war" had occasioned an agreement between himself and the journal's publisher, according to which the future publishing rights were to be transferred to him. Effective immediately, the organ for a group of some of Germany's most important water management groups—the Water Management Association, the Saxon Water Management-Association for Saxony and Thuringia, the Ruhr Valley Dam Association and the Dam Cooperative of the Upper Ruhr—had moved from Halle on the Saale to Breslau. To assuage any fears that the serial would cease to provide its usual forum for dialogue about important water issues, and reports about developments of interest in water use worldwide, Adam assured his readers that "the journal will be continued unchanged, even if the restrictions in length instituted by the previous publisher due to the war must persist for some time." Two months into the First World War, Adam gave no indication of a cessation in hostilities anytime soon.

According to the editor, the war was not only responsible for changes in the journal's publication. Directly below his message about the administrative changes for the journal, Adam devoted the issue's lead article to a reflection on the value of water power during wartime. At the outset, Adam acknowledged that water power indeed possessed many disadvantages. In contrast to thermal energy—which could be exploited in steam engines and motors—the point of generation for water power could not be shifted as necessary. Water power production was bound to a specific location, and this immobility brought with it certain vulnerabilities in wartime. The greatest problem with water power that Adam saw, however, was the recent trend towards generating water power in large central stations and transporting this energy via electricity to areas of consumption. This system of centralized energy production carried the distinct drawback that the disruption of the generating plant or distribution components meant that all connected facilities would lose power. Targeted hostile action could therefore have devastating consequences for the energy supply. For this reason, Adam argued, it had been necessary to forego the possible peacetime benefits of using water power to electrify railways—as was proposed in Bavaria—as the vulnerability of the rail network during war was simply too great a risk. On the other hand, Adam noted, water power was not alone in being generated in central stations. Fossil fuels were also used in this manner to produce electricity. Thus he concluded that water power generation, especially for traction, carried no greater risk than any other kind of centralized production. Hydro did however possess one substantial advantage over thermal power in Adam's estimation. With water power, he explained "the energy production succeeds continually by natural means, that only in rare cases might be cut off, while thermal energy production is dependent upon the artificial supply of fuel." Coal deliveries could be interrupted, and not necessarily by enemy operations. Adam prophetically observed that the transport demands of a country's own military could thoroughly disrupt the fuel supply. "Here water power facilities attain a superiority that up until now has scarcely been appreciated, that they exploit the continually flowing power of nature uninterrupted by such measures."[1]

Adam was correct in sensing that the new circumstances would change the way that Europeans thought about energy. This was certainly the case with white coal. The First World

[1] Georg Adam, "Der Wert der Wasserkräfte im Kriege," *Zeitschrift für die gesamte Wasserwirtschaft, für Wassertechnik und Wasserrecht: Organ des wasserwirtschaftlichen Verbandes des sächsischen Wasserwirtschafts-Verbandes für Sachsen und Thüringen (E.V.), des Ruhrtalsperrenvereins und der Talsperren-Genossenschaft der oberen Ruhr* 9, Nr. 19/20 (20 October 1914): 271-272.

War disrupted the supply of coal on an unprecedented scale and for unparalleled duration. The war and its aftermath therefore marked an important turning point in the appropriation of Alpine water for energy purposes. In countries where disruptions to the energy supply were most acute—in France, Switzerland, and Italy—the Great War prompted immediate attempts to intensify and expand the use of Alpine waterways. In the case of France, in particular, the wartime witnessed a considerable increase in hydroelectric production in the Alps. The close of the conflict had important consequences for the eastern Alps in particular. For the newly created states of Weimar Germany and Austria, Alpine water power emerged as an important source of alternative energy after the peace settlement greatly upset their previous coal supplies, as we shall see below. This chapter traces this history of how the First World War affected the Alpine It does so by focusing on developments in France and Austria, the two countries that felt the most extreme effects of the war and its aftermath, respectively. The fortunes of battle saw to it that in the case of France it was the onset of war in 1914 that provoked a rush of hydroelectric development, while in Austria it was the onset of peace in 1918.

Historians have begun writing the environmental history of the First World War, but much work remains to be done.[2] This is particularly true of the war in the Alps. Compared to the historiography of the main theaters of war, scholarship on the Alps (or the southwestern front as it's sometimes called) has been relatively sparse. Until very recently, even the academic study of the Alpine front depicted the combat in this region as a holdover from a more traditional era of warfare, where individual abilities and extraordinary physical and mental power still made a difference. The shorthand for these viewpoints resides in the widespread icon of the hardy

[2] One recent attempt is William Kelleher Storey, *The First World War: A Concise Global History* (Lanham: Rowman & Littlefield, 2009).

mountain warrior.[3] Despite this literature's fascination with the mountains, they serve mostly as a backdrop for human heroism. More recent research on the war in the Alps has explored different avenues of inquiry, emphasizing the impacts of the war for civilians, as well the conflict's influence on ideologies and mentalities. Environmental historical analysis, for the most part, has not been one of the new axes of exploration.[4] In tracing some of the most important environmental impacts occasioned by the war, this chapter hopes to contribute to a better understanding of the extent of war in this theater, and the environmental history of war in general.[5]

The Miracle of the Southeast

Writing in the immediate postwar period, the French author L.-J. Arrigon noted that the word "miracle" had often been used in reference to his country's experience during the recent conflict. "Miracle, the marvelous strategic reestablishment of its armies at the Marne; miracle, the amazing defense and inviolability of Verdun, which Europe witnessed under the formidable German assault. Miracle, the reconstitution of its industries, their expansion and adaptation to the war, effected under the menace of the enemy and despite the invasion of its richest *départements*." Arrigon believed that the term deserved to be used once more, to characterize the development "realized at the height of the war, by the French industries of the South-East, Savoy and Dauphiné, which drew from the inexhaustible reserves of white coal the power necessary to operate and achieve the results from 1914 to 1918." Arrigon had become convinced

[3] Hermann J.W. Kuprian and Oswald Überegger, eds., *Der Erste Weltkrieg im Alpenraum. Erfahrung, Deutung, Erinnerung. La Grande Guerra nell'arco alpino. Esperienze e memoria* (Innsbruck: Wagner, 2006), 11.
[4] One exception is Tait Keller, "The Mountains Roar: The Alps and the Great War," *Environmental History* 14 (April 2009): 253-274.
[5] On this theme, see Richard P. Tucker and Edmund Russell, eds., *Natural Enemy, Natural Ally: Towards an Environmental History of Warfare* (Corvallis, Ore., 2004); J.R. McNeill, "Woods and Warfare in World History," *Environmental History* 9 (2004): 388-410; Berthold Meyer, ed., *Umweltzerstörung: Kriegsfolge und Kriegsursache* (Frankfurt, 1992); Charles E. Closman, ed., *War and the Environment: Military Destruction in the Modern Age* (College Station, Tex., 2009).

of the miracle of southeastern industrial development during a visit he made to the region in the early months of 1918. There he witnessed and later described the results of a rapid expansion in all sectors of hydropower usage: electro-metallurgy, electro-chemistry, paper manufacture, and power transmission. Whether or not one agrees with the miracle descriptor, there is no doubting that the Great War prompted a flurry of energy development on waterways throughout the French Alps. This energy would play an important role for French economic production, both during the war and beyond.[6]

The need for a miracle was set up by the first few months of the conflict. In the hopes of swiftly knocking France out of the war, the Germans launched a surprise offensive in August 1914 through neutral Belgium and into northern France. While France managed to stave off defeat at the battle of the Marne, the ensuing crystallization of the Western Front left the country in a dire economic situation. From October 1914 until the end of the war, some three-quarters of the rich seams of the *départements* of Nord and Pas-de-Calais lay either in enemy hands, or within striking distance of its artillery. This had disastrous consequences for French coal production. According to L.-J. Arrigon, before the war France produced on average some 40 million tons of coal annually. At the same time, the country required over 60 million tons to satisfy its domestic and industrial demands. France made up the 22-million ton shortfall through imports, primarily from Great Britain, but also Belgium and Germany. The German invasion made the deficit even greater, removing at a stroke two-thirds of France's annual production.[7] The invasion of the north also resulted in the loss of almost all of this region's metallurgical industries. When added to the losses suffered in the eastern part of the country, French heavy industry had decreased by almost three-quarters. All of this happened precisely at a time when

[6] L.-J. Arrigon, *La Houille Blanche et l'Avenir Industriel du Sud-Est* (Paris: Attinger, 1918), 5, 8-9.
[7] Arrigon, *Houille Blanche,* 7.

France desperately needed to ramp up wartime production to satisfy desperate shortages, particularly of ordinance.

The water power of the French Alps emerged as the country's greatest source of supplementary power.[8] In the decades before the war, the French Alps had been the site of a recent industrial flourishing, based on the exploitation of the region's white coal. The new form of hydraulic energy spurred the growth of the region's paper industry—spearheaded by Aristide Bergès at Lancey. With the advent of hydroelectricity, the nascent electro-metallurgical and electro-chemical industries also established themselves in the Alps. The majority of this development had concentrated itself in the northern French Alps, where the climate, relief and economic conditions had proven more conducive to early hydro exploitation. Within the northern Alps, the main activity took place in the *Sillon alpin*—the large depression between the pre-Alps and the central massifs running roughly from the Arve River to the region around Gap in the south—and the large valleys of the inner Alps. Indeed, in these large interior valleys (those drained by the upper Isère and Arc rivers) white coal supported a density of industry and energy exploitation greater than anywhere else in France, or anywhere in the Alps for that matter.

During the winter of 1914-1915, many of these existing facilities switched to war production to help allay the country's most pressing concerns. The paper industry supplied cotton for powder manufacture, the electro-chemical industry numerous chemical compounds, and the electro-metallurgical aluminum, iron alloys, electric steel, and cast iron. But as the war progressed, it became clear that France needed to develop additional sources of power. For one thing, coal was becoming ever scarcer. An increase in domestic production had been negated by

[8] This history draws heavily from Raoul Blanchard, *Les Forces Hydro-Électriques pendant la Guerre* (New Haven: Yale University Press, 1924), 18-26.

the loss of imports caused by submarine warfare. Moreover, new material programs to supply France and its allies demanded new sources of production. In the event, a movement to increase the exploitation of France's white coal emerged. In part, this movement was motivated by a desire to solve the problem of the coal crisis by substituting white coal for its fossil cousin. In the court of public opinion, the harnessing of chutes was seen as a means to rid the French of the humiliating necessity of importing their energy from abroad. After the new facilities had done their part for the defense of the nation, they would then provide the power for French industry, light for both city and country, and traction on the country's railways. In order to pay for this critical program, the French state intervened in the world of finance. In addition to building some facilities with public money, the state advanced generous credit to entrepreneurs, to be paid back within ten years after the cessation of hostilities. The state also assumed responsibility for critical groundwork, literally so in the form of the geological studies necessary to site future dams.[9]

Wartime hydro development in the Alps proceeded in two broad phases. The first phase unfolded under the motto "*faire vite*!" In the period 1915/1916 French industry focused on quickly expanding capacity by augmenting the exploitation of white coal in the places where it already existed. Doing so saved time by avoiding the necessity of building transmission lines that cost both time and money. The centers of activity during this phase centered on the Arve, Arc, and the Grésivaudan. In the latter valley, the already exploited Bréda, a tributary of the Isère, was further put to work. With fifteen existing hydro facilities before the war, the Bréda was one of the most heavily exploited waterways in all of France. The war witnessed the erection of three additional power plants, more than doubling the energy wrung from the river basin to over 15,000 kilowatts. Nearby, the Grésivaudan paper industry availed itself of the last

[9] Blanchard, *Les Forces*, 7-9.

remnants of power remaining in the left-bank torrents rushing down to the Isère. As part of their wartime expansion, the Papeteries Bergès created an additional 1,000 kilowatts of power by equipping another chute on the upper stretches of the Laval stream. The additional energy enabled the Papeteries to expand its traditional production and venture into new areas as well. The plant began manufacturing cellulose and nitrocellulose (sometimes known as guncotton), the latter at the behest of the *Service des Poudres*. A small contingent of 150 workers at the factory even produced bombs. The wartime activity sparked growth throughout the establishment. The number of workers at the mill nearly tripled, from 1,000 in the summer of 1914 to 2,800 in 1918. The new production necessitated the expansion of the facilities outside of the gorge it had always called home. Transportation to the plant also improved after the connection of its private rail station to the nearby station of the Paris-Lyon-Marseille railway. This boom came at a propitious moment for the factories, as the entire French paper industry had been suffering prior to the war. Increasingly, the branch that had previously produced the pulp necessary to manufacture paper or cardboard found itself importing the material from abroad (particularly Germany and Austria-Hungary). The imports cost some 100 million francs, prompting the general director of the Papeteries Bergès to complain about his industry's tributary status to foreigners, and how it prevented domination of the domestic market, and barred entrance into the global one. By 1918, the Papteries' future looked considerably brighter.[10]

Besides the harnessing of the Laval, the mill's expansion wrought other environmental changes. One of the more far-reaching was the impact of pulp production on the region's forests. Whereas before the war, the factory consumed some 160 cubic meters of wood every day (to produce 40 tons of pulp), by 1918 this number had climbed to 380 (for 150 tons of pulp). In anticipation of the operation's expansion, Bergès' mills acquired vast forest holdings at the outset

[10] Arrigon, *Houille Blanche*, 36-39; 53-54.

of 1915. These were located not only in the factory's vicinity in the Dauphiné, but places farther afield in the Savoy and Jura. By 1918, the company held forests valued at some 5 million francs, and worked by 800 Spanish loggers. To get the timber to the factory in Lancey, the firm commanded a fleet of 200 horses, 15 trucks, and 8 power tractors.[11]

In this early phase, France also put her Alpine water power to an unprecedented use: producing chemicals for use on the battlefield. To hear Monsieur Arrigon tell it, France had been forced by the Germans to make use of these more "murderous chemical resources".   From his perspective, since the outbreak of hostilities the German combatants had banished all traces of humanity, violating the articles of the Convention of the Hague repeatedly. This flouting of the rules of warfare culminated in spring 1915, when the Germans used poison gas against their French counterparts at the second battle of Ypres. This succeeded in momentarily buckling the French line. But the troops and the home front quickly bounced back. Industrialists set about establishing facilities to produce chlorine gas. By May 1916 they were churning out appreciable quantities of the substance. At the end of the war, seven such plants existed in France, almost all of them in the Alpine region. Arrigon visited one of the most important of these liquid chlorine factories located within sight of the Belledonne massif in a suburb of Grenoble. The factory had become operational six months from the beginning of construction in September 1915. After the war, the factory switched from producing poison gas to several other chlorine byproducts, including sodium bicarbonate, hydrogen gas (for aviation), calcium chloride (chlorure de chaux), and sodium hydroxide (soude caustique). Small wonder then, that "the odor of chlorine reigned both within the factory and all around."[12]

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[11] Arrigon, *Houille Blanche*, 38.
[12] Arrigon, *Houille Blanche*, 31-33.

The second phase of hydro development in the Alps took place in the years 1917-1918. Under the specter of the failure of France's Nivelle offensive, and the intensification of submarine warfare, the "captains of white coal" felt the need to expand their vision. They wanted to harness water power on unprecedented scales. While projects completed during this era were still completed relatively swiftly, the understanding that the new facilities should be larger than traditional ones reigned among the French industrialists who directed these efforts. As such, developments during this period tended to concentrate on those areas previously neglected. The main theaters of this new spirit were in the southern Alps, and in the larger river valleys that lay just outside the arc of the northern Alps. French industrialists tapped into the Durance, the mightiest river of the southern Alps, with the creation of two large run-of-river dams. In the exterior valleys, the French engaged the slower rivers whose power sprang from their sheer quantity of water. The lower stretches of the Fier and the Isère were made to generate tens of thousands of kilowatts respectively. French industry even tackled the mighty upper Rhône.[13]

The ultimate destination of this water power was also new. Increasingly, the companies harnessing the power of the French Alps transmitted this electricity outside of the mountain region. Understandably, the new power generated by those rivers at the foot of the Alps often found its way to nearby industrial centers such as Saint Etienne and even Lyon. But these cities also increasingly became the destination even of energy produced in the new facilities of the mountainous interior. Alpine hydroplants also found new customers in Marseilles and the Mediterranean coast.[14] As we will see in the next chapter, from 1914 onward, this trend for white coal to be used outside of the mountains would repeat itself throughout the region.

[13] Blanchard, *Les Forces*, 31-35.
[14] Blanchard, *Les Forces*, 35.

In the conclusion to his account of the wartime developments in the Alps, Monsieur Arrigon attempted to summarize the significance of what he had seen in the mountain valleys. "Under the influence of war," he wrote "destructive, sower of death and ruin, here, but there, terrible creator of energy and wondrous stimulating power, the *départements* of the Alps, most particularly Savoy and the Dauphiné, have given in a few years the spectacle of an unheard of industrial boom."[15] There is much to support his reading. In 1914 Alpine water produced some 302,000 kilowatts of electric power, accounting for nearly two-thirds of all French hydroelectricity. During the conflict, an additional 233,000 had been wrested from the waters of the French Alps, equaling an increase of 77 percent in the span of four years. Since its emergence in the late nineteenth century, France's white coal industry had never experienced such an enormous period of growth. The increase in Alpine white coal accounted for over half of the country's new hydro development during this time period (although hydro development elsewhere in France slightly reduced its proportion of national production). Consequently, from a quantitative standpoint Alpine water power was the single most consequential addition to France's wartime energy supply.[16]

In light of the sheer scale of the changes enacted, it is understandable that many could perceive the business in the French Alps as an example of a marvelous effort for the national cause. But the wartime effort to bend the waters of the French Alps was also attended by bitter social conflicts as well. Raoul Blanchard briefly detailed some of these difficulties in his introduction to a study on French hydro development during the war. Hydro development provoked lively debates within the engineering community about the proper technological approaches to the problem. Even thornier was the issue of the infamous *barreurs de chutes*.

[15] Arrigon, *Houille Blanche*, 62.
[16] Blanchard, *Les Forces*, 36-37, 109-110.

These were riparian owners less impressed with the importance of white coal for the nation. The *barreurs* took advantage of the great demand for hydroelectricity by speculating in the real estate necessary to build dams and diversions, and selling to power companies only at exalted prices. But the greatest problems had to do with labor. The same environmental conditions that made the mountains the ideal place to build water power plants also made them one of the least pleasant for a construction worker to live. Remote valleys offered few possibilities for recreation, and mostly poor lodging (if at all). The same seasonal changes in hydrology that plagued rational hydro exploitation also made for unbearable, if not impossible, work conditions on the construction sites themselves. Cold and snow in the winter prevented building just as assuredly as the summer floods. Construction workers on Alpine hydro plants, therefore, had to subject themselves to living in austerity and seasonal unemployment. Even under normal conditions, it would not have been a simple matter to muster the workers necessary to rearrange France's Alpine rivers. The marshaling of all able-bodied men for the war effort made the situation acute. To skirt the labor issue, some industrialists imported colonial contingents and foreigners from countries such as Spain, Greece, Italy, and Armenia. In some cases, prisoners of war were also put to work. In doing so, they enjoyed the full support of the French government, particularly the minister of armaments.[17]

Lancey employed Italians, Spaniards, Swiss, Serbians, Montenegrins, Belgians, Armenians, Greeks, and Vietnamese. L.-J. Arrigon likened the scene he beheld there to "a kind of Babel where all of the nationalities, all of the races, all of the colors mix in picturesque variety, Spaniards and Italians, Slavs and Greeks, Armenians and Vietnamese, even Chinese, for whom special barracks were constructed whose doors are covered in characters of the Far East traced in chalk." Despite this rather positive depiction, Arrigon also implied the existence of

[17] Blanchard, *Les Forces*, 8-9.

some social tensions. The writer noted that among this group the Italians, who had a history of migrating to the Dauphiné for work, were held in great esteem and would be later welcomed to return in large numbers. Other nationalities, he observed, had not experienced a "full success with the crucial test imposed on them," but he believed that a core of good workers nevertheless existed among this group. Once the bad and mediocre laborers had been removed, he asserted, "the better ones, increasingly trained in their task and increasingly specialized, would furnish excellent service."[18]

The entrance of large numbers of female laborers into the workforce was another result of the wartime white coal expansion. In many parts of the French Alps, women made up an important part of the workforce . In the *département* of Isère, for example, 4,000 women worked in the machine construction industry by 1918, compared to 200 only four years earlier. While this development surely offended some sensibilities, the renowned geographer of the French Alps, Raoul Blanchard, predicted a future for female labor, while at the same time repeating the widespread opinion of the physical limitations of their sex. "The women are quite appreciated, they are a group full of vigor (*pleine de mordant*); all of the bosses expect to keep them after the war, as long as they specialize in those tasks that do not require great physical effort."[19]

The impact of the First World War on the waters of the French Alps lasted beyond the cessation of hostilities in November 1918. A slew of projects conceived or popularized during the conflict would only reach completion later. Some of these undertakings took longer because they incorporated new technological or economic elements in their designs. One of the main novelties of such projects was their provisions to regularize the flows of Alpine energy. Indeed, this movement to rationalize water power exploitation first took hold in wartime France. As

[18] Arrigon, *Houille Blanche*, 37, 55-56.
[19] Arrigon, *Houille Blanche*, 55.

described in the previous chapter, elsewhere in the Alps this movement initially focused on Alpine lakes as potential reservoirs, and in France it was no different. At the time, the lac de la Girotte was the most important lake-turned-reservoir in the French Alps. This small body of water, 1,736 meters above sea level, sat perched above the Dorinet de Hauteluce valley in the Arly basin. The lake itself measured only 57 hectares in area, and it received such scarce recharge that it could provide but little water for energy purposes. However the owner of one of France's most important steel mills in the nearby town of Ugine, Paul Girod, had the idea to transform the lake into a reservoir that would not rely on natural recharge to be filled. Girod outfitted the lake to be part of a pump-storage hydroplant. During the day, water drawn from the lake plunged in a penstock to a power plant in the valley below to produce electricity to help meet the demands of the workday. At night, this same electricity operated a pump that sent water back up into the lake. In this manner, the plant obtained reserves of water that could be used to cover the peaks in demand.[20]

Plans to achieve regularization of flows on a far grander scale also emerged. Large dam projects materialized in France—and throughout most of the Alps—in the course of the war. Indeed many of France's largest Alpine dams, realized in the interwar and postwar years, were children of the war. Schemes to erect dams on the swift flowing Romanche and Drac rivers for example, which would only be completed in the 1930s, first surfaced in 1918. Large-scale support for dams on the Durance and upper Rhône rivers finished after the Second World War—superlative projects that would rival some of the largest anywhere in Europe—also first gained momentum in the four war years. The latter scheme, symbolized by the large dam at Génissiat, was inextricably connected to the greater question of the development of the upper Rhône that

[20] Blanchard, *Les Forces*, 39-40. The reservoir was later augmented by the construction of a dam, begun during the Second World War.

would occupy all of France for several decades. The fate of projects such as these will be explored in the next chapter.

