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Large Wind Turbines

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Paul Gipe

La Puissance du Vent (The Power of Wind)--A Review



[*La Puissance du Vent: Des moulins à vent aux éoliennes modernes*](#) by Philippe Bruyerre is a major work on the history of wind energy particularly in France, but also elsewhere. His book earns a place in French analogous to Matthias Heymann's masterwork on [German wind energy](#) or Rinie van Est's [Winds of Change](#).

The book is the result of Bruyerre's doctoral thesis on the technical innovation and social-economic integration of wind energy in Germany, Denmark, and France (*Dynamiques d'innovation technique et d'intégration socio-économique. Le cas de l'éolienne en Allemagne, au Danemark et en France*). The book has won an "honourable mention" of the 2021 ICOHTEC (*International Committee for the History of Technology*) [Turriano Prize](#).

Bruyerre, an engineer, is one of France's wind energy pioneers. His firm Espace Eolien Développement, installed one of the first commercial wind turbines in France on a dike at Dunkerque's harbor in the early 1990s. This was the first part of a ten turbine project that has since been dismantled. Nevertheless, the project was ambitious for its day, using Windmaster's 25-meter diameter turbine.

I photographed that first turbine and have used pictures of that installation to show how wind energy can be integrated into the landscape and be compatible with recreational use. My photos show people, walking, jogging, and pushing baby carriages (prams) beneath the wind turbine.



It's been a long time since I've waded into a book on wind energy. Been there, done that, and moved on. However, if you're a student of wind energy—in all its forms—a book like *La Puissance du Vent* deserves a deep dive.

I've read a lot of books on the history of wind energy and the history of wind technology. Each adds something to this long and important story. Bruyere's book takes its place, especially for his analysis of French oil mills, Dutch post mills in common parlance, that were used to press oil in France, and especially for the behind the scenes look at the principals and their thinking on the two big French experimental wind turbines of the 1960s.

Divided into five parts, Bruyere examines the growth and decline of the oil mills surrounding Lille in the north of France, la Cour's development of his "ideal" windmill at Askov in Denmark during the late 19th century, Electricite de France's development of experimental wind turbines in the 1950s and 1960s, the rise of modern wind turbines at a former ship-building factory in Northern Germany in the 1990s, and finally a revue of the long history of wind technology development.

Lilles' Oil Mills

The history of wind energy is not just the history of the wind but also the history of machines, of invention, and of the manufacturers who made windmills possible. Echoing a theme by Edward Kealey in *Harvesting the Air: Windmill Pioneers in Twelfth-Century England*, Bruyere notes that the watermill was a fundamental part of feudal society. The windmill was affront to noble control. The miller was its sole master. The captain of his immobile vessel, says Bruyere. It could be--and was--owned and operated by the miller, a small-time capitalist or a *petit bourgeois*. The windmill was a symbol of liberty from feudal restrictions. This wasn't lost on the lords of the manor. Wind historians have noted the sometimes successful attempts to destroy windmills because they competed with the manor's water-milling rights.

The European or Dutch windmill was an original technological development that used the materials of the day. Though often compared to water mills, Bruyere contends, that windmills are a far cry from water mills. They incorporated the technology of the day, especially that from naval design, using wood as in sailing ships, and using cloth sails in much the same way as they were used on ships. The general design of windmills reigned for nearly 800 years.

To illustrate his themes, Bruyere turns to the history of wind energy in his region, the area in northwest France surrounding the industrial city of Lille, once known for its textiles.

In the 18th century, Lille was known for its *tordoires á vent* or traditional post mills used for processing vegetable oil. Oil mills were specialized. Some produced oil for soap, others for lighting, while others produced cooking oil. Most pressed rapeseed into oil but other seeds were also used.

There were so many wind-driven oil mills around Lille that travelers commented on a veritable forest of windmills or as professor Martin Pasqualletti might describe an "energy landscape." The oil industry was significant enough that not only could supply the region's needs, but half of its oil production could be exported to the Netherlands and Russia despite the Dutch's famed use of windmills themselves.

From the outside these mills looked like any other post mill used throughout Europe at the time. However, they didn't grind grain by spinning a mill stone. With the exception of the rotor and the general shape of the windmill, the oil mill has nothing in common with a grain mill. The interior workings are entirely different, writes Bruyere. They pressed the oil out of the seed by smashing it with a rack of metal tipped wooden hammers much like the stamp mills of California's gold country crushed gold-bearing ore in their stamp mills.

