SANCTIFIED SCIENCE

Medieval monks developed technologies that changed history

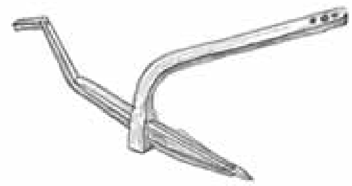
Wind-driven pumps were essential in low-lying areas like the Netherlands, where wind power could pump water out of agricultural fields reclaimed from the sea. —Tatiana Krakowiak/iStock

It might seem odd that much of the scientific and engineering progress that took place in Europe between the eleventh and fourteenth centuries was advanced by the innovations of a group of strict and reclusive monks. In 1098, abbot Robert de Molesme (1029–1111) and about twenty other Benedictine monks—in reaction to their fellow monks' lax practices of the core principles of monastic life: prayer, study, and work—left their monastery in Molesme, France, and founded a new monastery in Cîteaux, approximately 130 kilometers away.

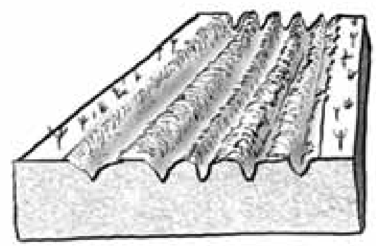
The first task for the monks was to drain the reedy swamps of the low-lying Saône floodplain surrounding their new home. The knowledge gained in the process was just the beginning of a series of innovations by the monks to work the land. A new monastic order was born, Cistercian, and the discipline and dedication of its members spawned monasteries throughout Europe. Over the next centuries, the Cistercians were instrumental in developing the agricultural technology and practices that allowed the European population to grow and incorporate a larger area.

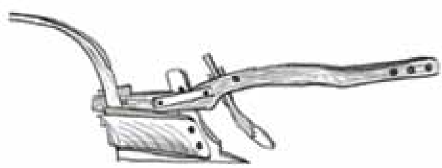
Most of Europe was an economic backwater in 1000. With roughly 38 million people, its population was a twentieth of the size that it is today. Most people lived in rural towns or villages. However, Europe's situation began to change after 1000. The population began to grow rapidly and spread into northern France and the Low Countries of Belgium and the Netherlands, as well as the Rhineland of western Germany, the Polish plains of eastern Europe, and the Po valley of northern Italy. Larger cities grew up, lived in by people who were neither peasants nor the ruling class of the old feudal order. This "middle class" consisted of traders, government workers, craftspeople, shopkeepers, and people in the Church or professional military. Urbanism grew steadily: Paris, for example, expanded to a population of over 200,000 by 1300. This was also around the time when Europe began to push outward at its boundaries. Explorers from Norway colonized Iceland and Greenland and explored the northeast coast of Canada. Germanic people pushed eastward into lands across much of eastern Europe that had been colonized by Slavic and Baltic people. The Crusades, intended to conquer the holy sites of Christianity, were set in motion in 1095, when Pope Urban II (ca. 1035–1099) called for Europe to aid the Byzantine emperor against Muslim states in the Middle East. And the Reconquista or "re-conquest" of Spain and Portugal began in earnest as Christian princes sought to expel Muslims who had conquered Iberia in the 700s.

One of the main reasons these developments were possible was a sharp increase in agricultural productivity in Europe. This increase came from new farming methods and new technologies that allowed farmers to bring lands under cultivation that had never been farmed before. It was also driven by developments in water and wind-driven mills that further increased productivity. There was a shift from subsistence farming, which supported a relatively static medieval population, to a form of farming that produced surpluses. These surpluses supported urbanism, a middle class, crusades to far-off lands, and new exploration and colonization. This surplus also made it possible to undertake the building of the great Gothic cathedrals of the twelfth century and after

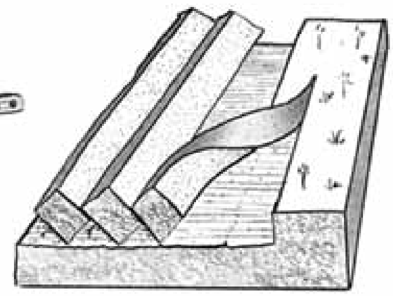


Ard or scratch plow





Mouldboard heavy plow



—S. Wilson after White 1962

(see "Cultures in Contact: The Forest of Notre Dame," *NH*, 10/23).

Cistercians helped make this economic transformation possible. While involved in religious reform, they were also technological leaders. They developed and refined a kind of heavy plow that could bring wet, clay-heavy soils to agricultural productivity. These soils, widespread in northern Europe, were fertile, but could not be cultivated with a traditional plow—a mainstay of agriculture that goes back to the first use of draft animals to pull a plow in Mesopotamia, Egypt, and the Indus Valley around 3000 BCE. The old plows, called in Europe the "scratch plow" or "Ard plow," dragged a symmetrical tear into the soil. It worked fairly well for the rich alluvial soils of the great river valleys, and well enough for the dry, crumbly loams of southern and central Europe. But for the heavy soils of the low countries of northern Europe, or for long-established grasslands, it was ineffectual, merely cutting a slash through the soil that then closed behind it. The soil was fertile, but too heavy and wet to grow the European domesticates.

The Cistercians developed a heavy plow with the technology to reach down and make a horizontal tear under the sod layer, turning over a layer of earth completely and leaving a deep furrow. The heavy plow combined several technologies. First, it had a *coulter*, from the Latin "culter" which means "knife" or "dagger," that sliced the soil vertically before the sharply pointed plowshare reached it. Following the incision made by the coulter, the knifelike iron plowshare cut more deeply and made an angled or even horizontal cut a foot or more below the surface. Another part, a concave "mouldboard," followed the blade of the plowshare and lifted up the earth and flopped it over beside the furrow. The heavy plow of the Middle Ages was a breakthrough technology that changed Europe. It required many changes in farming practices, involving much greater pulling power than the scratch plow. The heavy plow had stout oak beams and iron chains used to yolk together sometimes four or more oxen to rip such a gash in heavy soils, or horses and mules were harnessed in new ways to apply the agricultural system in places that could not be farmed before.