The Spullersee

On the occasion of the German Traffic Exhibition being held in Munich from June to October 1925, the Austrian Federal Railways prepared a small brochure celebrating the agency's most recent triumph. Published in English to accommodate the exhibition's international participants, *Over the Arlberg by Electricity* commemorated the electrification of Austria's Arlberg railroad. The Arlberg line represented a critical section of railway linking western and eastern Europe. It shared its name with the most important mountain pass (under which it tunneled) enabling travel between westernmost Austria and the rest of the country. In existence since the late nineteenth century, the electrified version of the Arlberg line had opened just before the start of the Traffic Exhibition, and the brochure trumpeted the event as an Austrian national success. The pamphlet emphasized the modernity and luxury of the Arlberg line, which it called "the quickest and most convenient communication on the route Vienna-Switzerland-Paris-Calais(London)." The entire final section of the promotional material was devoted to a fictive description of the journey from Vienna to Lake Constance intended to entice potential passengers.

The brochure also described the power plants that provided the railroad's modern energy. As the leaflet explained, traction for the Arlberg line came courtesy of two hydropower plants located in the Austrian Alps, one of which had recently completed specifically for this purpose. This was the Spullerseewerk, a power plant that tapped into the Alpine lake Spullersee as a high-pressure water reservoir. The Austrian Federal Railways had overseen and financed the conversion of the Spullersee into a power reservoir in order to have a means of covering the fluctuating peaks in energy demanded by rail traffic on the Arlberg. To increase the amount of water that could be stored in the lake, the agency's project had furnished the natural lake with two dam walls. To the author of the brochure, the Spullersee's dams appeared "cyclopean" and their construction a triumph of science and technology.[21]

Science and technology may have aided in the construction of the dams, but the will to put them there stemmed from a different source. The new lake they created was perhaps the foremost physical embodiment of the new Austrian republic's response to the energy crisis it faced in the wake of the First World War. Across Europe, the end of the Great War brought great economic upheavals, and with them disruptions to state energy supplies. For the newly created republic of Austria, the problem was that the dissolution of the multinational Habsburg Monarchy cut the state of from its previous sources of coal in Bohemia and Silesia. What the new republic of Austria did possess, however, was water power. Austria was in many ways an Alpine republic and an enormous amount of potential energy lay slumbering in its mountains. The war's denouement made Austria a white coal country: its greatest source of domestic energy was to be found in its Alpine water. Even as the new state attempted to resolve its political issues in the aftermath of defeat, its politicians took measures to address the impending coal shortage. The main thrust of these policies was to electrify the Austrian state railways, and it was in this context that the Spullersee emerged as the centerpiece of these plans. And although the republic eventually broke off its electrification program in 1928, this initiative (and the hydro projects it influenced) accounted for the lion's share of Austria's considerable development of

[21] Austrian Federal Railways, *Over the Arlberg,* 7, 26.

white coal in the 1920s.[22] As the Austrian republic dominated much of the eastern Alps, the experience of the small state had a disproportionately large impact on the Alps.

Plans to turn the lake into a power reservoir dated back to 1908. At that time, the Austrian State Railways performed some preliminary studies about the suitability of the Spullersee to serve as a power reservoir. During the Great War, however, the permitting process for the Spullerseewerk ground to a halt. In contrast to France, the First World War did not act as an immediate catalyst for the development of Austria's Alpine water power. Only with mounting difficulties to the coal supply did the development of domestic water power become a political issue. As in Bavaria, discussions of Austrian water power development also revolved around questions about Austria's industrial backwardness, particularly compared to western European powers. These culminated in the September 1917 announcement by the Austrian prime minister Ernst von Seidler of a program to stimulate the economy. The centerpiece of this agenda foresaw state measures to promote hydropower development and the electricity supply, and it was the first step in the passage of new national electricity legislation. Austria's technical community hailed the initiative and debated how these goals would best be achieved. In particular the Association of Austrian Engineers and Architects (*Österreichischer Ingenieur- und Architekten Verein*) devoted several intense sessions to this discussion.

The Spullersee was not at the top of their agenda. For Austria's engineers and architects, the issue at hand was how to promote domestic commerce, agriculture, and above all industry. At this point, the Association believed what the Austrian economy needed most was to make cheap, superpower-hydroelectricity available in the inner-Austrian centers of industry. The general consensus held this was best achieved through the development of superpower

[22] Georg Rigele, "Das Tauernkraftwerk Glockner-Kaprun—Neue Forschungsergebnisse und offene Fragen," *Blätter für Technikgeschichte* 59 (1997): 55-94.

hydroplants on the large Alpine rivers (Danube, Enns, Sava, Drava) in conjunction with hydraulic storage works on the rivers of the Sudetenland. This energy would then be brought to the industrial centers via high-voltage transmission lines.[23] Concerning the question of who should be executing these moves, the majority of Austrian engineers were also of one mind. Contrary to the "fad" at the time of pursuing socio-political goals through state involvement in electrification, the Association rejected a state monopoly on hydropower development. The group instead supported a "mixed-economic" (*gemischtwirtschaftlich*) approach where the state would complement and support the private sector in its promotion of the energy supply.[24]

The political events of late-1918 overtook these developments. Austria ceased to be the center of multinational empire. The centrifugal forces of nationalism had been severely straining the unity of Austria-Hungary since the late nineteenth century, and the specter of a losing war effort only increased their intensity. Throughout the conflict, leaders of nationalist movements within the Austrian half of the monarchy had been promoting their cause with the Allied powers abroad. Toward the end of the war—spurred on by the introduction of Wilson's Fourteen Points—the idea that Austria should be dismembered took hold. The deterioration of the military situation in the summer of 1918 set the wheels of national self-determination in motion. Although Emperor Karl declared his intention to reorganize the Austrian half of the empire along federal lines, this was too little too late. The formation of Czechoslovakia and Yugoslavia were already in progress, and Karl's proclamation had the unintended effect of permanently pushing Hungary away. German-speaking politicians in Austria resolved to form their own state

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[23] See the discussion in Karl Grünhut, ed., *Elektrizitätswirtschaft und Wasserkraftausnutzung: Wechselrede, gehalten in den Fachgruppen der Bau- und Eisenbahn-Ingenieure und für Elektrotechnik des Oesterr. Ingenieur- und Architekten-Vereines* (Berlin: Urban & Schwarzberg, 1919).

[24] Österr. Ingenieur- und Architekten-Verein, *Gutachten des Österr. Ingenieur- und Architekten-Vereines betreffend die Regierungsvorlage für ein Gesetz über die Elektrizitätswirtschaft* (Vienna: Verlag des Österr. Ingenieur und Architekten-Vereines, 1918), 1.

composed of all of the German-speaking territories of the Monarchy. They envisioned their state as part of a confederation of the other states emerging from the rubble of the Empire, but the other nationalities showed little interest in this scheme. On November 12, one day after Emperor Karl relinquished power, the Republic of Austria was declared in Vienna. Instead of an old-Austrian confederation of states, Austria sought unification (*Anschluss*) with Germany. However, as with much of central Europe, the provisional state's borders were in flux, and their fixation would await the outcome of the peace settlement with the allies.

These upheavals also completely changed the parameters of the debate surrounding the energy supply in Austria. Besides the fact that the dissolution of the Habsburg Monarchy put paid to plans to construct an empire-spanning electricity grid, or dams on the rivers of the Sudetenland, the loss of Czechoslovakia (particularly the Bohemian lands) meant the loss of Austria's previous source of domestic coal. The depth of the catastrophe is visible in a few numbers. In 1913, coal consumption within the borders of German-Austria equaled some 12 million tons annually, the overwhelming majority of it coming from the rich Bohemian seams. In 1919, Austria produced around 1.7 million tons domestically, and managed to import some 2.5 million with great difficulty from Czechoslovakia and Poland.[25] Industry and transportation in the country practically ground to a halt. In addition to drastically reduced access to coal supplies outside of Austria, the availability of domestic coal was also constantly uncertain due to the threat of strikes. Under these circumstances, the main problem facing the Austrian energy supply was not how to develop cheap power sources to promote industry, but how to ensure the critical supply of coal for the country's existing industries, railways, and households.

[25] AT-OeStA/AdR BKA BKA-I SL WEWA 1919, Kt. 3, 669/19: "Protokoll über die 1. Sitzung der Beratenden Kommission Wasserkraft- und Elektrizitätswirtschaftsamtes am 10. und 11. Juli 1919," 3.

At the state level, Austrian politicians glimpsed the answer to these energy woes in the substitution of the country's Alpine water power for coal. In particular Austrian leadership saw the electrification of the state-owned railways as the first and most crucial step. There were a number of reasons that using white coal for the railways appeared attractive. For one thing, the demand for traction already existed. Indeed, the Austrian state railways devoured about a third of Austria's total coal consumption. Not least important for the ascension of electrification was the increasing power of the Social Democratic party in Austrian politics after the collapse of the Monarchy. With social democrats holding some of the top posts in the provisional democratic state, the issue of using state water to power state trains—a favorite of socialists throughout the Alps—finally gained traction. In 1919, the movement to electrify could no longer be parried by its traditional enemy, the ministry of war. It is a measure of the new importance accorded to electric traction that the Austrian military administration begrudgingly agreed not to stand in its way.[26]

The transformation of the Spullersee and the electrification of the Austrian railways were not merely questions of energy supply. As a memorandum on the postwar Austrian energy supply composed by the Lower Austrian Chamber of Commerce argued, hydro development like that on the Spullersee was also an instrument to address the problem of unemployment. The demobilization of the Habsburg armies meant the return of thousands of men seeking jobs, and factories previously geared to war production suddenly found themselves searching for new contracts. The chamber argued that hydro development could employ both skilled and unskilled workers.[27] Notions of national honor and pride also played an important role in the politics of

[26] See the correspondence in AT-OeStA/AdR BKA BKA-I SL WEWA 1919, P.Z. 24.
[27] AT-OeStA/AdR BKA BKA-I SL WEWA 1919: Handels- und Gewerbekammer Wien, "Denkschrift betreffend die Energiewirtschaft in Deutschösterreich. Sitzungen des Ausschusses für steuer- und verwaltungsrechtliche Fragen am 5. Dezember 1918, 3. und 16. Jänner 1919," 9-10.

rail electrification. Many Austrians found their new country's dependence on energy from abroad—and particularly from former subjects of the Habsburg empire—distasteful and humiliating. Austrian politicians abhorred the "processions" they had to make to the new Czechoslovakian and Polish states in order to secure even meager coal imports.[28]

With the Austrian state committed to electrification, the development of the Spullersee became the state's most important water power initiative. The lake's special importance derived from its relationship with the Arlberg line. From its inception, the Arlberg railroad had possessed great strategic importance for Austria-Hungary. The route was named after the Arlberg Pass, which connected the rest of Austria with the westernmost part of the empire (called *Vorarlberg*). The line opened in 1884, after the completion of the 6 ½ mile tunnel underneath the Arlberg. Its construction created a rail link between Lake Constance and the Adriatic, Austria's outlet to the sea. When engineers began discussing the possibility of using water power to provide traction, the Arlberg—along with Austria's other Alpine roads—was considered one of the prime candidates. They believed mountain railways stood to profit most from electrification, above all because it would eliminate the smoke that plagued passengers in long tunnels.

Before this power could be developed, however, numerous issues had to be addressed. As with all hydro projects, a litany of property issues would need to be settled. There was also the issue of obtaining the approval of the province of Vorarlberg to proceed with the plan. Perhaps most important was the question of money. The Spullersee project would require two expensive dams in order to make the lake a bigger reservoir. In the best of times, funding such a project would have been difficult for a small, largely agricultural state like Austria. In early

[28] AT-OeStA/AdR BKA BKA-I SL WEWA 1919, Kt. 3, 669/19: "Protokoll über die 1. Sitzung der Beratenden Kommission," 4.

1919, with the state on the precipice of economic collapse, the problems of financing loomed as the most formidable of all.

To negotiate these obstacles, the newly created Water and Electricity Supply Office (*Wasser- und Elektrizitätswirtschaftsamt*, WEWA) stepped forward. Indeed, the Office had been created for precisely this purpose. The new bureau was the brainchild of Wilhelm Ellenbogen (1863-1951), a doctor and former social democratic member of the Austrian *Reichsrat*. Already on December 16, 1918, barely a month after the collapse of the Monarchy, Ellenbogen petitioned the State Council (*Staatsrat*) for the creation of the new authority. The councilor saw the necessity of promoting a unified, systematic approach to the development of postwar Austria's water power and viewed the creation of an overarching state authority as a precondition. Ellenbogen believed the WEWA should act as a broker between both the various sections of government interested in the question of the electricity supply, and the various economic and social groups involved as well. On January 3, 1919, the State Council approved Ellenbogen's petition. The agency which Ellenbogen headed was directly subordinate to the State Council.[29] As Ellenbogen made clear in a January letter addressed to the governor's of Austria's various provinces, one of the primary purposes of WEWA was to work against particular interests that stood in the way of the "rational" exploitation of the country's increasingly valuable white coal.[30] The doctor did not want selfish provincial politics to stand in the way of the greater good.

The WEWA quickly made the construction of the Spullerseewerk its first priority. In March 1919, the Office met with representatives of the province of Vorarlberg to discuss the development of this source of power. In many ways, the plans of the province and the agenda of WEWA dovetailed. WEWA required the Spullerseewerk to cover the spikes in demand on the

[29] Petition in AT-OeStA/AdR BKA BKA-I SL WEWA 1919, P.Z. 40.
[30] AT-OeStA/AdR BKA BKA-I SL WEWA, P.Z. 32: Letter Ellenbogen to provincial governments (13 January 1919).

Arlberg line, and Vorarlberg sought water storage works to compensate for the province's lack of hydro energy in the winter. Transforming the Spullersee into a reservoir fit into this plan, but the representatives of Vorarlberg had grander visions. In addition to the Spullersee, the province was exploring the conversion of two other Alpine lakes (the Formarinsee and the Lünersee) into power reservoirs. It was not clear, however, if either lake was geologically suitable to be used to store water. In the course of the negotiations between WEWA and Vorarlberg, the province secured federal support for the preliminary work needed to determine the geological condition of these lakes. The state railway administration also agreed to take a financial stake in the province's future development of the hydropower of the Ill River.

These initially successful negotiations, however, proved misleading. Despite WEWA's desire to move quickly on the Spullersee project, progress bogged down in the spring of 1919. The instability of the new state's currency also complicated matters, as the farmers who would be selling their land for the project worried that in the case of further devaluation, they would be exchanging valuable property for worthless money. On top of all of this, it was not even certain whether Vorarlberg would remain a part of the Austrian republic. Public opinion within the province overwhelmingly supported the fusing of the province to its neighbor Switzerland. Provincial leadership began negotiations along these lines after a May 1919 plebiscite, in which eighty percent of Vorarlbergers instructed them to do so. The Treaty of St. Germain put an ultimate end to Vorarlberg's overtures to Switzerland. Nevertheless, issues such as these prevented immediate action on the Spullerseewerk.

The stalling of the Spullersee project opened the door for the type of provincialism in the water power question that the WEWA hoped to avoid. In a meeting of the WEWA, the engineer Innerebner from Vorarlberg's eastern neighbor Tyrol made a coy case for the superiority of

Tyrolean water power. Playing on the fears about Vorarlberg's uncertain political future, Innerebner suggested that perhaps the new republic would be better off developing Tyrolean water power. "I hope and wish that Vorarlberg will not be detached from us, otherwise the work would have to be built not on the Vorarlberger side but the Tyrolean side. I just want to point out that we in Tyrol have very good water power, and that in this case one could also apply the saying: another mother also has a handsome child." The other fish in the sea that Innerebner referred to was Tyrol's Achensee, an Alpine lake also well-suited to serve as a power reservoir. For his comments, Innerebner received some critical looks from a delegate from Vorarlberg.[31]

As 1919 wore on, the urgency of hydropower development in Austria only increased. With the emergence of the Entente's proposal in Paris for the new borders of Austria, it had become clear that the state would likely have to surrender much more territory than originally anticipated. Disputed areas with large German minorities, which Austria's delegates had believed would be left to the new state according to the principal of self-determination, were slated by the diplomats to become parts of other states. In a WEWA meeting with representatives from all of Austria's provinces, president Ellenbogen outlined how the imminent border changes would result in the loss of already existing water power. He calculated that the border changes would remove twenty percent of Austria's hydroelectric capacity. The greatest losses would stem from the removal of territory in the Alpine provinces of Styria, Carinthia, and Tyrol. Ellenbogen argued that the true damage to the Austrian national economy would come not merely from the loss of existing capacity, however, but of hydropower potential. The disputed border areas contained some of the best locations for hydroelectricity. The steepness and size of the rivers of the southern part of the province of Tyrol demanded by Italy (Etsch,

[31] AT-OeStA/AdR BKA BKA-I SL WEWA 1919, Kt. 3, 669/19: "Protokoll über die 1. Sitzung der Beratenden Kommission," 14.

Eisack, Rienz) made them especially cheap to develop. The greatest impact would likely be the loss of certain sections of the Drau river as it flowed through Carinthia and Styria. According to the Entente's terms, parts of both provinces would cede territory to the Slovenian region of the new state of Yugoslavia. The president estimated the damage in the Drau basin alone at almost a half-million horsepower. "In addition to the other peace conditions," Ellenbogen concluded, "the loss of our water power will also hurt us badly."[32]

Under the specter of the impending peace conditions, the Austrian state government moved to close the deal on the Spullerseewerk. In July 1919, WEWA delegates traveled to the city of Bregenz in Vorarlberg to negotiate the province's final terms. At the end of difficult talks, the WEWA emerged with Vorarlberg's approval for the immediate construction of the Spullerseewerk. In return, the province managed to secure important concessions regarding the future development of its water power. As part of the Spullersee deal, the Austrian federal government promised to contribute about half of the funds necessary to prepare the Lünersee to act as a power reservoir (a total of one million crowns). On August 5, the Austrian state government officially announced its intent to develop the Spullersee power as part of the electrification of the Arlberg line. Reporting on the announcement, a Viennese newspaper commented that "it has now gotten serious with the construction of water power plants for electric traction."[33]

The decision to build the Spullerseewerk marked the beginning of a period of considerable activity. As work on the new facility proceeded apace, the republic of Austria enacted a law mandating a program for electrification of federal railways in July 1920. Besides

[32] AT-OeStA/AdR BKA BKA-I SL WEWA 1919, Kt. 3, 669/19: "Protokoll über die 1. Sitzung der Beratenden Kommission," 10-12.
[33] "Ausbau von Wasserkraftwerken durch die Staatsregierung," special printing of the *Wiener Zeitung* 179, 7. August 1919. Found in AT-OeStA/AdR BKA BKA-I SL WEWA 1919, 690/19.

the Arlberg line four other major railroads were to be electrified. These were the road running through the touristically important Salzkammergut region, the Tauern route over Austria's highest mountain range, and the railroads crossing the critical Brenner and Semmering mountain passes. By 1930, almost all of the federal railways west of the city of Salzburg had converted to electric traction.[34] The concessions made to Vorarlberg by the federal government in exchange for releasing the Spullersee for the federal railways' purposes also helped spur the remarkable development of that province's hydropower by the end of the decade (some of which will be addressed in the next chapter).

In the late 1920s, Oskar von Miller told an assembly of Austrian engineers that if their country did not exist, God would have been to forced to create it in order to satisfy the members of their shared profession. "Because there is scarcely a land," Miller argued, "where it has been made so certain that engineers will have the opportunity to demonstrate their arts, as our dear Austria."[35] After the First World War, Austrian engineers had ample occasion to practice their arts in pursuit of the state's goal of developing its Alpine water power resources. They left a lasting impact on many waterways of the eastern Alps, and represented a small harbinger of things to come.

Conclusion

The First World War and its immediate aftermath marked a watershed moment in the history of the Alps as an energy landscape. With the coming of war and its disruption of European coal supplies, the Alps began to loom large as a landscape of alternative energy. In the

[34] Austria, Generaldirektion der Österreichischen Bundesbahnen, Die österreichischen Eisenbahnen. Gedenkblätter zur Hundertjahrfeier der Eröffnung der ersten österreichischen Dampfeisenbahnen (Vienna: Verlag der österreichischen Bundesbahnen, 1937), 75. For more on the Austrian electrification program and its Swiss influences see Peter Staudacher, "'In der Schweiz zum Beispiel': Die Anfänge der österreichischen Elektrowirtschaft und das Schweizer Vorbild," in *Allmächtige Zauberin unserer Zeit: Zur Geschichte der elektrischen Energie in der Schweiz*, ed. David Gugerli (Zurich: Chronos, 1994), 185-198.

[35] Oskar von Miller, "Von Österreichs Ingenieurarbeiten," *Zeitschrift des Vereines deutscher Ingenieure* 74, no. 38 (30 September 1930): 1285.

combatant countries of Italy, and especially France, the demand for increased energy in wartime resulted in a spike of hydropower development. In France, Alpine white coal became the most important substitute for the fossil coal it lost to Germany in the opening months of battle. Throughout the rest of the mountain region, the conflict drew increased attention to the development of Alpine water power, and provoked societal discussions about the necessity of augmenting its exploitation after the war's conclusion.

Elsewhere it was not the early months of war that sparked a fury of hydroelectric development, but rather the first few months of peace. In the postwar period, the new German and Austrian states joined Switzerland, France, and Italy as "white coal" countries. Austria, especially, viewed the development of its Alpine water power as a question of state survival. The new state had little coal and little in the way of energy sources generally. Alpine water appeared the best solution to this dismal situation. Hydropower development in the early postwar years in Austria focused on utilizing white coal to power its public railways, and reduce its newfound dependence on coal imports from abroad.

CHAPTER FIVE

CONNECTING THE BATTERY

In a 1922 article, the Frenchman Henri Cavaillés drew a metaphor-rich comparison between hydropower and coal. "One is sedentary, terrestrial, autochthon; it is, according to widespread opinion, white coal. The other is nomadic, maritime, cosmopolitan; it is the carbon of the mines."[1] Cavaillés was stating, in a more vivid way than was usual among engineers, some of the reasons that he and most of his contemporaries considered coal the superior energy source. Chief among these was the relative ease of transporting the fuel to wherever it might be needed, a characteristic that gave coal unparalleled flexibility of use. White coal, on the other hand, was bound to the earth, and as such, far more subject to earthly rhythms.

From the 1920s onwards, Europeans opted for drastic measures to redress white coal's disadvantages. The first solution involved dams. At this time, Europeans began in earnest to impound the water of the Alps behind large dams. In the mountains themselves, such dams usually took advantage of glaciated valleys that served as ideal storage reservoirs. As the decade progressed, the idea of making white coal more nomadic and cosmopolitan by transporting it far beyond the borders of the mountains themselves also gained currency. In the 1920s, engineers viewed transporting abundant Alpine hydro to centers of greater consumption as both economically and politically important. Politically, many believed that interconnecting electrical utilities would lead to deeper connections between countries. By the end of that decade, however, the sentiment of international cooperation had been replaced by the desire to harness Alpine water power in the pursuit of economic autarky by many states. As is clear from the case of a dam project in Austria, white coal influenced both the run-up to WWII, and wartime economies as well. In the postwar period, even more reservoirs appeared on the Alpine

[1] Henri Cavaillés, *La houille blanche* (Paris: 1922), 202-203, quoted in Blanchard, "Water Power Development," 93.

landscape, many of which reflected Cold War anxieties. At this point, the activity since the interwar years had succeeded in transforming the Alps into Europe's Battery.