Bruyere laments that most historians of technology have paid little heed to "industrial" windmills in preference to the much more common and easily researched grain mills. Libraries are full of books depicting

grain mills. Yet it was the industrial windmill's importance to places like Lille and especially the Zaan district in Noord Holland that directly led to the industrial revolution.

Few today realize how integral traditional mills, such as Lille's post mills, were to society in the 18th century. Their ubiquity attracted the attention of the physicists of the day. Bruyere explores the role that Lille's windmills played in the work of [Charles-Augustin de Coulomb](#). Yes, that Coulomb of [Coulomb's Law](#) fame.

One of Coulomb's last works was his essay on windmills. Everyone knew that windmills worked, but no one knew why they worked the way they did. Coulomb set out to change that. As a result, he may have been the first to observe that the speed of the tip of the blade was 2.6 times the speed of the wind at the tip, describing what we now call the tip-speed ratio—a key characteristic of a wind turbine. This was at a time when the science of meteorology was in its infancy. Measuring the wind itself was a challenge that Coulomb had to overcome for his measurements.

Based on Coulomb's work, Bruyere estimates that each of Lille's oil mills produced about 22,000 kWh of usable work per year—or the equivalent of 220 “energy slaves.” Accordingly, the 400 windmills in the late 18th century produced the equivalent work of 1.5 times the then population of Lille. This places the significance of Lille's oil mills in their regional context.

Fossil Fuel Kills Lille's Mills

As in so many other cases, the introduction of fossil fuels killed the demand for Lille's windmills, but not in the manner commonly imagined. It wasn't the introduction of steam power that killed Lille's mills. That came later. No, it was the introduction of natural or city gas for lighting that cut the demand for the oil use for illumination. Gas was cleaner and easier to use than oil. And electricity wasn't far behind the introduction of gas for lighting.

About the same time steam was being introduced to make vegetable oil on an industrial scale, further reducing the need for windmills to press oil. By mid-19th century the price of vegetable oil had collapsed, leading soon afterward to the mass abandonment of traditional windmills surrounding Lille.

One consequence of these changes was the change in ownership and who would prosper. While a windmill was a costly structure, it was only twenty times the annual salary of the period. In contrast, the cost of a coal-fired, steam-powered mill for pressing oil was ten times the salary of the period. Only the wealthiest could own and benefit from the new industry. The miller and his family faced a bleak future. Once the captain of his own ship, he was left adrift.

By 1880 there were only 18 wind-powered oil mills operating. In 1830 there had been 93. By 1900 they were all gone. The landscape that once held the twirling arms of windmills as far as the eye could see had been transformed into one of belching chimneys and smoke that obscured the sky.

The post mills of Lille birthed the region's industrial might but in so doing cemented their own demise. Yet it didn't happen overnight. It took some 60 years for the transition to fossil fuels.

The decline wasn't solely due to fossil fuels. Bruyere points out that one of the factors in the disappearance of Lille's post mills was French colonial policy. Taxes on domestic oil were used to subsidize imports of vegetable oil from French colonists. Another was the French state's support of sugar beets which reduced the acreage devoted to rapeseed. The switch to lighting first by gas then by electricity played its part. The final nail in the coffin was the growth of Lille as an industrial powerhouse. The city burst out of its medieval walls, gobbling up the land devoted to rapeseed and wind mills.

The greatest physical enemy of Lille's oil mills, beside the wind itself, was war. Some 40% of the windmills built during a period of 500 years were destroyed by warfare. One windmill, Bruyere found, was burned three times over its lifetime in different wars.

La Cour and the Ideal Windmill

Bruyerre treads familiar territory in his discourse on Poul la Cour, the Danish Edison, and his influence on subsequent Danish development of wind energy. Not one to curry friends or favor, Bruyerre controversially challenges the notion that modern wind energy owes its success to Danes and Denmark. He calls this a “cultural canon” developed by Danes to further their own national identity and for promotion of their commerce.

Bruyerre devotes an entire chapter questioning whether la Cour is the father of modern wind turbines. Noting that la Cour’s “ideal windmill” is not ideal at all and modern wind turbines don’t resemble it at all.