Many of the elements of this kind of plow are quite old, and it would not be accurate to say the Cistercians invented it. Like most technological breakthroughs, many people in many places were working simultaneously at finding a solution to farming these soils and trying different kinds of plows and plowshares. The Cistercians designed and documented their version of the plow and over decades continued to improve it, dispersing iterations of their designs among the monasteries. Through their annual meetings at Cîteaux, they shared this information with monasteries throughout Europe. In organizational structure, liturgy, rules, architecture, and technology, the Cistercians sought to maintain uniformity among the various houses by means of documents, such as the *Carta Caritatis*, a founding constitution. They felt that an advance made by one house would help the others and so required a level of documentation that is reminiscent of the early scientists in Europe.

THERE WERE TWO OTHER parts of this revolution that also helped generate agricultural surpluses, and the Cistercians used and improved both. The first involved a three-field system of crop rotation. Under this system, in the first year farmers would plant a fall crop of wheat, rye, and other crops that grew over the winter and were harvested in late summer. The following spring, they would plant such crops as barley, oats, and beans. These included legumes, which enriched the soil with fixed nitrogen. And the next year, the field would have manure and other natural fertilizers added and be allowed to lie fallow for a year, which helped the soil regain its structure, biome, and fertility. This crop rotation system alleviated the problem of soil exhaustion caused by planting the same crop over and over, and by many estimates nearly doubled the long-term productivity of a plot of land. Another technological improvement was a carefully engineered horse collar. This was probably developed in China well before 1000 CE, and spread along the Silk Road. The new collar distributed the pulling weight evenly on the chest and shoulders of a horse or mule. With these collars, draft horses could plow much larger areas than teams of oxen could. Large and strong draft horses were bred for this purpose in Flanders, Belgium, and the Netherlands, and later all over Europe.

The other Cistercian project that changed Europe was the harnessing of water and wind for mechanical energy. These ideas were also not new, but the Cistercians brought about substantial innovations in the technology. Water-powered mills were widely used by the Romans, Chinese, Muslims, and Byzantines, but the Cistercians, especially, were known for finding new ways to use waterpower. Among the hundreds of Cistercian monasteries, a large fraction has watercourses running through the center of them, providing water and also supplying power for a wide range of uses. At the Cistercian Abbey at Clairveaux, France, for example, a canal brought water about a kilometer from L'Aube River. As it ran through the monastery, it was used to operate a grist mill, an olive press, a wool-fulling mill, and a tannery, as well as for the kitchen and baths. Finally, latrines emptied into the canal before the water returned to the river (where it carried on downstream to provide water to the town of Bayel). Water wheels were also used to power saws for cutting timber and stone. The Cistercians employed water in metallurgy, using waterpower to lift ore out of mines, pulverize it in hammer mills, and then use water-driven bellows and hammers to smelt it into iron. As Portuguese architectural historian Ana Martin observes, "The Cistercian hydraulic system represents something extraordinarily new. [Many scholars] point to Cistercian hydraulics as something exceptional in the context and at the time when the first Cistercian monasteries were founded."

The Cistercians were also innovators in using wind power. Wind power was not used for mills in the Roman world, nor in Mesopotamia, India, or China until the ninth century CE. Then, Persians used tall structures on ridges with the driveshaft mounted vertically to capture the wind's airflow. The wind passed through essentially a tall window and drove the sails of the turbine, while sails on the opposite side of the shaft were protected from the wind by a wall. Europeans adapted this principle, using a gearing mechanism so they could mount the driveshaft horizontally.

Water mills at Singraven, Netherlands, first documented in 1448, include an oil mill, a corn mill, and a saw mill. —Mark Wolters/Shutterstock

While masterful in using gravity-powered water mills, the Cistercians used wind power in areas where the topography would not support waterpower. This was especially true in the Low Countries of northern Europe and the vast eastern European plains, stretching 1,500 kilometers from northern Poland to the Black Sea in Ukraine. Wind-driven pumps were essential in low-lying areas like the Netherlands, where wind power could pump water out of agricultural fields reclaimed from the sea.

It is hard to measure the impact Cistercian "high tech" had on European development. Some technical improvements are nearly invisible historically and archaeologically, like a gearing mechanism to turn power from a horizontal driveshaft, such as a water or wing wheel, into the flat rotation of a millstone more than a meter in diameter, or to take the rotary power of a waterwheel and convert it to the back-and-forth motion of a sawmill. The same gears, clutches, and brakes that allow a rotating windmill to grind wheat can be used to employ an animal mill and winch to lift heavy stones to the top of a Gothic cathedral. And similarly, a gear that can drive a 600-kilogram millstone can also be scaled down to turn the hands of a monastery clock, like the one built in the Benedictine Abbey of St. Albans, England.

Like the technological changes in electronics of the last fifty years, the accumulation and combination of many small innovations was probably more important than solitary breakthroughs, and even the breakthroughs came when many people were all trying to solve the same problems simultaneously. Perhaps the Cistercian's greatest step forward was in documenting and disseminating their successes and failures, creating a model for the European scientific revolution of the 1500s.

Samuel M. Wilson is Professor Emeritus of Anthropology at the University of Texas, author of *The Emperor's Giraffe and Other Stories of Cultures in Contact*, and a contributing editor to *Natural History*.