Ascension of Dams

As alluded to in a previous chapter, dams come in different varieties with different purposes. Throughout history, dams have been utilized for different purposes in different geographic regions. The earliest dams overwhelmingly served to store water for irrigation. More recently, the goal of energy generation has emerged. Hydraulic experts distinguish between two broad types of dams. First there are "run-of-river" dams that create only a small reservoir and which cannot effectively regulate downstream flows. These dams are often created by lesser obstructions called weirs or barrages. "Storage" dams, on the other hand, are designed to create reservoirs to control the flow of water. These are dams in the sense of the German word *Talsperre* (literally "valley closer") While the distinction is sometimes difficult to draw, in many cases it offers a useful way of understanding both the function of a dam, and its impact on the environment. Up until the 1920s, the "dams" that proliferated on the Alpine landscape were generally of the "run-of-river" variety. With a few notable exceptions, these were smaller constructions whose primary purpose was not to store water, but divert it. The decade of the 1920s inaugurated an era of reservoir-building in the Alps.

Dam-building in the Alps was based on technology that dates back to ancient times. The first physical traces of dams have been found in present-day Jordan, where they diverted water to reservoirs as part of a sophisticated water supply system. By the close of the first millennium BCE, dams could also be found in China, Central America, and the Mediterranean basin. In South Asia, the island of Sri Lanka became home to some of the most impressive dams of their times. An ancient dam, raised in the fifth century CE, remained the world's tallest for a thousand years. Roughly seven centuries later, Sri Lankans built the largest dam by volume for almost a millennium, a fifteen meter high structure that stretched almost fourteen kilometers in length. Most of these early dams consisted of embankments composed of rock and earth. Early modern Spain continued building the hydraulic tradition passed down by Roman and Islamic culture. The 46-meter-high dam at Alicante, finished in 1594, remained the world's tallest for some three centuries. In the nineteenth century, the center of dam innovation shifted to Great Britain, where almost 200 dams taller than 15 meters were erected. The majority of these structures retained drinking-water supplies for the country's rapidly expanding cities. By the turn of the twentieth century, Britain nearly possessed more dams than the rest of the world combined. By this time, societies began building dams to harness hydroelectric power. The Alps, flush with white coal, became one of the early centers of hydroelectric dam-building. For the most part, early Alpine dams were of the run-of-river type.[2]

In the wake of the First World War—and the mid-1920s in particular—Europeans began taking advantage of the Alpine environment in order to create hydropower reservoirs. The calculus behind reservoir-building was much the same that underlay the initial movement toward water storage that had focused on natural lakes after the turn of the century (see chapter 3). Notions of electricity supply dictated that the ability to control the timing of hydropower was critical to its continued expansion. Initially, expansion focused on using water power as a substitute for coal on mainline railways, and on more efficiently utilizing flows of Alpine water power. Early on, taking advantage of the storage capacity of lakes had appeared as a simple means of gaining some of this control. Using existing lakes as reservoirs required far fewer modifications of local hydrology than the creation of new lakes behind dam walls. But after the

[2] McCully, *Silenced Rivers*, 13-14. A postwar survey of Alpine reservoirs calculated that up until 1914, only three percent of the total Alpine reservoir capacity as of 1970 had been developed. Reservoir building was a post-WWI phenomenon. See Link, " Bassins d'accumulation," 255.

First World War, Europeans began closing of valleys behind walls of concrete in earnest. Many of the most suitable natural lakes had already been converted into reservoirs. A new hunger for energy also no longer hesitated at massive incursions into the Alpine environment.

One powerful motivation for reservoir creation was the desire to create regional electricity supplies based almost entirely on hydroelectricity. Focusing on the supply side only, energy experts in the Alps determined that this could only be achieved by remedying the dismal situation of white coal in winter. In the early 1920s, the lack of winter hydropower available in northeast Switzerland led to the creation one of the country's first and most well-known large reservoirs. This was the Innertal reservoir, which began collecting behind a dam in the Wägital valley in the summer of 1924. The reservoir was the result of efforts by a partnership of cantons and the city of Zurich to significantly increase the amount of hydropower available in northeastern Switzerland during the colder months when rivers carried little water. Located some 40 kilometers southeast of Zurich at the northern edge of the pre-Alps in the canton Schwyz, the Wägital and the water-rich Wägitaler Aa that drained it had long attracted the attention of hydropower enthusiasts. The greatest interest centered on the inner-Wägital valley, whose exit was composed by a narrow canyon looming some 400 meters above the plains of the March district. Locals called this point the Schräh, and it was one of those countless places in the Alps where nature seemed to be calling for human improvement in the form of a dam. Already in 1896, a group of private individuals gained a concession to construct a 40-meter high dam in the Schräh. But the group failed to secure the financial backing of the Zurich city council, and their project languished. Eventually the city of Zurich acquired the group's concession to exploit the water power of the Wägital, but movement on the project stalled for several years.

It was the winter energy woes of two of the area's largest electric utilities that finally revived the Wägital scheme. Already before the First World War, the Zurich municipal electric utility had sometimes found itself forced to seek power beyond that provided by its own hydroelectric plants. By 1916, however, the scarcity of fossil fuels in particular sparked a huge increase in demand for hydroelectricity that the city could not meet from its own supply. Even with the purchase of outside current the city still found it necessary to enforce strict measures limiting electricity consumption during some winters. The Nordostschweizerische Kraftwerke, a company created and owned by several cantons in the region to harness and distribute hydropower, also shared Zurich's winter electricity shortages. By 1920, the utility consistently possessed only three-quarters of the necessary capacity in winter. At this point the city and the cantons, tired of winter electricity scarcity's impacts on their bottom lines, joined forces to expedite the realization of the Wägital dam. Construction for the project began in 1921 and was mostly finished three years later. When completed, a 110-meter tall gravity dam, replete with ornamental concrete columns at the crown, created a power reservoir whose water would be exploited in two separate stages. To increase the amount of water in the reservoir, engineers equipped the lower stage with a pump facility that could be operated by excess energy in periods of low demand. According to the plant's design, the facility would only operate during the five winter months (November-March). During this period, most of the water stored in the Wägital would be emptied out during the 10-hour work days of the nearly 130 winter weekdays. The "winter work", as it and facilities like it were called, completely altered the hydrological rhythms of the area. The Schräh dam also created one of Switzerland's largest reservoirs, a new mass of potential energy perched at 900 meters above sea level. The waters of the new lake stretched five kilometers in length, submerging almost 400 hectares of agricultural land and necessitating the relocation of 230 residents.[3]

Dams were also seen as the only means to harness certain types of Alpine water power. Especially after the First World War, energy experts advocated building high-Alpine dams in order to collect and harness the water power of the high-Alps. While there was no concrete definition of what constituted "high-Alpine" hydro, the term generally referred to hydropower harnessed in an altitude greater than 1200 meters above sea level. High-altitude water power exploitation was thus limited primarily to France, Italy, Switzerland, and Austria. Nowhere in the mountains, however, was the difference between summer drainage and winter drainage so stark as in the high-Alps. Throughout the chain, summer floods regularly made up eighty to ninety percent of the total annual flow at high altitude. In glaciated areas, the ratio between summer and winter flows approached twenty to one. Such irregular flows were anathema to the electricity supply, and the only way to artificially influence them was to capture and store this water. In 1932, one German expert estimated that high-Alpine water power represented about one-quarter of the possible annual hydroelectric power production in all of central Europe—including the vast water power resources of the Scandinavian lands as well. At the time, this power alone would have been enough to cover three-quarters of central Europe's demand.[4] But it was not merely the quantity of the high-Alpine water power that made it so attractive for the European electricity supply, but the quality. No energy source was more well-suited to provide valuable peak power than hydroelectricity. In contrast to thermal plants, which take some time to warm up, hydroelectric facilities can increase production almost at a moment's notice. Even if they were not providing peak power, utilities had a much easier time fetching a decent price for

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[3] Gustav Krück, *Das Kraftwerk Wäggital* (Zurich: Gebr. Fretz, 1925), 5-30.
[4] E. Mattern, "Die hochalpinen Wasserkräfte im Rahmen der mitteleuropäischen Stromversorgung," *Elektrotechnische Zeitschrift*, no. 38 (22 September 1932): 907-911.

their hydroelectricity if they had some control over its flow. Indeed, German electric engineers eventually came to refer to the hydroelectric current they could not regulate as "waste current" (*Abfallstrom*), and a utility could count itself happy if it managed to find consumers who would pay at least something for this power.

One early example of a network of high-altitude reservoirs is the Oberhasli Works. Beginning in 1925, a joint venture between the Swiss capital of Bern and the canton of the same name erected a series of high-altitude dams in the Bernese Alps to create one of the largest sources of constantly available water power in all the massif. In that year, the Kraftwerke Oberhasli AG started construction on its multiphase plan to harness the power of the upper Aare River. The Aare is one of the Rhine's main Alpine feeder streams (and the actual source of the famous Rhine Gold).[5] Already in 1906, Bern canton secured the rights to utilize the power of the Aare's headwaters in the Oberhasli district. There, in the area of the Grimsel Pass, the Aare and its tributaries spring from several mighty glaciers, natural water reservoirs that guaranteed constant availability of power if their summer floods could be captured. The upper Aare valley offered numerous opportunities for storage, including the Grimselsee, a small natural lake that lay below the mighty Unteraar glacier. The Oberhasli company's plan called for damming of the Grimselsee at such a height that the ensuing reservoir would back up all the way up to, and indeed wash upon the shores of, the tongue of the Unteraar glacier. Doing so required the construction of two dams, including Europe's first concrete arch-gravity dam, and one of the highest in the world at the beginning of its construction.[6] By the end of project, engineers had created two other large reservoirs and four smaller ones. In the decades after the creation of the

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[5] Cioc, *The Rhine*, 26.
[6] Bruno Thierbach, "Die Kraftwerke Oberhasli," *Elektrotechnische Zeitschrift*, no. 40 (6 October 1932): 955- 958

Grimselsee reservoir, the retreat of the glacier—aided by the erosive power of the reservoir itself—led to the growth of the reservoir beyond its original length.

Extending the Alpine Energy Landscape

In his turn-of-the-century book *Anticipations*, author H.G. Wells turned his considerable intellectual powers to reflection on the fate of humankind. In Europe, in particular, the Englishman foresaw inevitable conflict. To his mind, the forces of scientific and technological progress were radically restructuring traditional human communities, creating new economic connections and friction as they transgressed older boundaries of nation and language. On the Continent, Wells envisaged an epic clash between German and French for "the linguistic conquest of Europe, and perhaps of the world." The setting for this conflict would be a vast emerging urban region that Wells predicted would become one of the greatest in the world. This territory centered on the Rhine, stretching from Paris in the West to Prague in the East, would become the "industrial capital of the old world." Wells believed this region would remain intact despite a new, crucial development he perceived: "Even when the coal-field industries of the plain give place to the industrial application of mountain-born electricity, this great city region will remain in its present position at the seaport end of the Old World. Considerations of transit will keep it where it has grown, and electricity will be brought to it in mighty cables from the torrents of the central European mountain mass."[7]

In many respects, Wells' vision of the future was quite prescient, even if he got some of the details wrong. French and Germans did indeed engage in an epic, continental clash, but their conflict proved to be more than just a linguistic one. And while the development of mountain power that he witnessed at the turn of the century continued to flourish , it did not truly displace

[7] H.G. Wells, *Anticipations of the Reaction of Mechanical and Scientific Progress upon Human Life and Thought*, 2nd ed. (London: Chapman & Hall, 1902), 239-242, http://www.gutenberg.org/files/19229/19229-h/19229-h.htm (accessed April 24, 2013).

the fossil fuel industries of the plains. Rather, as Wells more clearly foresaw, Alpine energy was increasingly made available outside of the Alps by means of mighty cables. Beginning in the 1920s, the outlines of the Alpine energy landscape began to grow as its energy reached farther and farther afield. Establishing links between the white coal of the Alps and other European regions had many justifications. The engineers and economists who conceived these plans viewed export and exchange as a means of international cooperation. By the close of the 1920s, the first major extension of the Alpine energy landscape occurred with completion of a high-voltage link between Germany's Ruhr and the water power of western Austria. Far more comprehensive plans to make the Alps into Europe's battery soon emerged.

One particularly important forum that promoted the idea of sending Alpine water power far and wide was the World Power Conferences. The World Power Conference (WPC) was the brainchild of the Scot D.N. Dunlop. Dunlop (1868-1935) wanted to provide a forum for engineers and scientists to discuss energy supply and technology. Dunlop's idealism nicely complemented his own business interests. Prior to the WPC, the Scot had worked for electrical trusts and acted as head of the British Electrical and Allied Manufacturers' Association—a trade association and primary sponsor of the conference. The World Power Conference—later renamed the World Energy Council—held principal meetings every six years beginning with the 1924 inaugural conference in London. In between these more heavily attended main meetings, smaller sectional conferences were held to discuss more circumscribed energy themes. At the World Power Conferences of the 1920s, those interested in energy discussed the field as a means of promoting international cooperation in the wake of the First World War.[8]

[8] Several short historical treatments concerning the World Power Conferences exist. Two of these take the form of small articles in the published proceedings of the 11th Symposium of the International Cooperation in History of Technology Committee (ICOHTEC). See Hans-Joachim Braun, "Die Weltenergiekonferenzen als Beispiel internationaler Kooperation," and Bruce Sinclair, "Regenerating the Future: The First World Power Conference," in

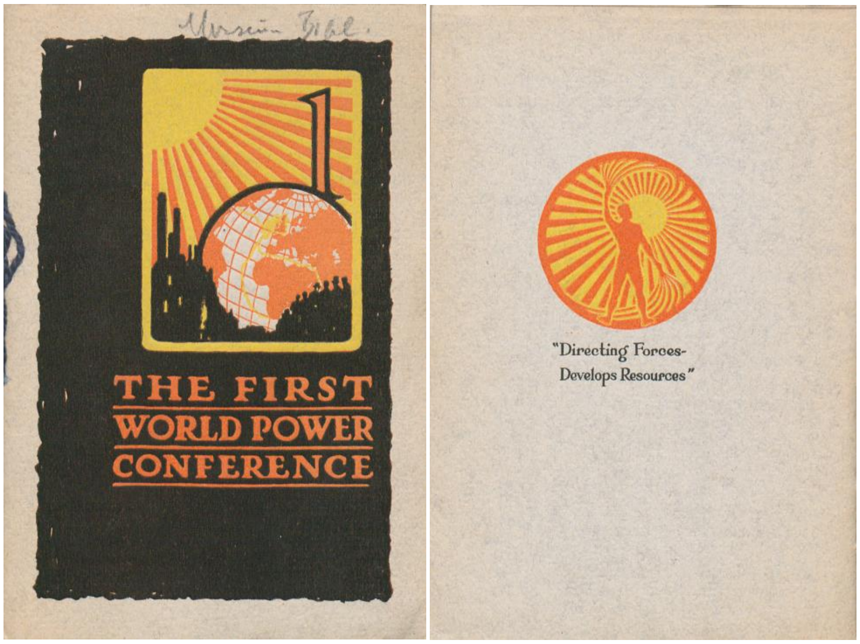

Figure 6. Cover of World Power Conference brochure and badge, 1924

The first meeting, held in London on the grounds of the British Empire Exhibit, was entitled "Resources of the World in Power and Fuel, and their use to the Greatest Possible Advantage." Some forty countries and colonies sent committees; the US contingent alone numbered three hundred members. Many of the participants in London expressed the belief that as a group, their ability to shape the development of energy resources enabled them to make an apolitical contribution towards healing the wounds between nations. O.C. Merrill of the American delegation argued that they had to come to London to talk about power in a different way. "Not the power of territorial possession or economic aggression," he explained, "but that of mechanical energy and electricity, the greatest tool ever placed in the hands of man." Speaking at the conference, the Prince of Wales—and future King Edward VIII—suggested that the participants comprised a sort of technological League of Nations, with a responsibility no less important than the actual existing international organization. Not all participants left London

Energie in der Geschichte: zur Aktualität der Technikgeschichte (Düsseldorf: [?] 1984) . See also Ian Fells, *World Energy 1923-1998 and Beyond: A Commemoration of the World Energy Council on its 75th Anniversary* (London: Atalink, 1998).

satisfied with the results of the meeting, or impressed with its ostensibly cooperative spirit. A correspondent for the German trade journal Water Power reported the French delegation's displeasure with the invitation of the former Central Powers to the meeting. He also decried the lack of true exchange of opinion and discussion.[9]

In London, the question of Alpine energy was—like most topics at this meeting—treated in a general way. On the one hand, the lands of the Alpine massif discussed the significance of white coal in their surveys of national power resources. But the Alps also figured prominently in the theme of international cooperation promoted by the conference. At the conference, the power development of navigable rivers and the export of electricity emerged as two main avenues of potential international cooperation, and both issues had Alpine connections. Many believed that Europe's great rivers held the "secret of the industrial transformation of Europe."[10] For the navigable stretches of Europe's large rivers could generate considerable power—enough, some felt, to become the Continent's main source of electricity—if harnessed under international administration. But for the most part their power development had stalled due to the conflicting interests of navigation. Developing the power of the Danube in particular, was viewed as a means of rehabilitating some of those lands along its banks that had suffered greatest from the previous war. The problem of developing the energy of Europe's navigable rivers extended to the upland stretches of the large rivers draining the Alps—the Rhône, Rhine, Po, and Danube—as well.[11]

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[9] C. von Gruenewaldt, *Die Wasserkraft: Zeitschrift für die gesamte Wasserwirtschaft* 15, no. 14 (15 July 1924): 235.

[10] The quote comes from a small brochure prepared for the Conference. See *The First World Power Conference June 30-July 12 1924. Under the Presidency of the Rt. Hon. The Earl of Derby, K.G. at the Conference Halls of the British Empire Exhibition Wembley, London* (London: Offices of the WPC, [1924?]), 16.

[11] In some cases, as with the upper Rhine, there had already been considerable hydropower development by the 1920s. Some at the time also advocated extending major shipping into the Alps. For example, plans to connect the upper Rhine, which permitted only local shipping, to the North Sea also existed. The scheme would have made a town in Austria the highest "seaport" in the world, but it failed for lack of a cost-effective way around the formidable Rhine falls at Schaffhausen. Cioc, *The Rhine*, 27, 63-64.

The Alps also stood out as a model of electricity export with great potential to grow. In the early 1920s the movement of electricity across national borders remained quite rare. One of the few countries that did export power was Switzerland, which fed hydroelectricity to many of its neighbors. At the WPC, exporting Switzerland's yet untapped hydropower seemed an ideal way to stimulate international economic cooperation by activating unused resources.[12]

A more focused discussion of the necessity of transporting Alpine water power out of the mountains took place at the next WPC meeting in Switzerland two years later. The follow-up to London was the first of the so-called "sectional" meetings, organized around the narrower topic of water power and inland navigation. There were many reasons to hold a conference on water power and shipping in the town of Basel. On the transport side, Basel was notable as the head of navigation on the Rhine. And as Dr. Tissot, the president of the Swiss national committee to the WPC, reminded the audience in his speech before the general

Facsimile of the cover of the Congress Card.
Facsimilé de la couverture de la Carte de Congrès.
Faksimile des Umschlages der Kongress-Karte.

Figure 7. Congress Card for the WPC Basel Sectional Meeting, 1926

[12] *The First World Power Conference*, 16-17.

assembly, Switzerland was also at the head of the class in matters hydroelectric. Tissot maintained that electrification in Switzerland was "the most developed and advanced" of any country. In Switzerland, Tissot noted, conference attendees would also find some of the most modern hydroplants in the world, including the recently completed Wägital dam.[13] In Basel, the connection between Alpine water power and international cooperation was given symbolic representation in the conference's badge, which depicted a heavenly handshake before a scene of a mountain dam. In the words of a representative from the Basel city canton, the intertwined hands had two meanings. First, they represented the conference themes of navigation and water power exploitation. But they also signified and invitation "to the peoples, separated by the world war, to extend each other their hands in common on the neutral ground of our land."[14]

In his speech during the opening session, president Dunlop also had words of admiration for Switzerland's water power accomplishments. But to his mind, Switzerland's success was merely one part of a broader regional success, borne of international cooperation with the potential for more. Indeed, Dunlop saw an Alpine "power zone":

> In the Alps especially, all the possibilities of complete co-operation and unification are present; the Alpine Power Block as spread over Switzerland, N. Italy, Austria, South-Eastern France and Bavaria, represents now generating plant [sic] aggregating over 4 million kilowatts, capable of producing 20 billion units, and as such has become one of the greatest power zones in the world.

Dunlop believed the "Alpine Block" had resulted from the efforts of five countries working more or less cooperatively to utilize to the fullest the natural energy resources present in the region, and he judged that the bulk of this achievement happened in the postwar period. Moreover, he believed the Alpine model was one worth emulating: "To constitute power zones in every part of

[13] *Transactions of the World Power Conference, Basle Sectional Meeting/Compte Rendu, de la Conférence Mondiale de l'Énergie, session spéciale de Bâle 1926/Berichterstattung der Weltkraftkonferenz, Sondertagung Basel 1926*, Vol. 1 (Basel: E. Birkhaeuser, 1927), 1192.
[14] *Transactions*, Vol. 1, 1204-1205.

the world where nature supplies the necessary resources, and through those zones raise the economic and industrial standard of development, remains one of the greatest problems now confronting scientists, industrialists, and engineers, and there is no doubt that the path to greater economic prosperity lies in this direction." While he recognized many obstacles lay before the realization of such a goal, Dunlop avowed that "When man will the good [sic], then the tempest of national and international jealousies will be stilled and the order of the starry heavens will be reflected on earth."[15]

Following Dunlop's speech, one conference panel devoted a great deal of discussion to the possibility of extending that Alpine power zone. In the section devoted to international "exchanges" of electricity, the subject of linking Alpine white coal up with other regional energy systems made up a fair portion of the dialogue. For one thing, as many of the panel's participants noted, the Alps were in fact one of the few places on the globe where international exchanges of electricity took place. In the report summarizing the essays Jean Landry, president of the large Swiss utility Energie de l'Ouest-Suisse (EOS) and professor at the university of Lausanne, noted that significant exchanges of electricity only occurred between Sweden and Denmark, Canada and the United States, and Switzerland with its neighbors Germany, France, and Italy. Indeed, Landry observed, in 1925 Switzerland had exported nearly twenty percent of its total electricity production. Nearly half of this energy went to France where it made up some three percent of that country's electricity supply. The common denominator in all of the global electricity exchanges, Landry explained, was that one of the partners possessed more water power than the other.[16] Why this should be the case, was obvious to the panelists. As Theodore Rich from Great Britain put it, "when the question of the export of electrical power first came up, it was

[15] *Transactions*, Vol. 1, 1199-1201.
[16] *Transactions*, Vol. 1, 1113-1114.

primarily on the basis of hydraulic power, because it is impossible to carry, as we have heard, the products of a waterfall in a cask or box."[17]

To the panelists, electricity exchanges should occur between areas with abundant and complementary energy resources. For Oskar von Miller, the units involved were not nations but regions with specific power resources. Exchange was not an international question, rather "a question between regions rich with water power and regions that control large amounts of coal or other fuels."[18] Robert Haas, director of one of the original large hydropower plants on the High Rhine, concurred, arguing that one of the most sensible long-distance exchanges in Europe would be between the Alps and Germany's lignite fields. Haas maintained that any geographic area where the lay of the land enabled the natural storage of water in lakes or artificial storage in reservoirs had the potential to generate large amounts of hydroelectricity. In this respect, the Alpine and pre-Alpine lands of Germany, Austria, and Switzerland were "richly blessed." Haas contended that these regions should take full advantage of that gift by exchanging surplus water power.