To build his case, he begins by tracing the use of wind mills in Denmark of various types in the 19th century, including the local manufacture of American or “Chicago” style mechanical wind pumps. He then sums up why early attempts by James Blyth (1887, Scotland), Duc de Feltre (1887, France) and Charles Brush (1888, American) were unsuccessful in adapting the windmills of the day to generating electricity. This sets the scene for Denmark’s la Cour.

For those who’ve long wondered about la Cour’s surname, Bruyerre sets the record straight. Poul la Cour’s family was of French descent. This is why he wasn’t known as Poul Madsen (the Smith of Denmark) or Poul Christensen (the Jones of Denmark).



In 1894, la Cour quickly realized that one of the obstacles to developing his “ideal” windmill was some way to store the windmill’s variable output. He chose to use electricity from his experimental windmills to electrolyze water into hydrogen. In this way the hydrogen could be used for lighting, heat, or power.

This was taking place only a few years after Brush’s use of a large “American” windmill to power the arc lights on his Cleveland estate. Brush, like Blyth, and the Duc de Feltre used batteries to store the wind’s variable generation. la Cour’s use of hydrogen instead of batteries initially was novel if not innovative for the time.

By 1896 la Cour had developed his own wind tunnel for testing model windmills. And it was through his wind tunnel tests that la Cour discovered that it was the total area swept by the windmill's rotor and not the surface of the windmills' blades that determined how much power it could deliver. This observation overturned hundreds of years of millright beliefs and still to this day is difficult for the uninitiated to understand. The "doubters" that modern wind turbines with their long slender blades actually work can blame it all on la Cour and his wind tunnel tests in the late 19th century.

In questioning the import of la Cour's work, Bruyere asks why then was la Cour's "ideal windmill" after a decade of study only modestly better than Smeaton's windmill of 150-years before. Or why was la Cour's observations more profound than Coulomb's observations a century before.

Bruyere is at his best digging up little known facts from the period. Who knew that the grand battle between those building, testing, and using conventional wind turbines—windmills that spin about a horizontal axis—and those who think vertical-axis windmills will be superior began at the turn of the 19th century. Apparently, nothing is new, not even the battle between HAWTs and VAWTs.

In 1901, some fourteen years after Blyth's primitive VAWT in Scotland, a Danish engineer attacked la Cour, accusing him of bias against vertical axis windmills. The engineer whined that all windmill designs must pass through la Cour for his *imprimatur* and that he wouldn't give inventors of VAWTs the attention they deserved. This was especially galling since la Cour's work was supported by the state. La Cour responded aggressively, says Bruyere, not unlike some of the so-called "gatekeepers" of conventional wind turbines today.

Despite his critics, la Cour promoted the use of his design. One manufacturer, Lykkegaard, built wind turbines of la Cour's design for half a century. The Lykkegaard wind turbine was used extensively in Denmark during both world wars and was used throughout Europe until 1957.

The Lykkegaard design was intended to be fully automatic and not require a "miller" to monitor the turbine. It used Jalousie shutters on the blades to regulate power and prevent storm damage. The rotor was turned toward the wind with two fan tails on the bed frame. Like windmills of old, the turbine drove a vertical shaft that could be used to pump water, power a grain mill, or generate electricity. Surplus generation during high winds would be stored in batteries and when the batteries were at capacity the charging would be automatically stopped.

During the Great War, one-quarter of all rural generating stations were using Lykkegaard wind turbines.

Part of the problem for la Cour in developing his ideal windmill was the seemingly simple task of measuring the wind, something we take for granted today. Like Coulomb and those that followed, the challenge was not a simple one. In the early days, wind was measured by the distance a feather flew downwind.

Blyth used the recently invented Robinson cup anemometer but that wasn't the end of the story. Bruyere dives into depth on why anemometers were needed and by whom. Mine disasters forced engineers to devise ways to measure how much deadly mine gases were being vented out of the mine. The great Tay Bridge disaster on the Firth of Forth led to the study of wind force and for that the engineers of the day needed to know the speed of the wind. Today's anemometer represents more than 100 years of research by some of the great names in physics.

Early on la Cour found that four blades were better than more, but fewer than four were hard to envision. His ideal windmill featured four blades in part because a rotor of this design was easy to fabricate—the same reason traditional windmills often used only four blades.

La Cour was not alone in studying the wind. Though communications and travel were limited, there were scientific journals that reported on the work of others. Some two decades before, the American engineer Thomas Perry constructed his own wind tunnel for experimenting with the multiblade American water-pumping windmill. He tested 60 designs and found that a windmill rotor with only six blades would out

produce a rotor with sixty by 2.5 times and that this had something to do with the ease of the air passing through the rotor disc.

At the turn of the 19th century there was a great intellectual debate among physicists about how windmills worked, was it due to the wind hitting the surface of the blades or the “sucking” of the wind as it passed by the blade in that great open space between the blades. This battle wouldn’t be settled for many decades and still to this day many inventors can’t imagine how a modern wind turbine with its one, two, or three slender blades can outperform a rotor nearly solid with many blades.

Famous French engineer Gustave Eiffel tested a series of windmills in his wind tunnel near Paris. Not surprisingly, he reached similar conclusions to those before him: reducing the number of blades on the rotor from four to two increased performance 30%.

These observations fly in the face of conventional wisdom and it has been a curse for those of us who work in wind energy. We are forever saying, “trust us, they just work better this way.”

These observations didn’t have theory to explain why they worked, but that they did. It was only in the late 1920s and early 1930s that the theory caught up with observations and wind tunnel tests.

Bruyerre now introduces the greats of aerodynamics that provide the theory for why wind turbines work the way they do. We move from Eiffel to the British aerodynamacist Frederick Lanchester and then on to German physicists Ludwig Prandtl and Albert Betz, the latter famed for the “Betz limit” to the performance of conventional wind turbines. Bruyerre rephrases this common expression as the Lanchester-Joukowski-Betz limit so as not to offend any British, German, or Russian chauvinists.

In conclusion, la Cour, argues Bruyerre, claimed to have developed the ideal windmill but he never provided the proof that he did. If la Cour’s windmill was ideal in any way, it was ideal for the rural Denmark of its day with its small communities, its cooperatives, and its decentralized technology. La Cour’s windmill, and his effort to spread its use, was an ideal fit with the times and the place.

The Windmill as a Service

At the time, the Lykkegaard turbines provided a service—lighting, or power—and not solely electricity. The company in fact only charged for the services it provided, the electricity the customer used. Because of the limitations of battery storage and the small size of the networks where the windmills were used, much of the wind energy available was not used. The batteries were full, for example, or it was daytime and lighting wasn’t needed. To some, especially those pushing the centralization of electricity, this was wasting wind. Not so to la Cour. The wind was free, not using it was not wasting it.

This dilemma still exists today. Small wind systems for remote homes are sized to produce more energy than needed. Yet they spill energy that can’t be used.

As in off-the-grid systems today, diesel generators are used only as a supplemental source--for backup when the batteries are empty and there’s not enough wind.

On the other hand, wind turbines connected to a centralized network can deliver all the energy they produce because the grid can nearly always take more.

Here, Bruyerre introduces the little known German engineer, Dimitry Stein, who during WWII studied Danish use of wind energy. Stein made the observation that Danish wind turbines produced three times more electricity when they were connected to the grid than when they were used on individual farms or for small municipalities. This may seem obvious to us today, but it was a significant observation at the time and a powerful argument for using wind energy on the network like any other energy resource such as coal or diesel fuel.

While la Cour may not have developed the ideal windmill after all, he was instrumental in popularizing its use among Danes, says Bruyerre. Particularly important was la Cour's role in organizing students to spread wind technology throughout Denmark in furtherance of the ideals of the *følkehojskole* movement.

Askov, where la Cour taught and studied wind energy, was part of the popular Danish folk high schools, or "schools for living" inspired by Danish theologian [N. F. S. Grundtvig](#). Few outside Denmark appreciate the profound influence that Grundtvig and his philosophy of self help and a sense of community had on Denmark, especially rural Denmark. La Cour followed Grundtvig's philosophy and dedicated the latter part of his life to aiding his fellow Danes in lifting themselves out of poverty and in sharing what life has to offer. La Cour did this by passing on the knowledge of how wind energy could be used to enlighten as well as light the lives of Danes.