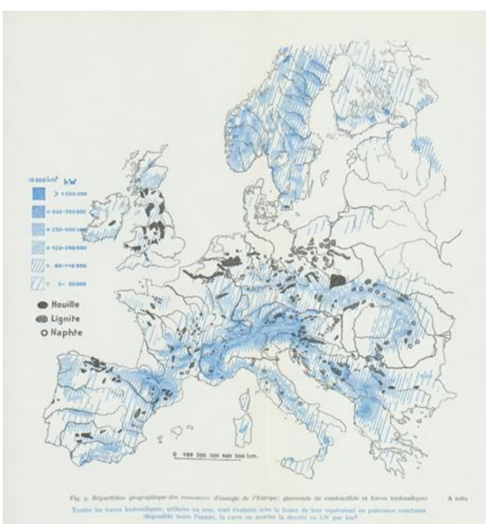

Figure 8. Geographic distribution of energy sources in Europe, 1926

[17] *Transactions*, Vol. 1, 1170.
[18] *Transactions*, Vol. 1, 1171.

For these engineers, the necessity of exchange was obvious. As Landry explained, "Nature has not distributed her wealth at all uniformly, and it is necessary therefore that what can be only imperfectly carried out within political boundaries should be obtained, wherever possible by the exchange of energy between countries which, from point of power resources, are supplementary."[19] Another panelist marshaled a map demonstrating the vast geographic diversity of energy resources in Europe, and hence the necessity of exchange. For the engineers in Basel, this relatively uncomplicated state of affairs was spoiled by politics. Robert Haas complained of the difficulties of exchanging electricity between Germany and Switzerland and blamed them on the latter country's national law on water power exploitation. Passed during the First World War, the law made it necessary for utilities to acquire federal permits for electricity exports, and thus opened any potential exchange to domestic political struggles. In the panel's closing discussion, Haas made a plea "that the statesmen, the lawmaker, the diplomat might not ruin, what the engineer, the businessman (*Grosskaufmann*) have created, by calling to life the possibility of the exchange of electrical energy." For this traffic in electricity represented "another important link in the peaceful cooperation of the nations."[20]

Even as the as these engineers were discussing the necessity and significance of electricity exchanges in Basel, one of Europe's most powerful utilities was in the process of establishing one of the most significant linkages of the Alpine energy region with the rest of Europe. That company was the Rheinisch-westfälisches Elektrizitätswerk AG (RWE), Germany's largest utility and operator of the world's largest coal-fired power plant at the time.[21] The RWE was a product of the fossil energy riches of western Germany—particularly the Ruhr—and the efforts of its most important director Hugo Stinnes (1870-1924). In its early

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[19] *Transactions*, Vol. 1, 1124.
[20] *Transactions*, Vol. 1, 1163.
[21] What follows borrows from Hughes, *Networks of Power*, 408-428.

years, the company lived off the combination of coal-mining, steelmaking, and the chemical industry located in the region. Eventually RWE would be a main driver of their success. After acquiring the company in 1902, the mine owner Hugo Stinnes would go on to become one of Germany's most important industrial barons, thanks largely to the success of RWE. Stinnes concentrated his efforts on making RWE the main supplier of electricity in the region through acquisition of other utilities and development of its grid. Just before the start of the Great War, RWE constructed a lignite power plant in the vicinity of Cologne, which it then rapidly expanded in order to swiftly meet the rise in wartime demand. The growth of the brown coal-fired Goldenbergwerk continued in the postwar period, as the Treaty of Versailles and Germany's reparations agreements stripped the country of much of its anthracite supplies.

Already in the early 1920s, RWE initiated a plan to expand its grid southward. After preparing the way with a series of acquisitions of south German utilities, RWE—inspired by the worldwide leader in long-distance power transmission of California—began construction of a high-voltage link to the Austrian Alps beginning in 1924. Starting in the lignite fields around Cologne, this 800-kilometer long transmission line was to feed power from the Austrian province of Vorarlberg, which was in the process of completing a high-altitude dam in the Ill River basin. After six years of construction, transmission began in 1930. The line represented a remarkable technical achievement as the first instance of a 220 kilovolt transmission in all of Europe. It would go on to form the backbone of Germany's burgeoning high-voltage grid. It also represented the linking of two of Europe's most important electricity producing regions. The Ruhr and the Alps were now wired in parallel on the same circuit, enabling the two regions to complement and supplement one another. The Ruhr could now take advantage of the cheap electricity that only could be provided by hydropower; Alpine hydroplants on the other hand, could now fall back on the unparalleled reliability of fossil fuel energy.

Bringing Alpine water power to the Ruhr was part of RWE's corporate strategy of rationalization they called *Verbundbetrieb*. RWE believed there were economic gains to be had by coordinating a grid of power plants spread out over a large area. In this system, the hydropower of Alpine reservoirs was to play for the distant Ruhr the role that it had been playing on a smaller scale since the turn of the century. This stored water power would act as a reserve for the network, to be employed whenever needed. With the Alps covering the grid's auxiliary power, RWE believed that it could use its other power sources—run-of-the-river hydro, lignite, and anthracite—more efficiently. Similar thinking inspired even grander visions of an even grander role for white coal.

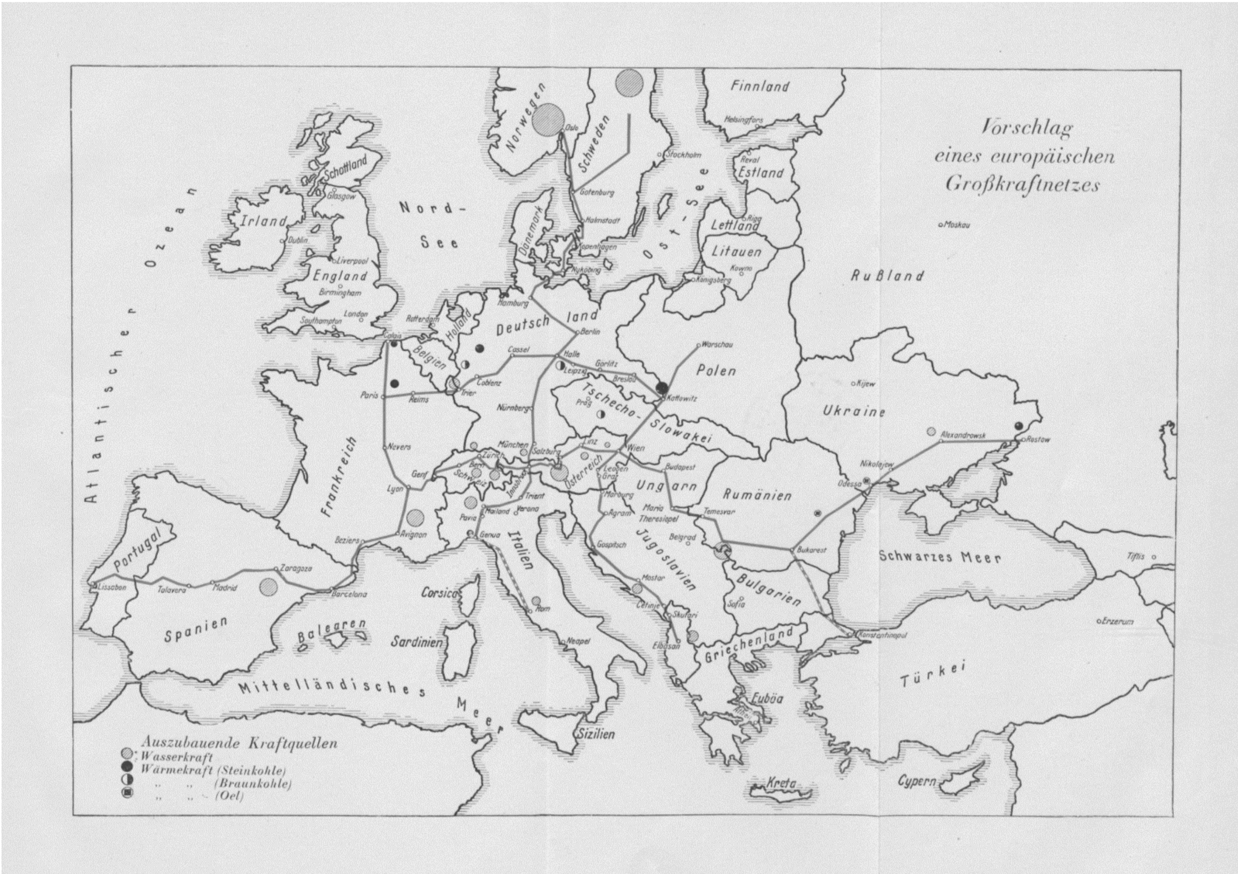

Figure 9. Oskar Oliven, Proposal for a European "Superpower" Grid, WPC 1930

One of these schemes marked one of the highpoints of the 1930 WPC meeting in Berlin. At the second principal meeting, Oskar Oliven, an executive with a German electrical company, outlined his plan for the creation of a European "superpower grid" (*Großkraftnetz*). While Oliven appreciated the work invested in the development of Europe's electricity grids, he believed their expansion thus far had been far too inorganic a process. Like most of his engineering colleagues, he particularly decried the lack of exchange between nations, and blamed it on short-sighted politics. Oliven believed the time had come to cooperate to create something big. "Now we stand before a task," he explained, "confronting all of the peoples of Europe, that only can be solved if we overcome all of the personal, material, and political difficulties and open the visible and invisible borders to electric energy."[22] Oliven recommended the creation of a high-voltage continental grid that would interconnect all of Europe's primary sources of electrical energy. He envisioned the construction of five primary transmission lines, two linking east and west, and three running north-south. His plan also saw for the further development of Europe's energy sources to feed into the grid. In his scheme, the Alps represented the fulcrum of the entire system.

The primary advantage of his plan, Oliven argued, lay in its ability to balance electricity production and consumption in Europe. How this would function, Oliven illustrated with an example involving the Alps:

> An electric connection between the water power of the high Alps, which reaches its maximum in summer due to the melt, the still-to-be built hydraulic works of the Danube at the Iron Gate, and further the power of the Adriatic coast, where atmospheric precipitation falls down to the valleys in the form of rain mainly in the winter, creates a balance that will make it possible to avoid large dams, or at least postpone them for future."

The same logic held for an electric linking of the Alps with the water power of Central Europe's secondary mountain ranges (*Mittelgebirge*), which also reached its maximum during the rainier portion of the colder months. The possibilities of balancing the load were even grander as the scale involved increased. Oliven argued that "on our continent, there exists a natural storage of water due to differences in climatic and atmospheric circumstances, and if we exploit this natural water storage at the right time and in the right places, and utilize our superpower network to deliver it to the necessary locations, we will be able to save capital on construction while using our works substantially more efficiently."[23]

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[22] Oskar Oliven, "Europas Großkraftlinien: Vorschlag eines europäischen Großkraftnetzes," in *Gesamtbericht. Zweite Weltkraftkonferenz. Transactions. Second World Power Conference. Compte rendu. Deuxième Conférence Mondiale de l'Énergie*, ed. F. Zur Nedden (Berlin: VDI-Verlag, 1930), XIX: 31.
[23] Oliven, "Europas Großkraftlinien," 32.

The superpower grid, Oliven claimed, would also balance consumption. As an example of how the supraregional expansion of grids improved utility load factors, Oliven pointed to the recent success of RWE, Europe's largest utility. Thanks to its expansion into the Alps, RWE enjoyed the best load factor, meaning it most efficiently utilized its existing plant. Oliven promised that a European grid would be even more efficient, as it would take advantage of various geographic and climatic conditions that RWE had not yet capitalized on. Harvests, vacations, construction: all took place on various schedules throughout Europe. If serviced by a single grid, aggregate capacity could be wheeled to meet periodic demands. The European grid would also flatten out peak demands which hindered the economy of works. Interconnection would allow power plants to run at or near full capacity constantly, by allowing them to ship electricity to wherever it was needed in the grid. When it was dark in Rostov, Oliven noted, Bucharest still had an hour of light. With the existence of a European grid, Oliven optimistically argued, unused afternoon capacity in Romania could be wheeled to Russia to provide nighttime illumination.[24]

Oliven's plan more or less marked the high point of interwar plans for cooperation in European electricity. Even as he presented his work at the World Power Conference in Berlin, the world was beginning to slide into economic depression. In Europe, the downturn extinguished much of the international goodwill that nourished plans like Oliven's, and eviscerated the capital necessary to build them. In the 1930s international cooperation gave way to another broad motivation for energy development.

The Alps and Autarky

After the First World War, a new justification for harnessing the power of the Alps emerged: the quest for national economic independence. In the interwar years, voices

[24] Oliven, "Europas Großkraftlinien," 32.

throughout west-central Europe called for the development of white coal as a means of achieving national autarky. Especially after the onset of the world depression such viewpoints gained in prominence and inspired a significant portion of the hydroelectric development in the Alps during the 1930s. One of the most interesting examples of Alpine hydro development in the name of interwar autarky comes from the Italian region of South Tyrol. This Alpine territory on the south side of the Brenner Pass belonged to the Austro-Hungarian crownland of Tyrol until 1918, when it became part of Italy. Beginning in the early 1920s, the Italian fascist state pursued water power development in South Tyrol for the benefit of Italian industry outside of the province. Eventually, hydro projects were conceived as a means to Italianize the area, by providing an industrial base to employ migrants from the south. These efforts culminated with the creation of an "industrial zone" in the province's capital of Bolzano around the time of Mussolini's formal announcement of his country's autarky program in 1936.[25]

Present day South Tyrol is Italy's northernmost province. The area is the cradle of the Tyrolean state, which evolved from a county in the medieval period to one of the Habsburg crownlands after the end of the Napoleonic wars. In the eastern part of the province lies the lion's share of the Dolomites, famous as one of the most optically impressive mountain formations in the world. South Tyrol's nearly 8,000 square kilometers are drained primarily by one river, the Adige, which has its source in the mountains bordering Austria and flows out of the province into the north Italian plain before entering the Adriatic north of Venice. The Adige's main tributary is the Isarco. South Tyrol's second longest river, the Isarco flows south from the Brenner Pass where it joins with the Adige to the south of Bolzano. The confluence of

[25] What follows draws from Josef Riedmann, *Geschichte Tirols*, 3d ed. (Vienna: Verlag für Geschichte und Politik, 2001), 218-220; 267-268; Othmar Parteli, ed., *Die Zeit von 1918 bis 1970; Südtirol*, Vol. 4, part 1, Josef Fontana ed., *Geschichte des Landes Tirol* (Bozen: Athesia, 1988), 53-55; 291, 652-653.

these two large valleys and transportation arteries has helped Bolzano ascend to the status of the region's economic and political capital.

The fact that the Adige drained to the Adriatic had long been seen by Italian nationalists as natural proof that all of the southern portion of the crownland of Tyrol that it drained should be part of Italy. The idea that the southern Tyrol belonged to Italy reaches back to the early nineteenth century, and it gained credibility thanks to the work of several Italian geographers who advanced a watershed theory of politics. Nationalist clamor for the annexation of South Tyrol intensified around the turn of the twentieth century. One of the conditions of Italy's entrance into the war on the side of the Entente in 1915 had been the annexation of Tyrol up to the Brenner Pass. After the Allies frustrated Italian designs for territorial aggrandizement on the Adriatic coast in favor of the new state of Yugoslavia, they gave in to Italian insistence on annexing the southern Tyrol. While the border change did bring hundreds of thousands of Italian speakers in the southernmost portion of Tyrol (now Trentino) into the kingdom, it also placed 250,000 German-speaking Tyroleans inside the north Italian frontier. This region from Salurn to Brenner with an overwhelming German-speaking majority was given the name Alto Adige. The Italian state would soon go about putting the upper Adige to work.

Before 1918, South Tyrol was an overwhelmingly agrarian region. This state of affairs changed dramatically after its incorporation into Italy. Particularly after the rise of Mussolini, who came to power in 1922, the Italian state sought to systematically develop the water power of its new territory. Mussolini's fascist regime was especially interested in nationalist goals like expanding military industries and promoting autarky in strategic economic sectors. Electricity supply was one such arena, indeed, one of the only sectors where Italy could hope to approach something near self-sufficiency. Though the country possessed almost none of the strategic resources necessary to increase industrial and military might, it could boast a large amount of potential electricity in its water power—particularly in the Alps. Electricity supply was all the more important because vast quantities of cheap electricity could in part compensate for a lack of heavy industry—through the magic of the electro-chemistry and electro-metallurgy. During the 1920s then, Mussolini's regime promoted white coal development throughout Italy's Alps.

In this climate, the development of South Tyrol's almost untouched water power resources had the full support of the state. In 1923, a royal decree changed South Tyrol's water law to facilitate hydropower construction. The legislation aided the realization of a power plant on the upper Adige near the city of Merano in 1925. The new electricity powered South Tyrol's first large industrial operation, a nitrogen plant run by Italy's leading chemical firm Montecatini. The factory provided work for large numbers of Italian-speaking immigrants from the city of Turin. Around the same time, the Società Idroelettrica dell'Isarco turned its attention to harnessing the power of that river. The Kardaun plant, completed in 1929 with the help of a five-million-dollar loan from the United States, became Europe's largest hydroelectric plant for a spell.

The proximity of the Isarco to Bolzano made its energy particularly useful for the centerpiece of Italian autarky plans in the newly acquired region: the creation of the so-called "Bolzano industry zone." Beginning in 1935, and with critical financial support from the Italian state, a number of major Italian industrial firms set up South Tyrolean branch operations in the former orchards south of Bolzano. Suddenly, Bolzano was home to a burgeoning metallurgical industry (steel, aluminum) a magnesium plant, and automobile production. From an economic standpoint, the location of these industries in the Alps was somewhat questionable. The raw materials they required for operation had to be transported from far and wide. Since the advent of long-distance power transmission in the 1890s, most Italian companies had opted to transport electricity to the more strategically located north Italian plain . But the various works in the Bolzano industrial zone —executed with massive state support—were also intended as a means of Italianizing the capital and its region. The workers who manned these factories came also exclusively from the south. The energy powering all of these industries came from the giant Kardaun power plant and several additional Isarco dams built after its completion.

The grand transformation of the waters of South Tyrol in the name of autarky and Italianization had correspondingly grand results. By the outbreak of the Second World War, South Tyrol's waterways generated one hundred times more electricity than in 1918. Their annual production of two billion kilowatt hours equaled twelve percent of Italy's total. Much of this electricity found its way to factories in northern Italy. But beginning with the establishment of the fertilizer industry in the late 1920s, the South Tyrolean branches of major Italian industries utilized this water power on the spot. The Montecatini plant in South Tyrol produced ten percent of the country's nitrogenous fertilizers. The operations of the Bolzano industrial zone also became an important part of Italian war production. The migration of thousands of workers to these workplaces led to an abrupt jump in the city's population, and sharply increased the number of Italians there. South Tyrol's new energy significance for the Italian state—and the substantial outlays required to create it—would remain an important argument for keeping South Tyrol Italian in the decades to come.

Storing Super Power: Austria's Hohe Tauern Mountains

Few schemes better epitomize the final chapter in the making of Europe's Battery than the one that concentrated on Austria's Hohe Tauern mountain region from the interwar years until the 1950s. From their inception, plans to develop the water power of the Hohe Tauern operated on a scale that dwarfed all previous efforts, including some of the large dams of the early interwar years. In contrast to earlier hydropower development, the goal in the Hohe Tauern was never to activate the power potential of one river, but to take advantage of the high-altitude water power of an entire mountain range. European engineers identified this mountain group as ideal for a large-scale power storage project in the mid-1920s. After clashes over the proper way to exploit this power, however, enthusiasm for the project waned with the beginning of the Great Depression. Excitement revived in 1938 in the immediate aftermath of the Austrian *Anschluss* with Germany, as the idea of large dam construction appealed to many Nazis. What the National Socialists began was finished in 1955 by the second Austrian republic, thanks in large part to Cold War-motivated credit from the United States. With its completion, the Austrians took the first step in exploiting the Tauern range for its unparalleled storage capacity, in the hopes of correcting white coal's glaring shortcomings.

Austria's Hohe Tauern mountain range is special in many ways. The Tauern form the continuation of the main crest of the Alps as it passes from the western provinces of Austria. Comprising an area of some 6,000 square kilometers, the range is home to Austria's two highest mountains in the Grossglockner (3797 m) and the slightly smaller Grossvenediger (3674 m). The former peak represents the center of the Hohe Tauern National Park, the largest nature reserve in the Alps. Since 1935, the Grossglockner and the Pasterze Kees glacier—one of the largest glaciers in the eastern Alps—have been accessible to motorists via the Grossglockner High-Alpine Road. This spectacular drive winds through the Tauern, crossing the main crest at an altitude of 2505 meters. Tourism in the Hohe Tauern has a long tradition. The classical spas of Mayrhofen and Badgastein in the northern part of the range have been attracting visitors into the Alps since the nineteenth century. The Tauern are well known in the geological community for the famous "window" that exposes the basement rocks of this part of the Alps at surface level. In terms of hydrology, the range is drained in the north and south by the Salzach and Drava (Drau) rivers respectively.[26]

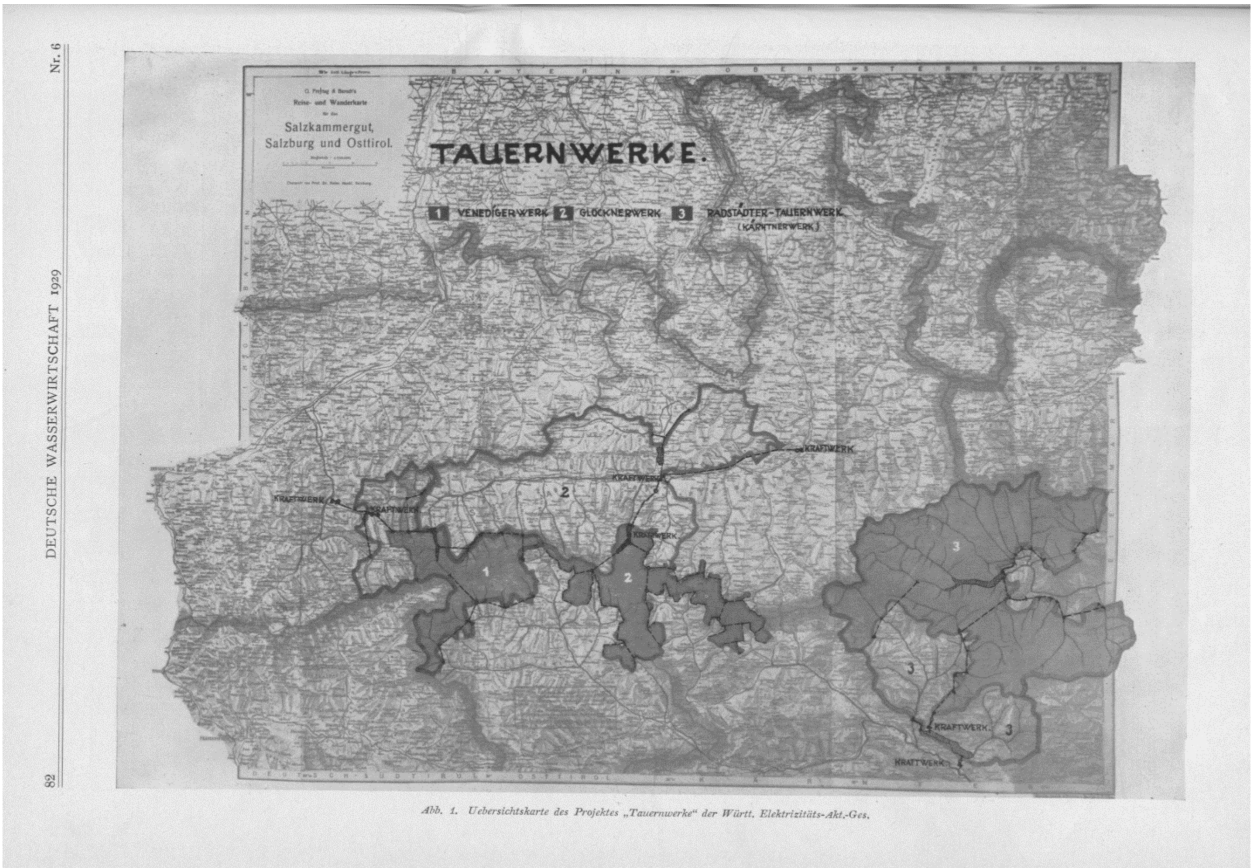

Figure 4. Overview of the "Tauern Works" Project of the WEAG from *Deutsche Wasserwirtschaft,* 1929

The idea of systematically exploiting the water power of the entire Hohe Tauern range first emerged in the mid-1920s. The plan was the brainchild of a smaller southern German utility called the Württembergische Elektritzitätswerke AG (WEAG). WEAG, like many German utilities at the time, was preoccupied with expansion strategies to meet the continually rising demand for electricity in that country. For several years, the company had been exploring the possibility of developing the rich water power of the Austrian Alps. Since the amount of power

[26] Nicholas and Nina Shoumatoff, *The Alps,* 32, 42.

slumbering in Alpine waterways was far too great to be utilized by the smaller Austrian economy, the WEAG planned on exporting power to Germany. The WEAG became convinced, however, that making this energy competitive with the cheap electricity generated by German lignite required a completely new approach to hydro. Instead of simply attempting to harness the power of individual rivers, the WEAG considered the prospect of developing the power of entire mountain ranges. This could be achieved by finding suitable high-Alpine valleys to serve as power reservoirs, and then concentrating water from throughout the mountain group in these basins. The WEAG believed it had found an ideal setting to do this in the Hohe Tauern range. Their plan saw for the construction of three separate "Tauern Works", two of which would utilize the water draining off of the Grossvenediger and Grossglockner peaks. A series of canals and tunnels would shunt the water that coursed down these mountains' north faces to several reservoirs, piercing watersheds, crossing Austrian provincial borders, and covering considerable distance if necessary. Water from the Grossvenediger catchment area was to be stored in the Krimmler Achtal valley, while the Grossglockner dams would be located in the steepest valley of the entire range, the Kaprun valley. The WEAG calculated that the turbines of their *Tauernwerke* would generate some 2 billion kilowatt hours of electricity, running twelve hours a day the whole year round. Of the three separate Tauern projects, WEAG deemed the Venedigerwerk to be the most promising, and envisioned beginning the development of Tauern hydro there. The plan's architects argued that the energy of the Tauern would be a salve for both countries economic woes, and a means of "tightening the bonds" between the two countries.[27]

[27] "Tauernwerke-Projekt der Württ. Elektrizitäts-AG Stuttgart," *Deutsche Wasserwirtschaft: Zentralblatt für Wasserbau und Wasserwirtschaft* 24, no. 6 (20 June 1929): 81-88.

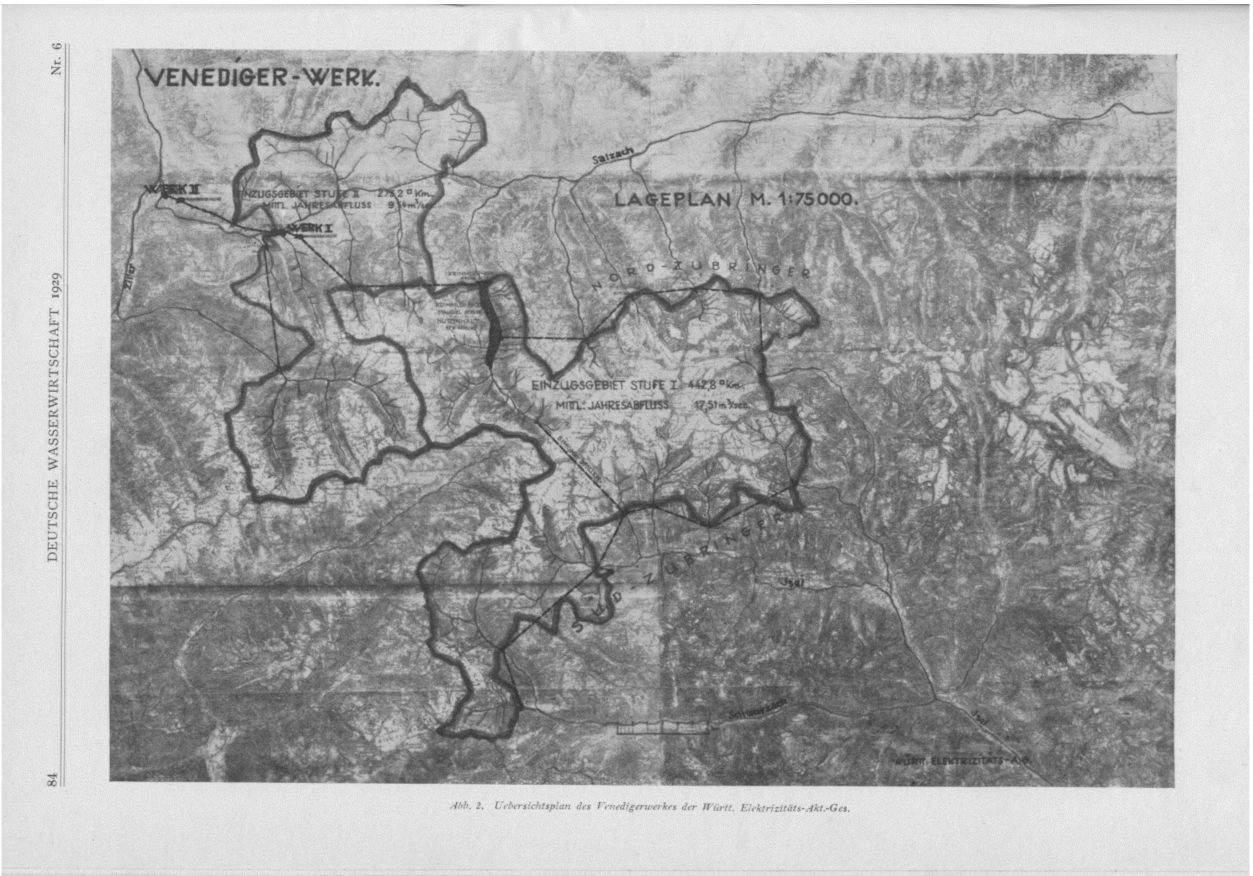

Figure 5. Overview of the WEAG Venedigerwerk from *Deutsche Wasserwirtschaft*, 1929

At roughly the same time the giant German electrical trust AEG publicized its own ideas for a more ambitious Tauern project. The AEG project was designed by Wilhelm Münch, chairman of the company’s hydropower department. Towards the middle of the 1920s, Münch had also turned his attention towards the enormous unused water power reserves of the Austrian Alps. His focus also narrowed on the Tauern water power, but Münch envisioned a grander project. Where the WEAG proposed building dams throughout the Tauern to store and harness power, Münch suggested centralizing all of the range's water in one valley. He chose the Kaprun valley because it was the steepest one with the necessary space to store the water, allowing for the "maximum generation of power."

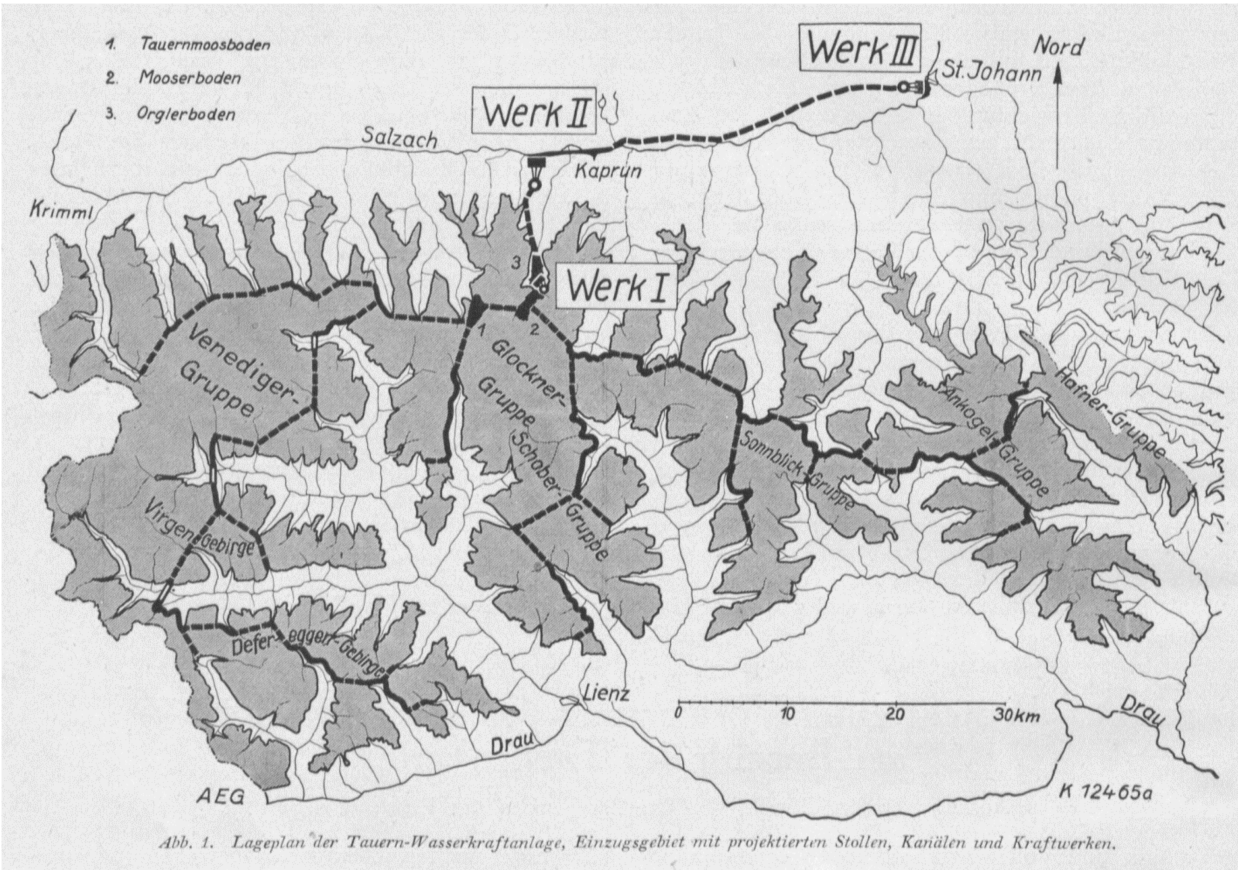

Abb. 1. Lageplan der Tauern-Wasserkraftanlage, Einzugsgebiet mit projektierten Stollen, Kanälen und Kraftwerken.

Figure 6. Layout of the AEG Tauern Work, 1929

The key to the AEG plan was the construction of an extensive system of high-altitude canals built into the slopes of the Tauern mountains (*Hangkanäle*). These canals would capture various rivulets before they collected into streams and deliver them to the reservoirs, acting like a network of high-altitude gutters on the roof of Austria's highest mountains. Only this method, Münch claimed, would achieve the greatest amount of raw water power available in the Hohe Tauern. Anything else was, in Münch's opinion, a wasteful depletion of precious natural resources (*Raubbau*). In all, the plan called for some 1,200 kilometers of canals and tunnels to channel Tauern water to the highest reservoir in the Kaprun valley at 2100 m. At nearly seven million kilowatt hours, Münch's Tauern Works would generate almost three times as much electricity as the WEAG plan, or almost half the entire public electricity supply in Germany in

1927. This enormous amount of power would be enough to cover all of Austria's demands—especially for critical winter electricity—while leaving plenty of extra capacity for transport to the industrial region in present-day eastern Germany. In justifying his gigantic project, Münch argued that every state had to develop all of its available water power resources in order to be able to keep up with competing national economies. He reckoned on a construction time of between ten and twelve years.[28]

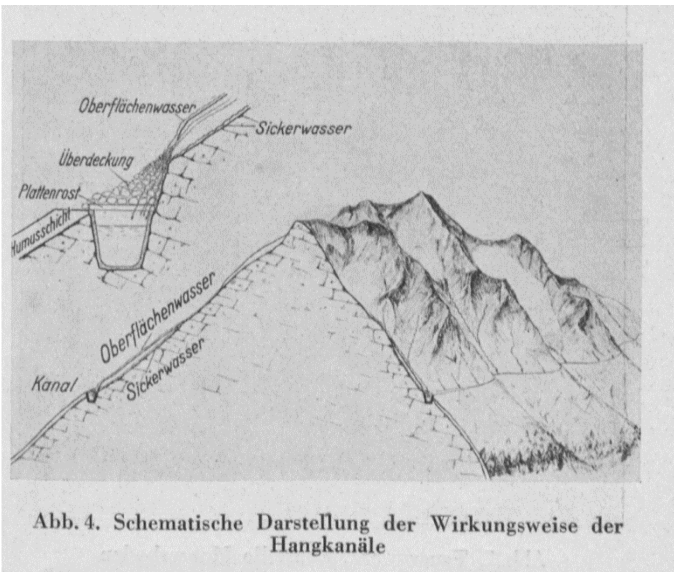

Figure 7. Schematic Diagram of the Function of the Slope Canals, 1929

At the outset, Münch's plan seemed to gain the upper hand. It found a powerful backer in the governor of Austria's Salzburg province, Franz Rehrl. Rehrl believed that Austria needed to move from the erection of "middling" hydropower plants to those "of the greatest dimension with the widest radius of action." And nowhere in the entire Alpine area, he claimed, was there the possibility to exploit such a high-lying area in so few stages, with such a steep gradient. In the AEG project, Rehrl saw a unique opportunity to animate the sluggish economy of his mostly agrarian province. Besides the benefits that would come from selling electricity to Germany, the

[28] Wilhelm Münch, "Das Tauernwerk," *Deutsche Wasserwirtschaft* 26, no. 1 (10 January 1931): 1-5.

project would provide an enormous boost to the local construction industry. The AEG project would create thousands of jobs building new roads, and performing the numerous hydraulic engineering tasks such an undertaking would require. Some of Rehrl's support may also have derived from a sense of competition with other provinces of Alpine Austria. Rehrl noted that Salzburg's western neighbor of Tirol had been transporting and selling its hydroelectricity to nearby Bavaria for several years. And tiny Vorarlberg in westernmost Austria had recently become the first Alpine land to send its water power hundreds of kilometers north to the heartland of coal-fired German utilities in the Rhineland.[29]

The battle lines over the Tauern power had now been drawn. Should the water power of the Hohe Tauern be developed in the decentralized manner, with a Glockner Works being just one of several distinct hydropower groups in the range? Or should Münch's more ambitious AEG plan to corral all the water in a giant Glockner Work get the nod? Throughout the 1930s, German and Austrian engineers debated this question at length in dozens of articles in German hydropower trade journals. In the ensuing "battle of the projects" over a dozen of different groups registered their opinion on the subject.[30] Attitudes varied by nationality, as well as by Austrian provincial identity. Nevertheless a general consensus formed (among Austrian engineers) that the AEG project was outsized, even utopian in scale. Most engineers deemed the

[29] Salzburger Landesarchiv (SLA) RehrlTW 1929/0001: Franz Rehrl, "Bericht der Landesregierung über das Projekt einer Verwertung der Wasserkräfte im Bereiche der Tauernkette" (29 January 1929).

[30] A smallsampling of this vast literature: Richard Moro, "Betrachtungen über das Tauernkraftwerks-projekt der AEG," *Die Wasserwirtschaft* 24, no. 8 (1931): 109-117; Thürnau, "Das Tauernwerksprojekt der AEG," *Die Wasserwirtschaft* 24, no. 11 (1931): 157-158; "Stellungnahme der Ingenieurkammer für Tirol und Vorarlberg zu den Projekten der Allgemeinen Elektrizitäts-Gesellschaft Berlin (AEG) und der Österreichishcen Kraftwerke A.-G. (Oeka) für das Tauernkraftwerk," *Die Wasserwirtschaft* 24, no. 11 (1931): 158-162; Richard Hofbauer, "Zeitgemäße Betrachtungen über den projktierten Ausbau der österr. Alpenwasserkräfte mit Bezug auf deren künftige Funktion in der Energiewirtschaft Mitteleuropras," *Die Wasserwirtschaft* 24, no. 12 (1931): 169-171; Erich Heller, "Technische Probleme des Tauernwerks," *Die Wasserwirtschaft* 24, no. 13/14 (1931): 181-187; Petersen, "Die Energiewirtschaft des Tauernkraftwerkes," *Die Wasserwirtschaft* 24, no. 13/14 (1931): 188-190; Oskar Vas, "Die Ausnutzung der Tauernwasserkräfte als österreichisches Problem," *Die Wasserwirtschaft* 24, no. 13/14 (1931): 191-201; Hans Dreyer, "Großwasserkräfte im Dienst der deutschen Energiewirtschaft," *Die Wasserkraft und Wasserwirtschaft* 26 no. 15 (1 August 1931): 177-183; Johannes Hallinger, "Das Tauernwerk im Wirtschaftsspiegel," *Wasserkraft und Wasserwirtschaft* 27, no. 2 (16 January 1932): 13-15.

slope canals to be technically unfeasible, and the idea of diverting so much water over such distances to be too radical. Hermann Grengg, a confident hydraulic engineer and technical director of the Austrian province of Styria's electrical utility, emerged as one of the project's greatest opponents, attacking the AEG's centralization idea as a "propagandistic derailment."[31] His opinion would later attain crucial importance for the future of the Hohe Tauern.

Ultimately, the discussion became moot. Although the Salzburg provincial government had taken several preliminary steps towards realizing the centralized AEG plan, little actual progress was made. The "battle of the systems" had raised doubts about the feasibility of Münch's ideas. More importantly, negotiations between the concerned provinces and their provincial utilities made little headway. By 1930, the worsening economic crisis diminished AEG's interest in the costly project. The ascent of National Socialism in Germany, finally, made AEG activity in Austria an impossibility.[32]

Despite the political and economic circumstances, German interest in the Hohe Tauern did not disappear for long. With the initiation of rearmament, German economic planners took a marked interest in the economic capacities of their southern neighbor. Multiple German government agencies highlighted the Tauern power in analyses of Austrian economic potential compiled after 1936. High-level actors within the Nazi state remained personally interested in the energy potential of the mountain chain. In a conversation just before the *Anschluss* for instance, Wilhelm Keppler, a German businessman and Nazi party functionary, informed the foreign minister Joachim von Ribbentrop about the Hohe Tauern. Keppler would go on to

[31] Rigele, "Das Tauernkraftwerk Glockner-Kaprun," 59.
[32] SLA RSTH V/3 212: "Tauernkraftwerk."

become Hitler's Reich Commissioner for Austria, charged with integrating the Austrian economy with the German.[33]

In March 1938, German forces invaded and occupied Austria. Before a jubilant crowd in Vienna, Adolf Hitler announced the *Anschluss*—the incorporation of Austria into the German Reich. With the results of a highly dubious plebiscite in April, the first Austrian republic ceased to exist, and Austria became a German province known as the *Ostmark* (Eastern March). With the annexation of Austria came the question of developing Austria's abundant water power resources. Indeed, the *Anschluss* put National Socialist energy policymakers in a kind of "water power delirium" in the words of one historian. Energy experts believed that Austria's white coal would put an end to the Reich's growing electricity supply problems and "place Germany in the position of a practically unrivaled energy-Great-Power." RWE quickly dug up previously buried plans for the continued development of Austrian Alpine water power, and were granted most of western Austria (especially the so-called West Tyrolean hydropower) as their own sphere of influence. Interest in the Tauern project also resurfaced. Perhaps because of National Socialist predilections for monumental works, the Tauern idea was swiftly adopted and prioritized by many, including one of the highest functionaries in the Nazi economy. The enthusiasm for Austrian water power and for the Tauern project in particular was infused with concern about Germany's long-term energy future. Rather quickly, however, it would become clear that what the German war economy desperately needed was more electricity in the here and now. But by

[33] Norbert Schausberger, "Deutsche Wirtschaftsinteressen in Österreich vor und nach dem März 1938," *Österreich, Deutschland und die Mächte: Internationale und Österreicische Aspekte des "Anschlusses" vom März 1938*, ed. Gerald Stourzh and Birgitta Bader-Zaar (Vienna: Verlag der Österreichischen Akademie der Wissenschaften 1990), 193-196.

that point, the German economy had already invested valuable time and resources into arduous hydraulic projects that suddenly had little prospect of completion.[34]

A mere two weeks after annexation, a German government study on how to incorporate Austria into the German war economy identified harnessing the Tauern energy as a priority. The report emphasized the urgency of exploiting Austrian water power for use in the chemical industry, and it recommended reexamining a "mostly finished" plan for a large-scale power plant in the Hohe Tauern: Münch's AEG designs. Based on Münch's figures, the author of the report concluded that the Tauern Works possessed "the greatest significance for the entire German electricity supply."[35] Three days later in a speech in Vienna, Hermann Göring declared the "immediate erection of a series of hydroelectric dams in the Hohe Tauern" as one of the priorities for the Austrian economy.[36]

Göring's speech was not mere rhetoric. A little over a month later, on the morning of Monday, 16 May, Göring traveled by a special train to Kaprun to lead the groundbreaking ceremony for the first step in the construction of the Tauern Works. Standing at the head of the Kaprun valley, surrounded by swastikas and villagers from the nearby town, Göring explained why the German Reich, attached such importance to the construction of dams: "We want to be a tremendous (*gewaltig*) people," the field marshal proclaimed, "a mighty nation. We say to all,

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[34] Quotation from "Österreichs Energiewirtschaft," in *Wirtschaft, Technik, Verkehr* 14, no. 5 (1939): 5-8. Cited in Helmut Maier, "Kippenlandschaft, "Wasserkrafttaumel" und Kahlschlag. Anspruch und Wirklichkeit nationalsozialistischer Energiepolitik," in *Umweltgeschichte-Methoden, Themen, Potentiale: Tagung des Hamburger Arbeitskreises für Umweltgeschichte, Hamburg 1994*, ed. Günter Bayerl (Münster: Waxmann, 1996), 260. Maier also seems to suggest, as I have here, that the focus on long-term energy projects like dam-building that did not result in immediate energy production was misguided. On RWE and the West Tyrolean water power and nature protection, see also Helmut Maier, "'Unter wasser und unter die Erde.' Die süddeutschen und alpinen Wasserkraftprojekte des Rheinisch-Westfälischen Elektrizitätswerks (RWE) und der Natur- und Landschaftschutz während des 'Dritten Reiches,'" in *Die Veränderungen der Kulturlandschaft: Nutzungen-Sichtweisen-Planungen*, ed. Günter Bayerl and Torsten Meyer (Münster: Waxmann, 2003), 139-175.