French Wind Development in the 1960s

France was behind most other industrial countries in the consumption of electricity and German occupation during the World War II didn't help. At the time France consumed one-quarter the electricity per capita as Switzerland. Post war France set a goal for a massive expansion of electricity to modernize the country. France consolidated electricity in a state enterprise, [Électricité de France](#), as a national priority. In 1946 EDF created a research bureau and subsequently a wind division in 1948.

For nearly two decades EDF studied the use of wind energy until the program—and its experimental turbines—were abandoned in the rush to nuclear power.

For all the work done by some of the leading wind engineers of the period, little has been written about these projects with the exception of the few books in French, Bruyerre complains. One reason, he suggests, was that the research archives were destroyed. That would certainly do it, but why would EDF do this is a question that's left unanswered.

Another reason may be that the principals didn't write books about their work, whether in French or English. Putnam made sure his project was documented in his *Power from the Wind*. Golding told the British story in his *The Generation of Electricity by Wind Power*. The cover of the version I have of Golding's book has a picture of a British wind turbine designed by a French engineer (Andreau). Hütter and his acolytes published widely in both German and English.

When EDF shut down the wind division it was as though wind never existed in France and maybe that's the way they wanted it. Bruyerre notes that the one published report on EDF's research was a 1975 article in *Houille Blanche* (White Coal or Hydro) by R. Bonnefille, responding to criticism that France was being left behind in the race to wind energy. On the contrary wrote Bonnefille in hopes of settling the matter, we studied it, tested it, and it didn't work very well.

BEST-Romani

In 1949 EDF presented the government with proposals for experimental wind turbines. One by BEST (Bureau d'Études Scientifiques et Techniques) led by Lucien Romani, their technical director was selected. The others, including one by Monsieur Andreau of Enfield-Andreau fame were rejected. Subsequently, EDF solicited a proposal from Neyrpic based on the work of Louis Vadot, a consulting engineer to Neyrpic.

EDF had confidence in BEST because it housed the best of France's aeronautic community. Romani had come to BEST from Eiffel's famed wind tunnel lab near Paris, a training ground for many of France's best aeronautical engineers.

As Bruyerre describes it, the BEST turbine incorporated the thinking of the day: three blades, stall-regulated, downwind free yaw, and a synchronous generator like that on the Smith-Putnam machine. Models of the

wind turbine were extensively tested in French wind tunnels beginning in 1949, including that at Saint-Cyr, the site of the French equivalent of West Point.

With a rotor 30.2 meters in diameter it was a giant for the day only superseded by Hütter's StWG 34 in Germany.

Rather than an induction generator as used by Johannes Juul at Gedser, EDF chose a synchronous generator because it was what they believed was better adapted to utility use.

The blades were made out of riveted aluminum and included cylindrical spoilers for overspeed protection, a necessary feature for a fixed-pitch, stall-regulated rotor. Bruyere notes that the spoilers degraded the rotor's performance because they interfered with the aerodynamics.

The BEST turbine was connected to the grid in the interior of France in the winter of 1957 at Nogent-le-Roi north of Chartres and west of Paris almost a decade after it was conceived. Unlike Putnam, who chose a site that he knew to be windy, the BEST turbine was placed in a region of low to moderate winds.

In the spring of 1958, engineers noted oscillations of the turbine as the blades passed behind the tower. Unusual even till today, the tower employed a streamlined fairing to reduce downwind turbulence on the rotor.

In the fall of 1959 the turbine reached a peak power of 1,025 kW, in the process destroying the generator.

Tests continued from 1960 to 1962 after the generator had been replaced. Fatigue cracks were found at the blade rivets in the fall of 1961. Nevertheless, from 1958 to 1962 the turbine operated for 5,400 hours and ran continuously for 7.5 months. Despite the mixed results, EDF declared the tests a success.

In the spring of 1962, BEST installed a new rotor with a higher tip speed with the goal to eliminate a stage in the gearbox thereby reducing cost. There was disquiet among the engineers that this was a risky gamble. After only 300 hours of operation, one blade broke and the turbine was stopped.

Romani wrote that the new rotor had not been studied as thoroughly as necessary. He noted that it takes a lot to bring such a big rotor to halt during emergencies when it relies on stall-regulation, something that was learned time and time again in the 1980s in California. This was the last straw for EDF and after nearly 15 years of development the project came to a close.

Romani and BEST were not ready to throw in the towel and proposed to EDF a wind turbine using contra-rotating dual 32-meter diameter rotors generating 1,000 kW. In the meantime, EDF had concluded that wind cost 30% to 50% more than oil-fired generation. In 1963, EDF decided to cancel the wind program and in 1966 they ordered the turbine dismantled.

From Hydro to Wind: Neyrpic

The second of EDF's wind projects was developed by Neyrpic (Ateliers Neyret-Beylier & Picard-Pictet) in Grenoble France. Like the S. Morgan Smith Company in York, Pennsylvania who designed the Smith-Putnam wind turbine, Neyrpic wanted to use its mechanical skills and diversify from hydro into wind energy.

Neyrpic was well-known for its hydroelectric turbines. They developed and manufactured the innovative bulb turbines for France's famed tidal power plant in the La Rance estuary that still operates today.

The company had also been active in wind energy due to the work of consulting engineer Louis Vadot. Interestingly, Bruyere discovered that Neyrpic held a patent on a wind turbine using aspiration, a method similar to that of French engineer Jean-Edouard Andreau for his British project with Enfield Cables.

Neyrpic also manufactured water-pumping wind turbines using modern high-speed rotors with three fiberglass blades in sizes from 8 to 16 meters in diameter. For water pumpers, these were big machines even by today's standards. This is another facet to Neyrpic and Vadot's work that isn't widely known.

Unlike the BEST-Romani project, EDF selected a windy site overlooking Jersey and the English Channel at Saint-Rémy-des-Landes on the Cotentin Peninsula. The site was 900 km (550 miles) from Neyrpic's plant and this was at a time when there were no TGV, *autoroutes*, or frequent air travel.

Probably based on their previous experience, Vadot and Neyrpic were less ambitious than Romani. Their first turbine used a rotor 21.2 meters in diameter rated at 132 kW. Similar to Romani, Vadot used a three-blade rotor downwind of the tower. Unlike Romani, Vadot chose an asynchronous or induction generator rather than the more difficult to use synchronous generator favored by EDF.

And in contrast to the fixed-pitch, stall-regulated BEST-Romani rotor, Vadot chose variable pitch blades to regulate overspeed.

Wind tunnel tests began in 1955 and a prototype was assembled near Grenoble in 1956. By the end of the year the test turbine was installed on the French coast and tests were conducted from 1957 to 1958.

According to Bruyere's research, EDF interfered with Vadot's choice of materials and refused his three-piece blade design. They should have listened to Vadot, writes Bruyere. The aluminum blades EDF chose failed and were removed in 1959.

Vadot and Neyrpic then chose to use fiberglass blades like they were using for their water-pumping wind turbines. EDF finally agreed and the new blades were installed in 1960. This was a good choice. The turbine operated untended from 1962 through 1966 by which time it had generated a total of 700,000 kWh. Though production was much less than expected, the turbine had an availability—an industry measure of reliability—of 95%. (We didn't see reliability this high in California until the late 1980s.) In a technical sense, the turbine was a great success, particularly in comparison to that of the BEST-Romani design.

Bruyere's research has unearthed more gems from this period of experimentation. Later analysis found the coefficient of performance for the Neyrpic turbine was 0.42 using a modern cantilevered rotor with modern materials. This was a significant improvement on the 0.33 calculated for Juul's Gedser mill with its crude blade construction and a rotor braced with struts and stays.



Interestingly, the specific area of Neyrpic 1 was $2.7 \text{ m}^2/\text{kW}$ similar to that of Juul's Gedser mill of $3.1 \text{ m}^2/\text{kW}$. Contrast this with a specific area of less than unity for the BEST-Romani turbine, one of the lowest in recorded history.

The very high ratings of the BEST-Romani turbine, and the subsequent Neyrpic design were likely due to pressure from EDF. Bruyerre as much as says this when he notes EDF constantly interfered with their consultants decisions. EDF wanted a machine closer to its own conception of what an ideal generator size was for its network regardless of what the technology was capable of. In this EDF pushed too far and this is revealed in the low specific area of less than unity.

However, Bruyerre makes the perplexing argument that the Neyrpic turbine performed particularly well relative to the performance of Hütter's StWG 34 and that of Juul's Gedser machine. Agreed, Hütter's turbine seldom operated unattended and seldom for long stretches. It was not a successful wind turbine. It was a test bench for technology, particularly fiberglass blade technology.