[35] BA Berlin, R 3112 45: Reichstelle für Wirtschaftsausbau, "Erste Ermittlungen zur Aufstellung eines Vierjahresplanes für das Land ÖSTERREICH," 5, 16.

[36] Hermann Göring, "Aufbauprogramm für Österreich," Keesings Archiv 1938, 3488. Found in Norbert Schausberger, *Rüstung in Österreich 1938-1945: Eine Studie über die Wechselwirkung von Wirtschaft, Politik und Kriegsführung* (Vienna: Hollinek, 1970), 186.

but especially clearly to those who are not happy to hear it: Germany above all!" In typical National Socialist style, Göring also emphasized the significance of action. "The opus is not accomplished and completed through speeches and celebrations, rather hard work alone leads to success." Finally, Göring declared that the time had come to put the natural resources of Austria to work. "We have enough mountains and water," declared the field marshal, perhaps anticipating criticism about the environmental effects of gigantic dam projects. "Now it is time to collect their powers. As the National Socialist movement once collected all the forces, all passionate currents, consolidated them, dammed them, and applied their concentrated powers, so the dammed forces of nature will create great value here, where they once, unrestrained, senselessly devastated the fields and annihilated the harvest."[37] After completing his speech, Göring reached for a shovel and broke ground at the site of the future powerhouse (in the wrong place, as it turned out). On the hillside above him a row of flags marked the future path of the penstocks.

To finance and control the development of the Tauern power—as well as several other large hydroplants on Alpine rivers—the Reich created a state-owned corporation, the Alpen-Elektrowerke AG (AEW).[38] In the company's first annual report, it emphasized the necessity of developing Austria's unused Alpine hydropower as a means of substituting a renewable energy resource for coal wherever possible, in order to save the fossil fuel for other more important uses in the national economy. The report also noted that Alpine water power would be key for the

[37] BHSTAM MHIG 3235: "Baubeginn des größten Kraftwerks Deutschlands," *Völkischer Beobachter*, no. 137 (17 May 1938, page number not shown). Göring's insistence on quickly beginning construction on the Tauern project and his rhetoric about action was also likely intended to impress Austrian audiences with the effectiveness of their new political leaders. Another article on the project in the same issue entitled "Six Weeks Later the Deed" explicitly the new Nazi regime and its chancellor, Kurt Schussnig, a man who "made promises galore," which "lacked only their fulfillment."

[38] AEW was a subsidiary of the Reich owned industrial giant *Vereinigten-Industrieunternehmungen AG (*VIAG). On the history of the AEW, see Maria Magdalena Koller "Elektrizitätswirtschaft in Österreich, 1938-1947: von den Alpenelektrowerken zur Verbundgesellschaft," (PhD diss., Karl-Franzens-University of Graz, 1985).

expansion of Austrian industrialization.[39] As technical director in charge of the critical Tauern project, the AEW named Hermann Grengg, one of the hydraulic engineers who had earlier criticized the AEG plan. Among his other credentials for the job, Grengg (1891-1978) had a joined the National Socialist party in 1932, when membership in the Nazi party was illegal in Austria. Despite the preference of the Salzburg provincial government for the AEG plan, as well as the apparent initial preference of the Nazi state for Münch's concept, Grengg managed to implement the first step in a Tauern project more or less reminiscent of the original, decentralized solution.

In a postwar publication, Grengg recounted the process by which he opted for a decentralized Tauern plan. Grengg began drafting a detailed project in the fall of 1938, after investigations had been performed in the Kaprun valley to determine its suitability for reservoir construction. Grengg recalled standing before the "grotesque necessity" of having to decide once again between the centralized AEG plan—what he dubbed the "Super Tauern Works"—and decentralization. Preliminary observations convinced him of the wisdom of at least one component of the AEG plan he had earlier criticized: the diversion of runoff from the north face of Grossglockner across the main ridge of the Alps into the Kaprun valley. This involved drilling a tunnel over ten kilometers long directly through the main ridge, and it represented an unprecedented interbasin transfer of water. But it would give the power plants in Kaprun access to the prodigious meltwater of the Pasterze glacier, and Grengg now saw it as necessary to fill the reservoirs in the Kaprun valley. Grengg rejected diversions from the remaining Tauern catchment area as unfeasible, thereby confirming his earlier viewpoint that decentralization was

[39] Although the report did not explain why Austrian industrialization was important, many Germans viewed Austria as strategically important as an area less vulnerable to potential air attacks than Germany. AT-OeStA/ AdR, 04 "Bürckel-Materien", kt. 68, 2155/O: Bd. II-E-wirtschaft in der Ostmark allgemein, Alpen-Elektrowerke AG Wien, "Geschäftsbericht über das erste Geschäftsjahr 1938," 5.

the correct choice. Belatedly, another consideration persuaded him that centralization was foolhardy. By his calculations, the tallest permissible dams in the Kaprun valley would not be high enough to store water from throughout the range. Some geological surveys of the valley had concluded that the underlying bedrock was less than ideal in several respects for the construction of dams. While Grengg planned on making the Kaprun dams the tallest in Europe at the time, he believed the dams necessary for the AEG plan exceeded the limits of safety. In light of this evidence, Grengg wondered, "Why divert so much water with such violent means into the Kaprun valley if it cannot even be stored there?"[40]

Grengg supported decentralization for another important reason. He argued that only by building dams throughout the various valleys of the Tauern could the AEW achieve the greatest amount of "super storage" (*Großspeicherung*) possible. For Grengg super storage represented nothing less than the "special function of the Tauern water power in the big picture." Super storage, he explained, consisted of adapting the release of water for power generating purposes to the annual rhythms of energy demand. Essentially, Grengg wanted to create a series of "winter works" in the Tauern, hydropower facilities that utilized all of their stored water during the winter months when other water power plants experienced shortfalls. Utilizing the Hohe Tauern for super storage was necessary in the first place because the range represented one of the few places on German soil where it remained possible. Western Austria's reservoirs—as we have seen—had already fallen into RWE's sphere of influence.

But Grengg had a more doctrinaire reason for his pursuit of storage. Like many hydraulic engineers throughout the Alps, he had come to believe that the high-Alps should be exploited to the fullest for their unique storage capabilities, in order to fulfill a critical role in the regional electricity supply. High-Alpine reservoirs, he believed, had to serve as the "regulators"

[40] Hermann Grengg, *Das Großspeicherwerk Glockner-Kaprun* (Vienna: Springer, 1952), 2, 3.

for the regional electricity grids in the Alps. Reservoirs, he argued, eased the difficulties that arose from trying to coordinate the pooling of current from a number of different sources within an electricity grid; they offered "steadiness". And in contrast to brown coal—which otherwise functioned as excellent supplementary energy to inconstant water power—Alpine reservoirs lay nearby. Accessing their power did not require expensive—and vulnerable—transport infrastructure . In his arguments in favor of super storage, Grengg acknowledged that the concept likely seemed foreign to the water management concerns that animated the other German lands, but maintained it was necessary in the high-Alps. Grengg and other Austrians would continue to have trouble getting experts from outside the uplands to recognize this Alpine imperative.[41]

Above and beyond these arguments, Grengg believed that practicality and expedience also spoke in favor of a decentralized project. As he later wrote of the Münch plan, "It had not required the mathematical demonstration of the inferiority of this plan vis-à-vis a development in separate groups to help the latter to victory. For a sober consideration of the situation at the time revealed that neither the possibility, nor the need, existed for a Super Tauern Works." The centralized plan was impossible in Grengg's estimation, due to the very limited economic resources of labor and materials that were being spread throughout all sectors of the Austrian economy following the *Anschluss*. The resources for the realization of normal hydropower projects scarcely existed, to say nothing of the materials that would be required for a supersized facility. Moreover, the centralized plan called for the Tauern water power to play a role in an interconnected, Reich-spanning electricity grid that did not yet exist: "It seemed to me a mistake to want to even consider developing the power of the entire Tauern range with exceedingly

[41] SLA RStH V/3 171: "Die Eigenart und die besondere Aufgabe der Tauern-Wasserkraft im Rahmen der deutschen Elektrizitätswirtschaft (zweite Auflage Jänner 1939)," 5-9.

expensive storage works for use in a German electrical pool (*zentralisierte deutsche Verbundwirtschaft*) that had not even been conceptualized, rejecting a natural development of the Tauern water power for a "once-and-for-all" in the Kaprun valley."[42]

In reflecting on the value of the Tauern power, Grengg noted some advantages not directly related to storage that spoke in favor of hydro development. Many of these revolved around the value of the range's substantial glaciers. From an energy perspective, glaciers are not unlike the fossil fuel stores. They are reservoirs of potential energy created long in the past. Grengg noted that the glaciers of the Alps composed a vast multiple of the amount of stored water that even the most intense dam-building could achieve (his Tauern Works mustered only a total of thirteen square kilometers of artificial storage area compared to the region's 183 square kilometers of glaciers). While the water molecules in a given stretch of a river in a non-glaciated region may have been part of the ocean a mere week before, the water that flowed off the Pasterze glacier on the Grossglockner had likely been there for centuries or millennia. Glaciers ensured that the differences between annual drainage figures in the Alps were comparatively small. In glaciated catchment basins, waterways ran high even in warm and dry summers thanks to glacial melt.

This latter reality led to one of the more significant assets of Tauern hydro: its hydrology offered a useful counterweight to the flow regimes in other German water power areas. Grengg elaborated that sometimes climatic contrasts within a larger economic area created river systems with complementary hydrologies. By this, Grengg meant flow regimes whose maximum and minimum flood periods occurred at different times of the year. To a small extent, the *Anschluss* had expanded German territory just to enough to capitalize on some of these climatic contrasts. Now in addition to the—admittedly modest—central German "water power winter", Germany

[42] Grengg, *Großspeicherwerk Glockner-Kaprun*, 4.

possessed high-Alpine areas whose hydrology counterbalanced the remaining water power of the Ostmark. While non-glaciated Alpine river basins experienced summertime droughts, for instance, the watercourses of the Hohe Tauern usually swelled with glacial runoff. Though Grengg estimated that the new German "water power climate" was not as ideal as the French one, which possessed climatic contrasts in the Pyrenees, the Massif Central, and the Western Alps, or Italy's—which took advantage of the complementary hydrologies of the south slope of the Alps and the Apennines, the addition of the high-Alps nevertheless marked an improvement. Finally, Grengg also noted that the period of glacial melt that had been underway "for a long time" meant that in the Tauern, annual drainage was much greater than precipitation. While he welcomed the long "nice weather period" that increased available water power, the engineer acknowledged that the inability to predict periods of glaciation made designing the storage dams especially tricky.[43]

[43] SLA RStH V/3 171: "Eigenart," 2-4

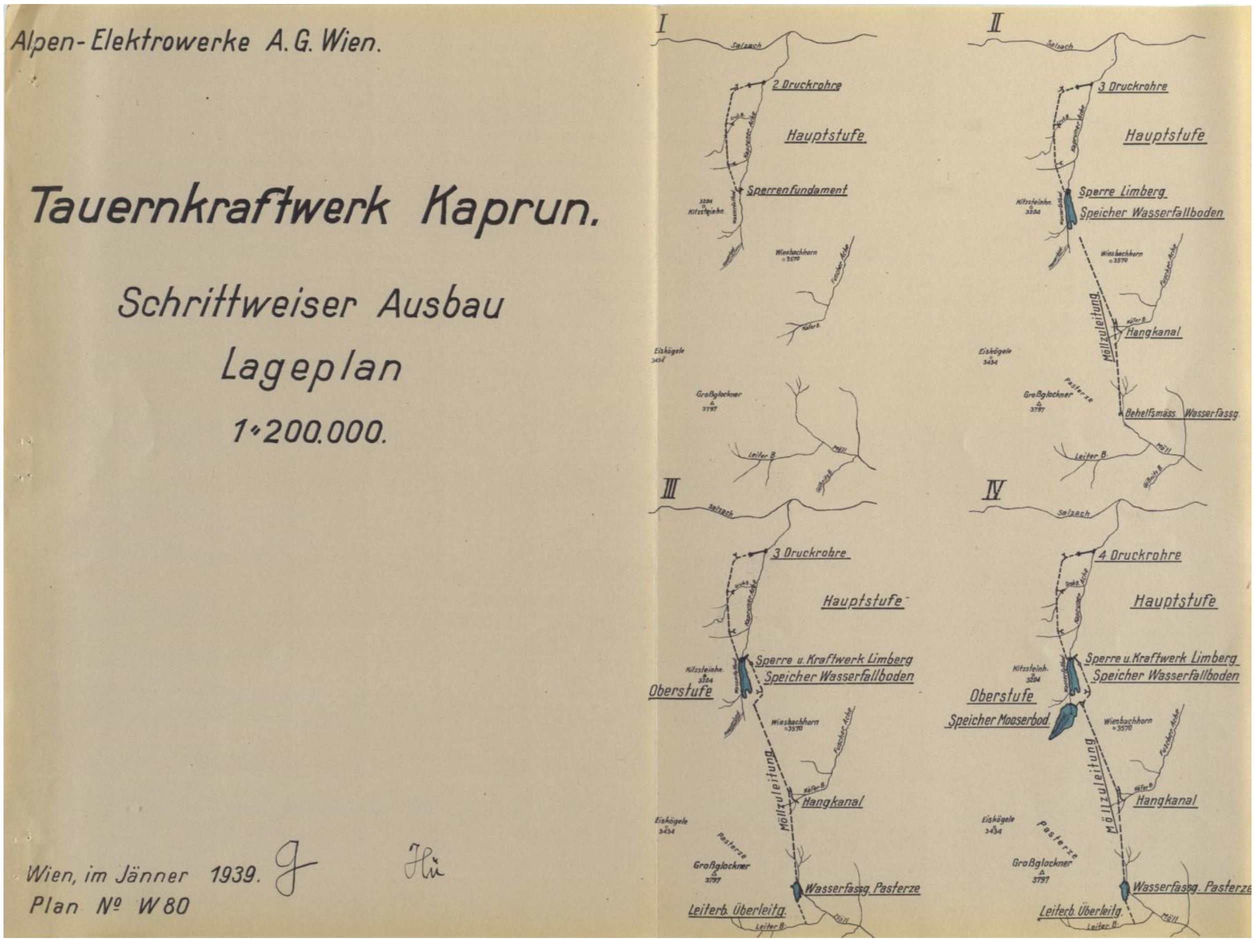

Figure 8. Tauern Works Kaprun, Step-by-Step Development, January 1939. Salzburger Landesarchiv

Under these circumstances, Grengg opted for the decentralized plan. Construction was to proceed in four phases, with the erection of the *Tauernkraftwerk* Kaprun-Glockner coming first. This first phase would consist of an upper and a main power stage in the Kaprun valley, each replete with its own high-altitude reservoir. First the main stage would be completed. Grengg reckoned that by 1941, the main stage would be able to operate as a run-of-river plant; after five years the completion of the main stage dam would enable the plant to function as a storage work. The schedule for the upper stage reservoir was left for the future. Initially, the Kaprun-Glockner dams were to serve the electricity supply of eastern Austria, the location of the country's greatest industrial and urban concentration. By the mid-1940s, as development of Austria's other white coal expanded enough to cover Austrian energy demands, the Tauern power would be connected to the high-voltage line heading north from Austria into East Germany, in order to send any excess current to the industry of the lignite fields there. Completing the main stage became the first order of business, and to ensure that it could begin delivering at least some power within three years, Grengg had to

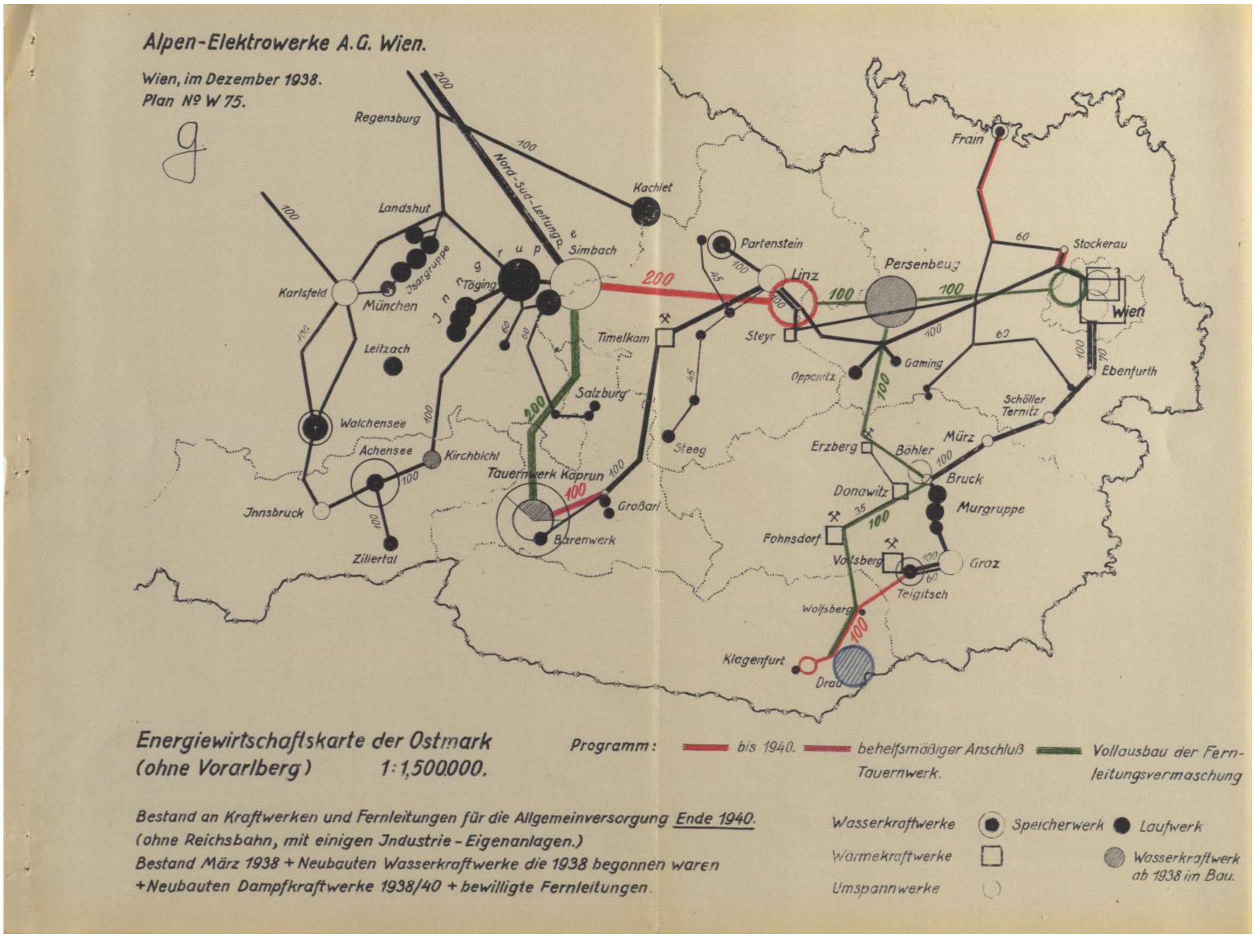

Figure 15. Energy Supply Map of Austria, December 1938. Salzburger Landesarchiv

fix certain dimensions of the project. To a degree, these actions literally set the future of the project in stone. Tunnels, for example, had to be measured and drilled in accordance with the amount of water the powerhouses would process. Enlarging them belatedly would be extremely costly. Foundation work for the dams also largely dictated the future height of the reservoirs. It was these sorts of path dependencies which made Grengg's decision an "ultimate" one, and even if it did not remain unquestioned, "it determined up until this day and in the future the development of the Tauern water power."[44]

Though he did not discuss it in any further depth in his postwar article, Grengg's "ultimate" decision was indeed subject to hefty criticism. In early 1939, the engineer found himself compelled anew to persuade the authorities that the decentralized development was the correct path. The occasion appears to have been the result of bureaucracies working at cross-purposes, a defining characteristic of National Socialist governance. Parallel to AEW's planning, Josef Bürckel, Commissar for the Reunification of Austria with the German Reich, asked two German engineers—identified only by their last names Thürnau and Schmidt—to evaluate the two main Tauern power variants. Bürckel invited the pair of engineers to his office in Vienna for a meeting where they listened to both Münch and Grengg present their projects and had the opportunity to ask both questions.[45]

In their written evaluation, Thürnau and Schmidt came out in favor of Münch's centralized project. This was not entirely surprising. During the "battle of the plans" earlier in the decade, Thürnau—a professor at Leipzig—had written an article in favor of the AEG project.[46] Thürnau and Schmidt concurred that Münch's designs deserved support because they came closest to what they called the "optimal final development." For them, it was irrelevant which project promised an easier start, or which design was capable of delivering electricity into the grid at the earliest juncture. Rather, the best plan was the one that harnessed the maximum amount of raw water power that was technologically and economically possible. This meant

[44] Grengg, *Großspeicherwerk Glockner-Kaprun*, 5.
[45] The task of performing the evaluation and the subsequent meeting are described in SLA RStH V/3 171: "Gutachten Thürnau-Schmidt," (11 April 1939).
[46] Dr. Ing. Thürnau, "Das Tauernwerksprojekt der AEG," *Die Wasserwirtschaft* 24, no. 11 (1931): 157-158.

concentrating and storing as much Tauern water as possible in the steep Kaprun valley. All calculations about how big to make the Kaprun reservoirs were superfluous. The motto needed to be: "as big as conceivably possible." Restricting the dams to this one valley would make the development of the Tauern power more cost effective by reducing the amount of materials and construction sites necessary. To Grengg's assertion that the geology of the Kaprun valley did not permit the construction of dams tall enough to hold all the Tauern water, Thürnau and Schmidt, showing their alignment with Nazi ideology, countered with the conviction that engineers must overcome difficulties through technical means.[47]

All of this effort, according to Thürnau and Schmidt, was necessary and justified to help water power fulfill its critical purpose in the German war economy: to substitute for coal in electricity generation. Coal was urgently needed for specific industrial processes critical to the war economy, especially in the production of synthetic fuels for military aircraft and vehicles. Energy experts, according to Thürnau and Schmidt, knew that coal was far too precious a commodity to be wasted making steam to drive turbines. In the near future, comparative costs of water power and coal would not even matter, as the latter fuel would become invaluable as an input for the chemical industry. Both engineers admitted that it would probably never be possible to satisfy all of Germany's electricity demand with water power. But they argued it was "a national duty" to cover as much of this demand as possible with water power. This purpose could be satisfied by constructing the Tauern works to produce the greatest number of kilowatt hours possible.[48]

Bürckel's intervention in Tauern affairs once again threw the future of the Tauern into uncertainty. Appealing to another of Hitler's commissars, Just Dillgardt, Bürckel managed to

[47] SLA RStH V/3 171: "Thürnau-Schmidt," 7-8, 11, 28.
[48] SLA RStH V/3 171: "Thürnau-Schmidt," 33-34.

bring progress on the Kaprun-Glockner facility to a halt. Dillgardt, the former mayor of the city of Essen, had been named the Plenipotentiary for the Energy Supply by Göring in early 1939, and the field marshal had endowed his position with far-reaching competencies to hasten the expansion of the German electricity supply. After several months at his post, Dillgardt had become convinced that the harnessing of Austria's Alpine water power was the most important problem facing the German energy supply. In April 1939 Dillgardt traveled to Vienna to discuss unresolved electricity supply questions in the Ostmark with Bürckel.[49] Thereafter, Dillgardt forwarded the Thürnau-Schmidt report to Hermann Grengg at AEW and demanded a swift response.[50]

In his reply, Grengg made several new arguments against the Super Tauern Works. In great detail, Grengg explained the devastating environmental impacts of the Münch plan: "If the centralized system of slope canals fulfills even half of its intended purpose, then it will deprive numerous valleys in the provinces of Carinthia and Salzburg of their water." Grengg argued that such a system would contradict the precepts of the "new German water management" that sought to take into account the various competing uses of water. In this case, he claimed, agriculture would suffer mightily, a prospect that would not please the all-important Reich Food Estate, responsible for organizing Germany's food supply. Grengg concluded by noting that altering the Kaprun-Glockner project to enable a centralized harnessing of the Tauern power could only be achieved by casting aside all of the progress that had been made. It would require compiling a detailed centralized project, and renewed negotiations with concerned parties. "The Tauern water power," he argued, "would thereby bow out of the energetic struggle for existence of German water management." This mountain energy would not be able to aid Germany in its

[49] AT-OeStA/ AdR, 04, "Bürckel-Materien" 2155/2: Letter Dillgardt to Bürckel (9 March 1939).
[50] SLA RStH V/3 171: "Stellungnahme der Alpen-Elektrowerke A.G. Wien (AEW) zum Gutachten Thürnau-Schmidt vom 11.IV.1939."

economic struggles at any time in the near future. Sacrificing such an important source of power would only be justified if the Super Tauern Works had better future prospects. Grengg was convinced that this was not the case.[51]

In the end, Dillgardt decided against the centralized solution and ordered the continuation of the AEW project. In a meeting in Bürckel's office in late May 1939, Dillgardt explained that both military and agricultural reasons spoke against the concentrating of the Tauern power in one valley. In terms of military considerations, Dillgardt presumably feared the ease of disrupting the entire hydropower of the range in a centralized scheme. In terms of agriculture, Dillgardt echoed Grengg's concerns about the effects of diverting so much water over such long distances via the slope canals.[52]

The AEW was unable to complete the project during the war. Although the Plenipotentiary for the German Energy Supply had declared the construction project as "politically significant" and "urgent", it almost immediately ran into war-induced difficulties. In a meeting at the Reich Ministry for the Economy in Berlin on 19 September 1939, the AEW was informed that only very small amounts of iron could be made available for its most important water power projects. The Tauern works and a dam project on the Drava river were included in this privileged group. But it is a testament to the already difficult situation that construction on a hydropower dam on the Danube had to be halted completely. Kaprun, moreover, would not receive the iron it needed for its electrical equipment or for its penstocks. It was estimated that

[51] SLA RStH V/3 171: Hermann Grengg, Stellungnahme der Alpen-Elektrowerke A.G. Wien (AEW) zum Gutachten Thürnau-Schmidt vom 11.IV.1939 in Sachen Tauernrkraftwerk," 10, 14.
[52] SLA RStH V/3 171. A vocal current within the National Socialist electrical engineering community opposed centralized electricity production because of its security implications. For an expression of this viewpoint from its leading proponent see Franz Lawaczeck, *Elektrowirtschaft* (Munich: Lehmann, 1936).

these privations would delay the plant's initial launch by at least a year and probably more.[53] The situation worsened considerably when the project lost its urgent wartime status in 1943. Wartime events also made their impact felt on the project. When in the night of May 17/18 1943, British bombers attacked a number of west German dams and succeeded in destroying the Möhne valley reservoir, questions were raised about the security of the dam designs in Kaprun. The German military eventually vetoed the planned buttress dams—whose primary virtue had been cost-effectiveness—and Grengg opted instead for arch dams.[54] A last ditch effort in 1944 succeeded in the erection of a small temporary barrage that allowed Kaprun to begin feeding small amounts of electricity into the eastern Austrian grid. Even this minimal achievement had only been made possible by the use of thousands of forced laborers on the construction site. Since the beginning of the war, the work of forced laborers and prisoners of war had been exploited on a number of hydropower projects in Austria. Kaprun by far received the greatest number of these workers. Initially, the POWs came primarily from Poland and France; after 1943 they were joined by prisoners from the Soviet Union. The use of forced labor reached a peak in 1943 and declined precipitously thereafter. As Germany's military situation deteriorated in 1945, all progress came to a standstill. Construction would not resume until after 1945.[55]

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[53] AT-OeStA/ AdR, 04 "Bürckel"-Materien 2155, Kt. 88 "Bericht über die Energieversorgung der Ostmark", author unknown, September 1939?," 5-6.

[54] Grengg later explained that he utilized the bombing crisis to make the switch to arch dams, a choice which he gradually had come to prefer but feared to make lest he provide attack fodder for the opponents of dam-building during wartime. Grengg maintained that Swiss engineers also later migrated to arch dams for similar reasons. See Grengg, *Großspeicherwerk Glockner-Kaprun*, 31.

[55] On the construction history of the Tauern project during the National Socialist period and the use of forced labor Margit Reiter, "Das Tauernkraftwerk Kaprun," in *NS-Zwangsarbeit in der Elektrizitätswirtschaft der "Ostmark", 1938-1945*, ed. Oliver Rathkolb and Florian Freund (Vienna: Böhlau, 2002), 127-198. Helmut Maier has observed that by the end of the war, the bulk power producer Kaprun—built with slave labor—had been interconnected to the bulk power consumer Auschwitz. He also cites an estimate of 400 deaths among the nearly 4,000 forced laborers at Kaprun. See "Systems Connected: IG Auschwitz, Kaprun, and the Building of European Power Grids up to 1945, in *Networking Europe: Transnational Infrastructures and the Shaping of Europe, 1850-2000*, ed. Erik van der Vleuten and Arne Kaijser (Sagamore Beach, MA: Science History Publications, 2006), 129-158.

The postwar period finally witnessed the completion of the Kaprun valley reservoirs. Progress was difficult at first. The project lost most of its direction at a stroke when the US authority charged with denazification arrested all leading AEW engineers in the wake of the American liberation of Salzburg in 1945. Only in the summer of 1946 did the American occupiers transfer the property at Kaprun in trust to the reconstituted Austrian government. The next year, after the nationalization of Austria's electricity supply, a federally owned company called the Tauernkraftwerke AG assumed control of Kaprun as well as responsibility for its completion. It would take several more years to finish the Limberg dam that held back the main stage reservoir, and in 1952 that part of the facility finally went into operation. In 1955, the erection of four more dams marked the completion of the upper stage. At this point, the Tauernkraftwerke Glockner-Kaprun (as the project has been known since the postwar period) assumed the shape and function it retains to this day. The upper stage consists of two giant reservoirs with their own hydropower station. One of the reservoirs resides on the north side of the main Alpine ridge at the top of the Kaprun valley, the other laps at the tongue of the Pasterze glacier on the south side. The main stage consists of a single reservoir and its power station. Several torrents diverted through tunnels from nearby valleys help to fill the reservoir. The two main reservoirs each contain over eighty million cubic meters of water. Almost two-thirds of this water comes from the southern Alps by way of a twelve-kilometer tunnel that diverts Pasterze meltwater. The creation of this new hydraulic system at the foot of the Grossglockner is an early example of the environmental impact of the Cold War.[56] For the Kaprun dams were financed overwhelmingly with the aid of the Marshall Plan.

[56] J.R. McNeill and Corinna R. Unger, eds., *Environmental Histories of the Cold War* (Cambridge: Cambridge University Press, 2010). The Alps must be added to the list of regions where American strategic interests encouraged the spread of high dams. See Richard P. Tucker's chapter in this volume "Containing Communism by

Groups interested in the economic reconstruction of Europe viewed the development of the water power of the Alps in general, and Austria in particular, as critical for the reconstruction of Europe. As one of the European regions that both produced great quantities of energy and possessed vast unrealized energy potential, the Alps were very much on the minds of economic planners. The United Nations' Economic Commission for Europe, for instance, viewed the Alps as one of three critical regions in continental Europe with the potential energy to fuel reconstruction (the other two being the Rhineland and Silesia). The Commission's electrical energy subcommittee created a special regional study group focusing on the problems confronting further development of white coal.[57] At the Paris talks in the summer of 1947 that paved the way for the Marshall Plan, planners discussed the role of Austrian Alpine water power in European reconstruction in particular. For the assembled, Austria had a special mission to fulfill in the context of the European electricity grid that was to be built to satisfy the substantial expected demand in northwestern Europe.

> Austria believes that it will benefit from the economic integration of Europe and its reconstruction with the help of the expected creation of new potential in some sectors of its economy by the Marshall Plan. Austria is aware that one should not just take, but must also give, and it is ready to contribute to the best of its power to the buildup of Europe. This will be possible by harnessing the available water power.[58]

As it turned out, most Austrians did not include the Tauern power as part of Austria's European energy contribution, at least not directly.

The postwar situation in Austria also convinced American occupation officials of the necessity of repairing the Austrian electricity supply. After the surrender of Nazi Germany in

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Impounding Rivers: American Strategic Interests and the Global Spread of High Dams in the Early Cold War," 139-163.

[57] SLA Präsidial-Akten 1948/49: Vereinte Nationen, Wirtschaftskommission für Europa, "Bericht des Elektro-Energie Komitees auf der 1. Tagung der Wirtschaftskommission für Europa," 2.

[58] Vas, *Anteil*, 27.

1945, Austria's electricity supply lay in shambles. Electricity rationing and blackouts were the rule. Temporally, the situation was particularly dire in winter, when available hydropower diminished, and geographically, the city of Vienna suffered above all. While in the western, mountainous Austrian provinces the hydroelectricity flowed more or less uninterrupted, Vienna's reliance on disrupted coal supplies left the city much more vulnerable. Rationing, especially in winter, became the norm. The electricity supply situation was further complicated by the division of Austria among the four Allied occupying powers. In the hopes of rectifying the situation, a nationalization law in 1947 specified that the country's electric production would henceforth be in public hands, split between the provincial utilities and the federal government. The provincial companies would be responsible for all power plants within their borders, and would also take care of distributing electricity to end-users. The Austrian federal republic would own and operate a national grid, and also be responsible for the development of large hydropower plants, and those facilities that spanned one or more federal provinces.

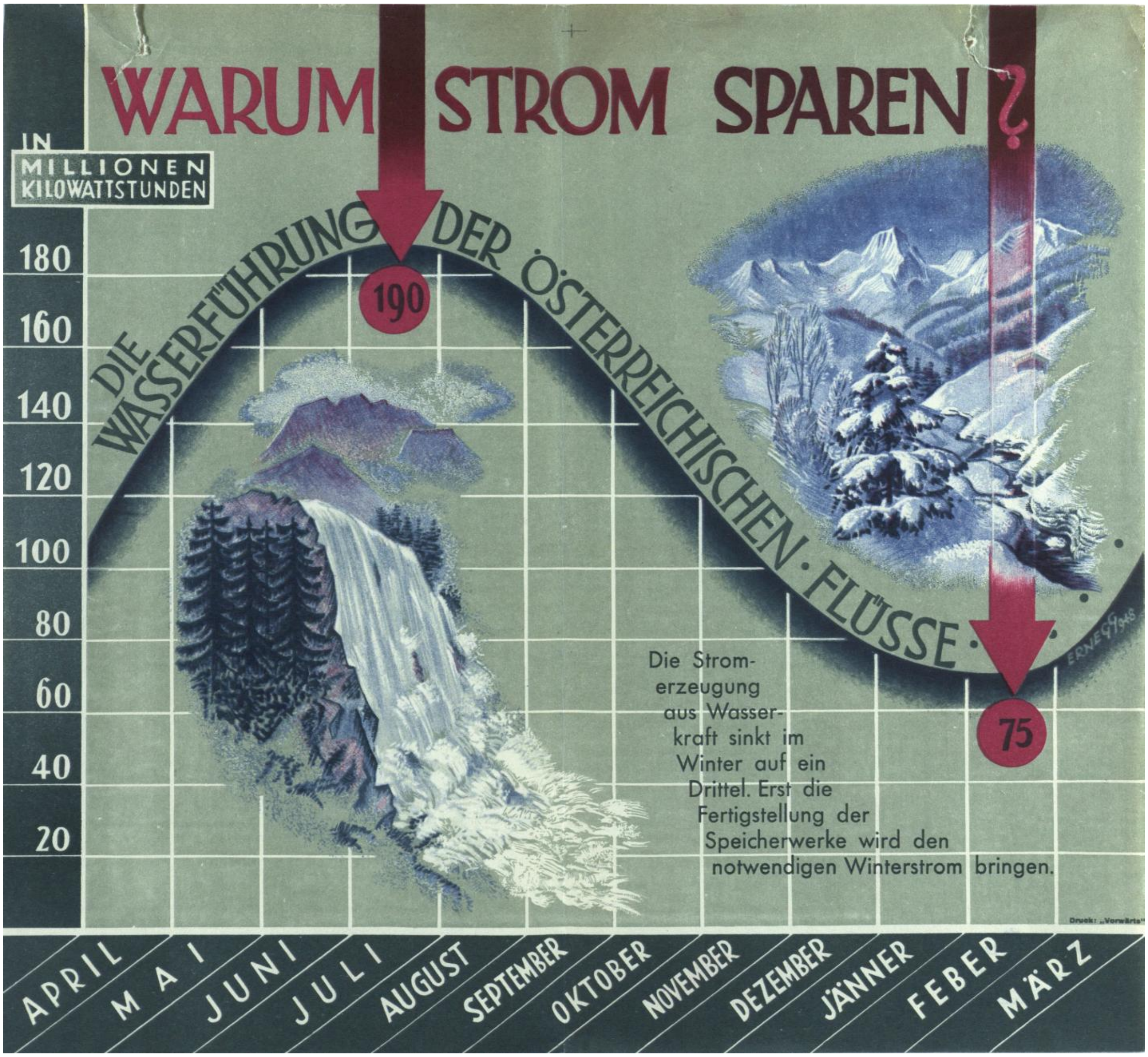

Figure 16. "Why save electricity? Electricity production sinks by two-thirds in winter. Only the completion of the storage works will bring the necessary winter electricity." Austrian poster, 1948. Salzburger Landesarchiv

It is in this context that the dispensation of Marshall Plan funds must be understood. In Austria as throughout the rest of Europe, the US feared that poor economic conditions would push populations towards communism. In Austria, as elsewhere (particularly Germany), the overwhelming majority of Marshall Plan money flowed into the electricity supply, and Kaprun received the largest share of the money in this sector. From 1948 until its completion in 1955, Kaprun received almost half of all Marshal Plan funds invested in the Austrian electrical sector, making it by far the largest single project financed in all sectors of the Austrian economy. Financing for the completion of Kaprun's main stage dam came rather easily. The Americans hoped to achieve quick results with their investments and recognized that in order fully to take advantage of the capital and material investments made during the Nazi period—it is estimated that the AEW completed about one-third of the entire project—the reservoir had to be created. The Austrians later convinced the Americans of the necessity of completing the upper stage dams as well, though not without some difficulty. Many have argued about the significance of the Marshall Plan in Europe's postwar economic expansion. In the estimation of one Austrian historian, without the Marshall Plan, it is possible that the project in its present form would not even exist. Had Austrians attempted to construct the existing Kaprun plant without American support, however, he estimates the project would have been delayed by at least ten years.[59]

Thanks to the Marshall Plan, The Tauern Works Glockner-Kaprun immediately expanded the reach and influence of the Alpine energy landscape—but not directly. As a disagreement between American occupation authorities and Austrian electricity policymakers over the building of Kaprun's upper stage shows, the Austrians intended the power plant to serve the Austrian electricity supply. Indeed, Austrian intentions for Kaprun ran into stiff resistance on the part of some Americans. As had long been the case, the Austrians wanted to build more dams in Kaprun in order to be able to store more hydropower for the winter months. This energy would then be employed in the eastern Austrian grid, and provide reserves for Austria's new aluminum industry. Both the American and Austrian authorities believed this industry, built up by the Nazis during the war, had great chances at finding export markets if it could be supplied with

[59] This section and much of the next draws from Georg Rigele's excellent article on the Marshall Plan and Kaprun, "Der Marshall-Plan und Österreichs Alpenwasser-Kräfte: Kaprun," in *"80 Dollar": 50 Jahre ERP-Fonds und Marshall-Plan in Österreich, 1948-1998*, ed. Günther Bischof and Dieter Stiefel (Vienna: Ueberreuter, 1999), 196-216.

cheap electricity. Austrian planners expected the Kaprun upper stage to provide this energy, but American authorities objected that these dams were far too expensive, and that there were other more cost-effective ways that American credit could be used to generate this electricity. At this point, Austrian energy experts felt compelled to explain to their American counterparts about the importance of winter energy. They also rejected the suggestion that instead of exporting Alpine water power to Germany, Austria might use this electricity to support the aluminum industry during the winter. Although the proposal made perfect sense, it would have upset the long-standing structure in the Austrian electricity supply whereby western Austrian water power was reserved primarily for the German market.

In the end, the Austrians received the Marshall Plan money for the construction of the additional reservoirs, due to a combination of diplomatic skill and intervention from the microbial world. The upper stage's main American opponent fell ill just at the critical time, and was unable to cast his veto. By covering the electricity demands for Vienna and Austria's industrial centers in eastern Austria, the Tauern Works freed up the water power of western Austria for increased export to northwest Europe, precisely the region the Marshall Plan officials had identified. However, as noted by one Austrian upon completion of the main stage, Kaprun's large capacity meant it could eventually function in larger, European-scale grids as well.[60]

The Kaprun dams are concrete proof of the appeal of these structures to political regimes of all stripes, and a testament to the significance of electricity as a panacea for a myriad of economic problems. They also demonstrate that history has no shortage of irony. In the postwar period, Austria—with massive assistance from the United States—completed a project begun by

[60] Alexander Kothbauer, "Die Bedeutung der Hauptstufe der Kraftwerksgruppe Glockner-Kaprun für die österreichische Elektriztitätswirtschaft," in *Die Hauptstufe des Tauernwerks Glockner-Kaprun: Festschrift Herausgegeben anlässlich der Fertigstellung der zum Krafthaus Kaprun-Hauptstufe gehörenden Anlagen September 1951*, ed. J. Götz (Vienna, Ueberreuter, 1951), 12.

National Socialists, and for many of the same reasons. The National Socialists had hoped to enlist the water power of the Hohe Tauern to free up critical coal resources for their geopolitical struggles. These included, among other things, a reckoning with the communist Soviet Union in the East. In its bid to vanquish the Soviet Union, Nazi Germany at once ensured the unavailability of the resources necessary to complete the dams, and gained access to much of the slave labor that permitted what meager progress they actually achieved with these projects. After 1945, the Americans provided Austria with that which Barbarossa took from the Nazis: materials and time. In Kaprun, Austrians saw a means of stabilizing their electricity supply, improving market prospects for its Nazi-built aluminum industry, and legitimizing the newest iteration of Austrian democracy. For the US, Kaprun's hydroelectricity stood to fight communism according to its preferred method, by bolstering standards of living in Austria and Germany.

From the 1960s through the 1980s, the TKW completed its development of the Tauern power. Four additional high-altitude dams were erected in the western part of the range, near the joint border between the provinces of Salzburg and Tirol, and the national border with Italy to the south. During this time period, the Austrian state continued to build dams to increase storage capacity throughout the Alps. Thus, the importance of Kaprun and the other Tauern dams diminished in relative terms. Nevertheless, as of 1990, the Tauern facilities delivered approximately one-third of the total electrical energy produced in Austrian storage facilities.[61] This energy was a critical component in making the postwar Austrian republic one of the most hydro-powered countries on the planet.

[61] Tauernkraftwerke AG, *Die Tauernkraftwerke Aktiengesellschaft* (Salzburg: TKWAG, 1991), 6.

Conclusion

Beginning in the 1920s, Europeans began altering the Alpine landscape in ways that cemented and forged its status as a source of electrical energy on a continental scale. In Switzerland, some of the most important early dams were built to combat the dwindling of water power in the winter time, as well as to open up the water power of the high-Alps. At the same time, engineers across Europe advocated an expansion of the Alpine energy landscape by feeding its water power into international electricity networks, thereby contributing toward the recovery of Europe from WWI in a cooperative manner. The momentous interconnection of the hydro-rich Alps with Europe's mightiest coal fields in the Ruhr represented the first major step in this direction, pushed through by the German utility giant RWE. RWE envisioned economic gains in expanding its service area, and in gaining access to the water power stored in Austrian Alpine reservoirs (these hydropower dams were later described by one German as the "aorta" of the German electricity supply).[62]

The development of Alpine energy also occurred for reasons antithetical to international cooperation, especially after the onset of world depression. The quest for energy independence motivated hydropower expansion in the new Italian province of South Tyrol, where Italian endeavors toward autarky were also connected with the effort to Italianize the region. The South Tyrol episode, in which thousands of industrial workers moved to newly electrified factories, also demonstrates that hydraulic projects shift populations in ways other than displacement to make room for reservoirs.

The story of the giant reservoirs completed by the Austrian state in the Hohe Tauern during the postwar period in many ways reflects the final chapter in the building of Europe's

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[62] BayHStAM MHIG 3235: "Oesterreichs Elektrizitäts Wirtschaft, ihre Bedeutung für das Reich: Nutzbarchmachung der österreichischen Wassekräfte als Zukunftsaufgabe," *Völkischer Beobachter*, 22 March 1938.

Battery. Initially conceived as a cooperative international project by the Nazi state, construction of the dams began after one of the boldest bids for interwar energy autarky, the annexation of Austria. The dams, like many projects in the postwar Alps, were duly completed thanks to the largesse of the Marshall Plan. While they were designed primarily to serve the Austrian electricity supply, their scale also ensured that should it prove useful to Austrian interests, Tauern energy could be made available far outside of the mountains. This proved to be the case, and the Tauern Works Glockner-Kaprun remain a cornerstone of the postwar European electricity grid to this day.

Worldwide, dam-building usually involved political calculations as well as engineering and economic ones. Writ large, the Alpine environment provides proof of the near universal political attraction of dams. Large Alpine dam-building took off in an era defined by the emergence of a multitude of political ideologies in rapid succession. From the end of the First World War to the aftermath of the Second, even as internationalist and nationalist paradigms struggled against one another for supremacy, both agreed on the necessity of impounding Alpine water. Fascist dams symbolized the grandiosity and activism of the movement; Marshall Plan dams illustrated the can-do spirit of capitalist technology. Dam building and hydropower offered something to all of the many currents washing over the Alps in this period.