However, the Gedser turbine was designed and operated as a working wind turbine for an electric utility and it performed well—even by the standards of the 1980s. Particularly in the early years, it performed well; delivering yields of up to $800 \text{ kWh}/\text{m}^2/\text{yr}$. Yields such as this wouldn't be seen again until the late 1980s or early 1990s. During its lifetime, the turbine generated 2.2 million kWh, producing nearly 370,000 kWh during its best year or half that of the total production from Vadot's Neyrpic turbine. In a six-year period, the Gedser turbine generated an average of 275,000 kWh per year. Juul's ungainly, clunky turbine performed as well if not better than that of Neyrpic over a longer period.

As implied by Bruyerre, Neyrpic might have done even better if it had another client than EDF. Unfortunately for Vadot and Neyrpic, EDF was the only possible client in France. The success of the turbine at Saint-Rémy-des-Landes led EDF to order a bigger turbine from Neyrpic.

The new turbine was 35 meters in diameter or almost three times larger than the first design and rated at an astounding 1,000 kW. Though the 1 MW generator was deemed the "ideal" size by EDF, the rotor driving it yields a specific area of almost $1 \text{ m}^2/\text{kW}$ or almost as bad as the BEST-Romani turbine.

As with the BEST turbine, Neyrpic's second design was a wind turbine too far for the day. The turbine began operation in 1963, operated for some 2,000 hours before being stopped due to noise in the drive train. The turbine generated 500,000 kWh during a seven-month period—less than Neyrpic's first design and less than half that from Juul's Gedser mill.

That was the end of Neyrpic 2 and also the end of EDF's wind division begun in 1948. In 1964 EDF decided to dismantle the turbine.

What Went Wrong

Bruyerre suggests that the origin of modern wind energy results rather than from national styles of development, espoused by German historian Matthias Heymann, but from styles of technological development. For example, the BEST-Romani turbine evolved from the aeronautical style like that of helicopter blades. Juul's Gedser mill came more from the mechanical style. Neyrpic and Vadot were closer to the mechanical style because of their practical work with hydroelectric turbines. Other historians of the period phrase it differently. They attribute the different results depending upon whether the technology was developed from the top down (the aerospace approach) or from the bottom up (the Danish approach). Bruyerre poses the question I've raised as well, would Denmark have been as successful with wind energy if it had an aerospace industry?

Neyrpic's choice of a fiberglass blade was innovative at the time. This is what Hütter was trying to do with his StWG 34 in Stuttgart. Though Hütter is credited with the blade design feature, the Hütter flange, which

launched the Danish wind industry, Bruyerre argues that Neyrpic's fiberglass blade was more technologically successful because it enabled a functioning, productive wind turbine in the early 1960s.

This and the success of Neyrpic 1 have been lost to wind history because the principals didn't write about, and the records of its achievements were destroyed by the client who ordered the turbine, EDF. Subsequently, French contribution to modern wind energy has remained in the shadows.

Bruyerre's Quality Indicator

How far have we come in developing wind turbines? That's a question those of us writing about wind energy have often grappled with. How do we measure the difference between a traditional Dutch windmill or one of Lille's oil mills and a modern wind turbine? I've tried my hand at it in various ways.

Bruyerre does it by looking at how one of the great wind engineers approached the question. Ulrich Hütter, says Bruyerre, proposed an "indicator of quality" or we could say "performance." Hütter proposed using the product of the coefficient of performance of a wind turbine's rotor—a measure of its efficiency—and the rotor's tip-speed ratio. Slow-speed traditional windmills with a relatively inefficient rotor will have a low number. In contrast a modern wind turbine with an efficient rotor operating at high speeds will have a higher number. The higher number will be an indicator of overall performance because it will indicate that the modern wind turbine will use materials more efficiently with its long slender blades and, thus, most likely be more cost effective. Importantly, this assumes all are equally reliable.