CONCLUSION

Since their creation some 100 million years ago, the Alps have conducted innumerable water molecules on spectacular journeys. The mountains themselves helped to draw the molecules out of the sky, their peaks forcing moist air to rise and shed its water freight. Molecules that fell on the main ridge during winter might take their place beside countless of other frozen water molecules on a vast Alpine glacier and wait. There they might rest for hundreds of years, until a hot summer day, when the water particles might finally leave the snowfields in liquid form. Now, as part of a mountain torrent, the molecules would crash down from the heights, performing imperceptible work all the way. Their voyage might then be interrupted by the cascade's confluence with the slack waters of a mountain lake. Eventually, these molecules might be escorted out of the uplands by one the region's larger rivers, the Rhône, Rhine, Po or Danube. It is conceivable that the same single molecule may have made this journey several times over the eons. Over the course of the previous millennium, this molecule may have also done its small part to turn one of the many waterwheels then proliferating in the Alps.

Since the beginning of the twentieth century the waypoints of this hypothetical trip have changed drastically, and with them its consequences. While it may have still included a glacial sojourn, a shooting of rapids, and a lake visit or two, water molecules' passage to the sea now likely encountered more and different obstructions, and resulted in different types of work. Water molecules are now far more likely to be waylaid behind a gigantic concrete wall in a fully artificial reservoir, or to rest a while in a lake. Their journey might now include a trip through a tunnel connecting once separate watersheds, and a rapid descent in an iron pipe onto the blades of a turbine.

Any water molecule that happened to cross paths with a turbine coupled to an electric dynamo kicked off the voyage of another caravan of microscopic particles. For this action set in motion a flow of electrons, particles that might, in the instant after their generation, be transported hundreds of kilometers away. Leaving the powerhouse where they were born, these electrons passed through a transformer designed to increase their voltage, thus creating the tension necessary to push them overland through a narrow metallic wire. A series of electrical substations determined these electrons' route, switching the particles' path to a destination decided upon by an anonymous grid operator. This might be a steel plant in the Ruhr, an aluminum smelter near Grenoble, or an electric cooking range in Innsbruck. If the electrons' fate was indeed to heat up a coil to prepare someone's food, they would first need to pass through another transformer, this one stepping-down their voltage to make them safe for household usage.

These hypothetical journeys are intended to illustrate the magnitude and extent of the changes wrought by Europeans in the Alps in the nineteenth and twentieth centuries, changes that form the focus of this study. As I have tried to show, in this time period Europeans completely rearranged the landscape of the Alps to turn the mountains into one of the Continent's most important energy-producing regions. They also took advantage of the mountain environment to give the region a unique energy purpose: to store seasonal flows of water power. By the early postwar period, the mountains that acted as a continental water tower had also become a continental battery of sorts, an energy landscape designed to generate electricity and store water power.

Up until the turn of the twentieth century, Europeans focused mostly on the electricity part of the equation. Using the new technologies of turbines and electricity, they harnessed completely new flows of power on an unprecedented scale. First, French engineers discovered white coal in the French Alps, creating a new type of water power in the process. With the advent of man-made electricity, Europeans modified Alpine watercourses towards new ends. By the end of the 1890s, the rural Alps were one of the most electrified landscapes in the world.

By 1900, however, simply using Alpine water to generate electricity for the region was no longer enough. Those interested in expanding the supply of hydroelectricity saw an obstacle in the inconstancy of flows of Alpine energy. Inconstancy stymied efforts to use water power efficiently and it made hydro a tricky substitute for coal on mainline railroads. At this point, the unique nature of the mountains offered the possibility of a technical solution instead of more difficult socio-cultural one. Europeans avoided making serious changes to the industrial rhythms of their energy use by taking advantage of opportunities to make serious changes in the Alpine landscape in order to store water. First they did so by converting existing lakes into reservoirs. After the First World War, interventions into Alpine hydrology everywhere became more intense, and the rationing of water more purposeful. From 1920 to 1955, Europeans set to damming the Alps even as they plugged Alpine hydroelectricity into burgeoning European electricity grids. By the mid-1950s, Europe's Battery was complete.

The world obtains its useful energy through the manipulation of environmental resources—in other words through the creation of energy landscapes large and small. Though it has gone mostly unrecognized, at this point the Alps had emerged as one of the world's most important energy landscapes. At this time it is no exaggeration to say that the Alps were comparable in significance to the other grand European energy landscapes such as the coal fields of Britain, Germany, and Russia, or the hydropower of Scandinavia. As a hydropower region, the Alps stood above all else. The mountains' importance was twofold. First, the Alpine water power was both quantitatively and qualitatively substantial. The Alps generated over half of western Europe's electricity after WWII. Qualitatively, Alpine water power was special in that much of it could be stored in high-altitude reservoirs and employed when required. Second, the Alps were also a part of a nascent European electricity grid, indeed one of the reasons for its existence. The quest to harness remote Alpine water power motivated the development of the polyphase alternating current system that enabled long-distance electric power transmission. The Alps were in many ways the Midlands of the second industrial revolution.

The story of Europe's Battery adds to knowledge in several historiographical fields. On the environmental history front, my dissertation adds to knowledge of the environmental history of one of the globe's most iconic landscapes. Focusing on water, an important part of the Alpine landscape, it shows that energy considerations reigned above all else in the remaking of the mountains' waterways. In many ways this study also functions as an environmental history of a transition to an alternative energy source. This study demonstrates some of the connections between the history of the environment and technology as well. Environmentally based resources such as white coal acted as a spur to technological innovation (in the form of the turbine, dynamo, and transformer) and required technological infrastructure for distribution. The transformation of a transnational mountain landscape also has much to say about European history. The story of the Alpine energy landscape sheds light on a unique moment in modern European history when the Alps loomed large as a region of critical resources. It also points to an alternative energy and industrial history for west-central Europe, a region where coal is presumed king.

Though this study stops in the early postwar period, the development of Alpine hydropower has continued until the present day. In the period from 1955 until 1970, the number of reservoirs increased by fifty percent while the usable storage capacity of the reservoirs more than doubled.[1] It was during this time that the grandest of all high-Alpine reservoirs was built, the Grand Dixence in western Switzerland. With a storage capacity of 400 million cubic meters and an energy capacity of 2,000 megawatts, the Grand Dixence is by far the largest hydroplant in Switzerland.[2] 1970 seems to have marked the high tide in Alpine hydropower development. With the entrance of oil, natural gas, and nuclear power into the European electricity supply, the economics of Alpine hydropower development have changed drastically. Moreover, burgeoning environmental movements throughout Europe have dampened the enthusiasm for water power projects. Nevertheless, these developments lie outside the boundaries of this study. The quantitative increase in both the water storage capacity of the Alps and the energy generated there was a continuation of the pattern that had been established by the early post-WWII period. They amount to an expansion of Europe's Battery.

Though their relative importance has diminished since the early postwar years, the Alps still play a crucial role in the European electricity supply. Alpine water generates nearly 100 terawatts per year. To produce this amount of energy would require the most modern of coal-fired plants—which manage to convert about half of the fuel's thermal energy into electricity—burning twenty-three million tons of anthracite each year. Over twenty different long-distance transmission lines cross over the Alps. The installed capacity of all Alpine hydropower plants is forty thousand megawatts. The Alpine contribution to the European electricity supply is comparable then to French nuclear power, Ruhr coal, and North Sea natural gas.[3]

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[1] Link "Bassins d'accumulation," 247.
[2] By way of comparison, one of the world's largest hydroelectric plant Itaipú on the Parana river between Paraguay and Brazil has an installed capacity of 12,600, six times that of Grand Dixence and 600 more megawatts than all of the hydroplants in Switzerland combined. Itaipú supplies almost all of Paraguay's electricity, and about one-fifth of Brazil's. Sixty percent of Swiss electricity comes from its water power. Botteri Balli, *Wasserkraftwerke der Schweiz*, 19.
[3] Bätzing, *Die Alpen*, 195-196.

The Alpine Damscape

In the period of this study and beyond, European ideas about how to use Alpine energy made the mountains one of the premier dam landscapes on the globe. As of the mid-1990s, three of the world's ten largest dams could be found in the Alps, two of them in Switzerland and one in Italy. For almost two decades, from 1961 until 1980, the Grand Dixence dam in Switzerland stood as the tallest in the World. In terms of reservoir volumes and hydroplant capacities, the Alpine dams cannot compare to those that impound the large rivers of the world. But Alpine hydroplants are unique in how quickly they can empty their reservoirs. Many of these projects were designed to generate power solely during the winter. Unlike many other damscapes, the Alpine one was almost exclusively about power production.[4]

Converting flows of energy into forms useful for humans always comes with costs. The most dramatic consequences of activating Alpine energy, from a human standpoint, have been the failure of the dams that concentrated mountain water power. From the beginning of the dam-building era until the present, the Alpine zone has experienced three catastrophic dam disasters, two of which resulted in over ten fatalities. The first two occurrences concern dams built during the period of this study. In 1888 the failure of the small Sonzier reservoir in Switzerland caused several casualties. Then in the 1920s, the Gleno dam in the Lombard Alps burst after the reservoir's first filling, claiming six hundred lives. In 1963, a landslide into the reservoir of the Vajont dam in the Alps north of Venice triggered the overtopping of that reservoir.[5]

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[4] In the meantime, perhaps due to the expansion of the European energy mix, Alpine dams are enlisted in the battle against floods as well. The hydropower section of the French Electricity Board (EDF), for instance, now plays a major role in civil defense through "contingency plans to counter the effects of floods on their structures or reservoir management programmes." See Charles Obled and Patrick Tourasse, "Uncertainty in flood forecasting: A French case study," in *Coping with Floods*, ed. G. Rossi et al. (Dordrecht: Kluwer, 1994), 474.

[5] The next sections based on Link, "Bassins d'accumulation," 279-281; McCully, *Silenced Rivers*, 101-122.

The Vajont disaster in particular stands as one of the worst dam catastrophes to date. The 260-meter high Vajont dam (world's fourth highest as of the mid-1990s) closes off a limestone canyon at the foot of Mont Toce in Italy's Friuli region. In the fall of 1960, as the reservoir began to fill for the first time, seismic shocks were recorded and portions of the gorge began to slide towards the reservoir. Operators partially drained the lake, and the seismic activity almost completely ceased. The reservoir was filled again in the spring of 1962, and the tremors returned. Engineers, however, believed that the rockslide the seismicity set in motion would fall harmlessly into the reservoir. Heavy rains in the summer of 1963 filled the reservoir to unprecedented heights, and by early September the seismic shocks had increased dramatically. Within the span of a few hours during the night of October 9/10 1963, the slope's movement began to accelerate and then suddenly broke loose. A two-kilometer long section of the hillside composing some 300 million cubic meters of material slid at high speed into the reservoir. The impact created a wave that crashed first into the opposite side of the valley at a height of 200 meters, and traveled upwards into the valley, laying waste to the banks of the reservoir. Finally, a flood wave overtopped the dam by nearly a hundred meters—the height of a twenty-storey building—sending approximately 25 million cubic meters of water into the Piave Valley below. About two minutes later the water reached the nearest village of Longarone, devastating the community and killing nearly all of its inhabitants. Several other villages also washed away. All told, the catastrophe caused over 2,000 deaths. With the exception of some damage at its crown, the dam held, a fact which many engineers at the time interpreted as evidence of the safety of well-founded arch dams. The accident prompted the evaluation of the integrity of the landscapes around reservoirs throughout the Alps, and promoted the study of rock mechanics to better understand the dynamics of landslides. Many suspect that the Vajont episode represents a case of reservoir-induced seismicity (RIS), meaning the existence of the new lake helped trigger earthquakes that led to the landslide. While the science behind RIS remains unclear, most believe that the increased seismic activity near some reservoirs stems from the extra water pressure in subterranean microfissures caused by the added weight of the water. To this day, the Vajont reservoir remains unused.

The safety record in the Alps is a sobering one. Outside of China, some twelve thousand humans perished due to dam failures in the twentieth century.[6] The Gleno and Vajont dam accidents by themselves account for about twenty percent of this figure. In terms of numbers of disasters, there have been about 200 large dam failures since 1900. The International Committee on Large Dams estimates that two percent of dams built before 1950 failed, and half of one percent of those constructed since then. The Alps show that dam failure is not simply a problem in developing nations.

The creation of this Alpine damscape also has a global legacy of sorts. Making the Alpine energy landscape created national industries and expertise that states have sought to support by promoting hydro development abroad. One of the most important avenues for doing so is in the provision of "aid" money to finance projects around the globe that otherwise might go unbuilt. Countries like Austria—home to some of world's foremost dam construction firms and equipment suppliers—can lend money for hydro development abroad secure in the knowledge that much of those funds will return to Austria to purchase the necessary goods and services. In the desire to support domestic construction and equipment industries that cut their

[6] The preceding caveat is necessary to gain some perspective on global dam disasters in the twentieth century. In the worst dam catastrophe in history, up to 230,000 Chinese may have been killed by a dam failure in August 1975.

teeth on the dams of the Alps, European governments have subsidized the outsourcing of their field of activities.[7]

The Effects of Europe's Battery

Creating a system on the scale of the Alpine energy landscape carried important political consequences. After the Second World War, the United States was happy to support the development of Alpine hydropower through programs like the Marshall Plan because it believed that such measures would be critical in warding off communism in western Europe. The political importance of white coal also had effects on borders. Perhaps the best example of this comes from the Italian province of South Tyrol, annexed by Italy after the First World War. In the aftermath of WWII, the question of South Tyrol's political status once again seemed uncertain. Despite initially being open to a scenario where South Tyrol would be ceded to Austria, the United States lent its critical support to Italy's maintenance of the region. Among other reasons, Italy kept South Tyrol because leading politicians convinced US authorities of the importance of the province's water power for the maintenance of the capitalist Italian economy. Abundant white coal permitted some Alpine states increased flexibility in making national energy choices. Austria's complete eschewal of nuclear energy, would be nearly unthinkable in the absence of its Alpine hydroelectricity.

An extension of this political importance was the mountains' military significance. Alpine hydropower played an important role in the two world wars that defined early-twentieth century Europe. In the First World War, white coal was a lifeline to countries with scant domestic coal resources such as France, Switzerland, and Italy. National Socialist energy planners saw the water power of the Austrian Alps as the key to freeing up its coal for strategic

[7] For a multifaceted look at the connection between dams and political economy See McCully, *Silenced Rivers*, chapter 9.

purposes, and energy considerations were among the most important economic justifications for the annexation of Austria. As the Swiss discovered, locating power plants in the mountains had some security advantages as well. Beginning in the 1940s, the Swiss began building inside of mountains as a means of protecting them from air attack.

Water as a resource is particularly entangled in the web of social relations, and the complete transformation of Alpine water use had important impacts on European society. These impacts occurred from the changes in the land necessary to generate water power, and the energy it liberated. As many have pointed out, our term *rivalry* comes from the Latin *rivus*, meaning river. In antiquity, *rivalen* were riparian neighbors with competing interests on the same watercourse. The word underlines the reality that in some cases, certain types of water use preclude others. Utilizing water to generate electricity represented a stark departure from previous arrangements. The shift to a new use of Alpine water meant the demise of certain social groups. In this study I have touched briefly on the decline of traditional fisheries and the timber rafting trade as a result of the damming of Alpine waterways. But there were many others. The energy converted by this hydraulic retooling of the Alps was part of a process that thoroughly remade European society. Late twentieth-century society is an electrified society of nighttime illumination, urban tramways, and more comfortable factory floors. This electricity was a critical component of the rise of consumer society as well. While cheap oil gets much of the ink in energy-based explanations of the advent of consumerism (and its devastating environmental consequences) it is hard to imagine in the absence of the electricity grids that powered the factories producing many consumer goods and the households that used them. In west-central Europe, Alpine hydro was a crucial part of the electricity supply upon which consumer society depended.[8]

Creating Europe's Battery entailed massive environmental changes. These modifications of Alpine hydrology carried with them important consequences for Alpine ecology. The results can generally be distinguished between those impacts generated by the creation of run-of-river schemes, and those called forth by storage works.[9]

From the perspective of environmental scientists, the consequence of run-of-the-river dams has been the complete alteration of Alpine river and floodplain habitats caused by the disruption of sediment dynamics. A study from the 1990s concluded that of the 10,000 kilometers of main Alpine rivers, only ten percent are in "close to natural form" ("*naturnaher Zustand*"). Alpine hydropower development has also led to the channelization of many rivers. The interruption of sediment flows by weirs and barrages causes the rivers downstream of the obstruction to scour into their beds. This lowers the water table, thereby damaging floodplain ecosystems. In the worst case this can result in *Sohlendurchschlag*, where in a very short time span the river cuts down several meters into its bedrock. This has happened for example on the Inn, Isar, and Lech. All of these effects accelerate flood waves. On the Inn, for example the time it takes for a flood to occur has dropped by two-thirds. Retention ponds constructed to compensate for accelerated flooding are prone to sedimentation, thus quickly losing their effectiveness. Hydraulic engineers refer to the time when these works were created as the "Hydraulic and Concrete Era" and see their job in large part as an attempt to correct its "extreme aberrations" ("*fehlentwicklungen*").[10]

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[8] Christian Pfister, ed., *Das 1950er Syndrom: Der Weg in die Konsumgesellschaft* (Bern: Haupt, 1995).
[9] What follows mostly from Bätzing, *Die Alpen*, 197-198 and Maier, "Kippenlandschaft."
[10] Maier, "Kippenlandschaft," 253.

Storage works submerge vast amounts of land, thereby altering the distribution of species, nutrient cycles, water temperature, sedimentation, and ground water levels. Reservoirs change microclimates and can sometimes have impacts on regional climates as well. The long-distance diversion of water to fill reservoirs also had devastating consequences for sensitive Alpine nature. Many torrents, diverted at high-altitudes, run completely dry for long stretches. The lack of water completely destroys flora and fauna. The phenomenon of hydropeaking also has rude consequences for the Alpine environment. Hydropeaking occurs when a reservoir power plant periodically releases water to cover energy demands. For a short time, a watercourse's ecosystem experiences a rush of water which then ceases again. Hydropeaking also occurs regularly as a cheap means to flush out some of the sediments that build up in reservoirs. Alpine reservoirs also cause a kind of hydropeaking on a much larger scale. True to many reservoirs' purpose, the dams store summer flood waters to be released during the winter months. Throughout the Alps then, reservoirs have caused a shift in the seasonal distribution of water, to which the biota adjusts as best it can.[11]

Centralized electric production also has its environmental impacts. High-voltage transmission lines required for centralized electricity production, for example, intervene substantially into ecosystems. Besides the aesthetic impacts, high-voltage lines required the clearing of substantial corridors. Since the air between the wires and the ground is intended to function as an additional isolator, vegetation underneath the lines cannot exceed a certain height. Up until the 1980s, herbicides were employed to limit the growth of plants below the lines. On agricultural lands, impacts are restricted to the area around the foundation of the towers. But wherever transmission routes intersect with forests, the consequences multiply. To ensure safe operation, swaths up to seventy meters in width must be cleared through the woods. These lanes

[11] Maier, "Kippenlandschaft," 254.

make surrounding trees more vulnerable to winds, and change the local climate. In Germany, high-voltage wires were also suspected of decimating avian populations—particularly storks—prompting the placement of colorful balls on the lines in order to catch the birds' attention. It has also recently come to light that the paints used to treat and rustproof the masts contained high quantities of lead that then pollute the ground below. Lead levels in the soil beneath high-voltage towers in RWE's grid, for instance, sometimes contained five times the acceptable amount.[12]

Energy development was the source of the greatest human interventions in the Alpine hydrosphere over the last century. In the coming century, it is possible that the Alps' function as Europe's water tower will take on even greater importance for Europe. If global temperatures continue to rise, and if this rise is accompanied by drought on the European continent, then water will likely emerge as *the* critical resource of the Alpine region. Then Europeans will have to decide anew what form they would like to give to the Alpine landscape.

Epilogue

On the night of June 11/12 1961, the traditional fires of the *Herz-Jesu* celebration were accompanied by a number of additional flames in the Italian province of South Tyrol. The new fires were the result of terrorist bomb attacks, almost forty of them, carried out by South Tyrol Liberation Committee (*Befreiungsausschuss Südtirol*, BAS). The BAS had been founded in the 1950s in order to halt the Italianization of South Tyrol, a task its members no longer believed politicians could accomplish. For years, the BAS had planned a large-scale demonstration of their disaffection. The night they chose for their attack was symbolic. The *Herz Jesu* celebration

[12] Wiebke Rögener, "Gift unter Strommasten: Bleihaltige Rostschutzfarbe verseucht das Erdreich—noch immer wird in Deutschland wenig dagegen getan," *Süddeutsche Zeitung*, 6 February 2009. This newspaper also notes the continuing suspicions that the electromagnetic fields created by high-voltage electric transmission can cause cancer to humans. Maier, "Kippenlandschaft," 254.

had been occurring since 1796, when the estates of Tyrol determined to entrust the fate of their land to the heart of Jesus as the occupying armies of Napoleon approached. Ever since, *Herz Jesu* night meant the appearance of fires, some in the shape of hearts and crosses, on the darkened slopes of Tyrol's mountains at night. The target of the attacks also had their own symbolism. The main victims of the night were not human—although the action resulted in the death of a road worker killed by explosives attached to a tree beside the highway. Rather the bombs focused on the hydroelectric infrastructure of South Tyrol, and particularly of the area around the capital of Bolzano. In all the BAS destroyed thirty-seven electric towers, two high-pressure water pipes that fed hydroplants, and several railroad masts. Authorities managed to defuse one bomb that had been fixed to a dam an hour before it was set to explode. The attacks of this night have gone down in the history of South Tyrol as the *Feuernacht*. They were the beginning of almost a decade of political terror in South Tyrol—"the bomb years"—a period that ended only after Italy's extension of wide-ranging political autonomy in 1969.[13]

In many ways, the *Feuernacht* offers a microcosm of the significance of the new energy landscape Europeans superimposed on the Alps in the nineteenth and twentieth centuries. In the most immediate sense, the bombers' targets point to the political importance that Alpine hydropower gained throughout much of west-central Europe after 1890. For many areas, white coal was the primary source of power, a resource that compensated for the lack of fossil fuels. With the attack on hydroelectric infrastructure, the BAS focused on an energy source crucial to the Italian economy. Tiny South Tyrol accounted for over ten percent of Italy's annual electricity production. More importantly, since the aftermath of WWII, the province possessed the most useful sort of water power. This was water power that could be stored, and in the late-1940s and

[13] Rolf Steininger, *Die Feuernacht: und was dann? Südtirol und die Bomben 1959-1969* (Bolzano: Athesiadruck, 2011).

early 1950s Italian electrical utilities took advantage of the province's Alpine valleys to store white coal in gigantic reservoirs. The BAS bombings also remind of the symbolic importance attached to the creation of the new energy landscape. In their minds, the extremists targeted icons of the Italian—and especially Fascist—"colonization" of their ethnic homeland. The preponderance of bombs in and around the industrial zone built up by Mussolini in the vicinity of the capital of Bolzano was no accident.

The *Feuernacht* and the "bomb years" in some ways marked the end of the peculiar era that helped manufacture Europe's Battery. The terrorist attacks in South Tyrol were small remnants of nationally-inspired violence which twice devastated Europe in the course of two world wars. These nationalist antagonisms also contributed their share to the making of the Alpine energy landscape in the form of geopolitical imperatives within European nations to develop their energy sources, including white coal.

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