To make comparison easier, Bruyerre sets the relative value of a Lille post mill (0.26 Quality Indicator) to 1 and proceeds to the Lykkegaard (0.53) with a relative value of 2. That is, the Lykkegaard is twice as effective as the Lille post mill. He does the same for France's Neyrpic (2.26) with a relative value of 8.6. That is, the Neyrpic turbine is nearly 9 times more effective than the traditional windmill and four times as effective as the early Danish design. He then compares these to a modern wind turbine produced in 2010. The Repower turbine Bruyerre uses—it could have been any competitive turbine of the day—has a quality or performance value of 15.8 (4.1) or more than 16 times more effective than a traditional windmill. Significantly, the Repower turbine is two times more effective than the Neyrpic turbine of the 1960s.

Bruyerre's chart showing the exponential growth in "quality" or effectiveness from 1750-2015 is alone worth the price of the book.

The Silent Wind Revolution

Bernard Chabot will be happy. Bruyerre appears to be one of the few French engineers working in wind energy who understands what Monsieur Chabot's "[Silent Revolution](#)" is all about. Bruyerre also seems to understand what Chabot was trying to do when he designed France's feed-in tariffs for wind energy to be [differentiated by resource intensity](#).

First, Bruyerre explains how the German manufacturer, Repower, introduced a series of successive models based on the same 2 MW platform. That is, Repower developed a series of wind turbines with different size rotors, but all with a 2 MW rating. They began in 2002 with a 70 meter-diameter rotor rated at 2 MW. They followed that in 2003 with a 2 MW turbine using an 82-meter rotor. In 2005 they introduced a 2 MW turbine with a 92-meter rotor. The series concluded with a 2 MW turbine driven by a 100-meter rotor.

Repower's 2 MW series flew in the face of what was conventional thinking of the time. However, Monsieur Chabot had been shouting that this was in fact what the industry needed all along to develop low and moderate wind sites. Now it's standard practice throughout the industry.

Bruyerre explains it simply. The 70-meter wind turbine installed at a moderate wind site would generate 3 million kWh per year. The 100-meter turbine would generate more than 6 million kWh per year at the same site. The 2 MW peak power from the larger turbine would be easier to integrate into the grid than say a much

larger generator. You can produce a lot more electricity while minimizing the effect on the grid at interior sites by keep the peak power low. This is the beauty of what Chabot calls the Silent Wind Revolution because it doesn't require any sexy new technology, it simply uses bigger rotors. And it's the rotor after all that makes a wind turbine.

American wind developers finally saw the light as well. Today, DOE brags about the rising capacity factor of wind farms in the USA and journalists frequently exclaim what a startling development this is. It's not anything earth shaking at all. In part it's due to the weak grid in the USA where the role of wind turbines with large rotors and small generators are much more important than in a place with a strong grid like France. And in part it's a natural product of making wind energy pay in interior areas with low to moderate winds.

From there, Bruyere goes on to show how the French feed-in tariff worked, which flew in the face of conventional economic theory too. A French owner of wind turbine would be paid more for their electricity at a site with a lower resource intensity—a lower wind speed—than they would at a windier site.

What? Yes, the payment per kWh was inversely proportional to the windiness of the site. Had the land of Descartes lost its way?

The objective, Bruyere explains, was to spread economic wind development across the breadth of France and not concentrate it only on the windiest sites, often locations of high social importance, such as on the coast of Normandy. With these innovative feed-in tariffs differentiated by resource intensity, the French were successful. There are wind turbines throughout France, including some in the same region where the Nogent-le-Roi turbine was tested in the 1960s not far from Chartres Cathedral. They are not all concentrated on the Cotentin Peninsula or along the beaches. For two decades both France and Germany had followed the same philosophy with great success, distributing wind energy and its economic opportunity to all of their regions and all of their citizens.

And that's the final message from Bruyere's *La Puissance du Vent* that there are lessons to learn from all those who've worked in wind energy--French, German, Danish, British, and American--in both how they approach technology and why they do so—and for whom. The French have given us feed-in tariffs differentiated by resource intensity. Like French work with wind energy in the 1960s, this contribution has remained in the shadows. French engineers from Eiffel to Darrieus, from Constantin to Vadot join the pantheon of German and Danish greats who have given us modern wind energy.

Bruyere, Philippe. [*La Puissance du Vent: Des moulins à vent aux éoliennes modernes*](#). Toulouse, France: Presses universitaires du Midi, 2020. 261 pages. ISBN-10: 2810706751, ISBN-13: 978-2810706754. 25.00 € paper. 16 x 1.3 x 24 cm. Printed in France.

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