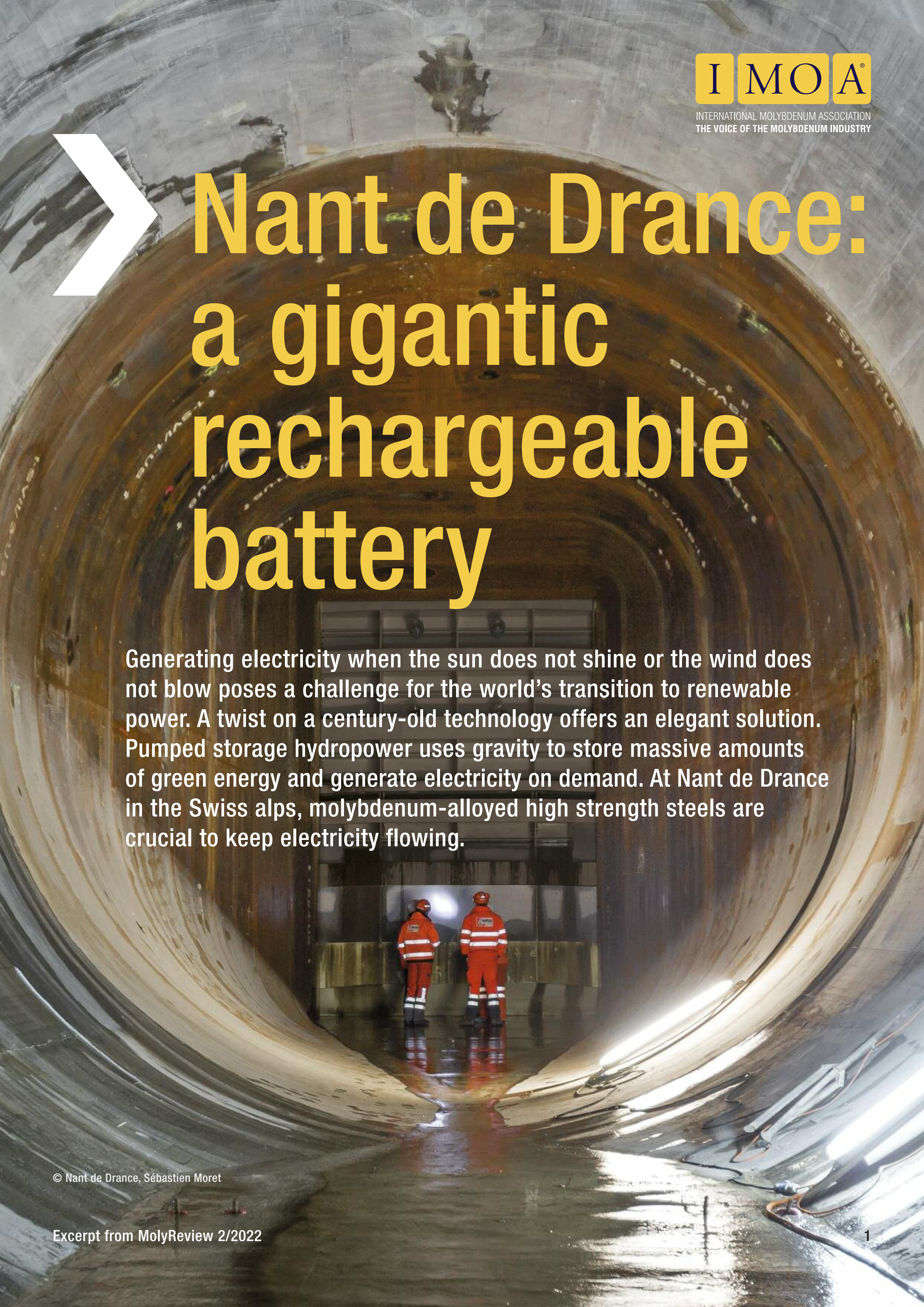


Nant de Drance: a gigantic rechargeable battery

Generating electricity when the sun does not shine or the wind does not blow poses a challenge for the world's transition to renewable power. A twist on a century-old technology offers an elegant solution. Pumped storage hydropower uses gravity to store massive amounts of green energy and generate electricity on demand. At Nant de Drance in the Swiss alps, molybdenum-alloyed high strength steels are crucial to keep electricity flowing.

Among renewable energy sources, solar and wind are considered the most viable to reduce greenhouse gas emissions by 2050, according to the International Energy Agency. However, the availability of both depends on the course of nature, making electricity supply variable, unlike that from fuel burning power plants. For instance, if a very windy day produces more power than needed, that power is wasted without adequate storage. A mismatch in supply and demand puts communities at risk of black outs or power surges. Hydropower storage, also known as pumped storage, offers both a solution and an alternative to massive utility-scale battery banks. When there is excess electricity in the power grid, it is used to pump water from a lower reservoir into a second reservoir at a higher elevation, like recharging a giant battery. When demand necessitates, the water is released and uses gravity to drive a turbine, producing electricity. Currently, pumped storage is the largest battery technology by far, representing over 90% of all installed energy storage capacity globally, according to the International Hydropower Association. The amount of energy stored in the world's hydropower plants dwarfs all traditional batteries on earth combined, including all electric vehicles (EVs).

Nant de Drance in numbers

900 MW: generating capacity

6: Francis turbines, each with a capacity of 150 MW

20 Mio. kWh: storage capacity ~ 400,000 EV batteries

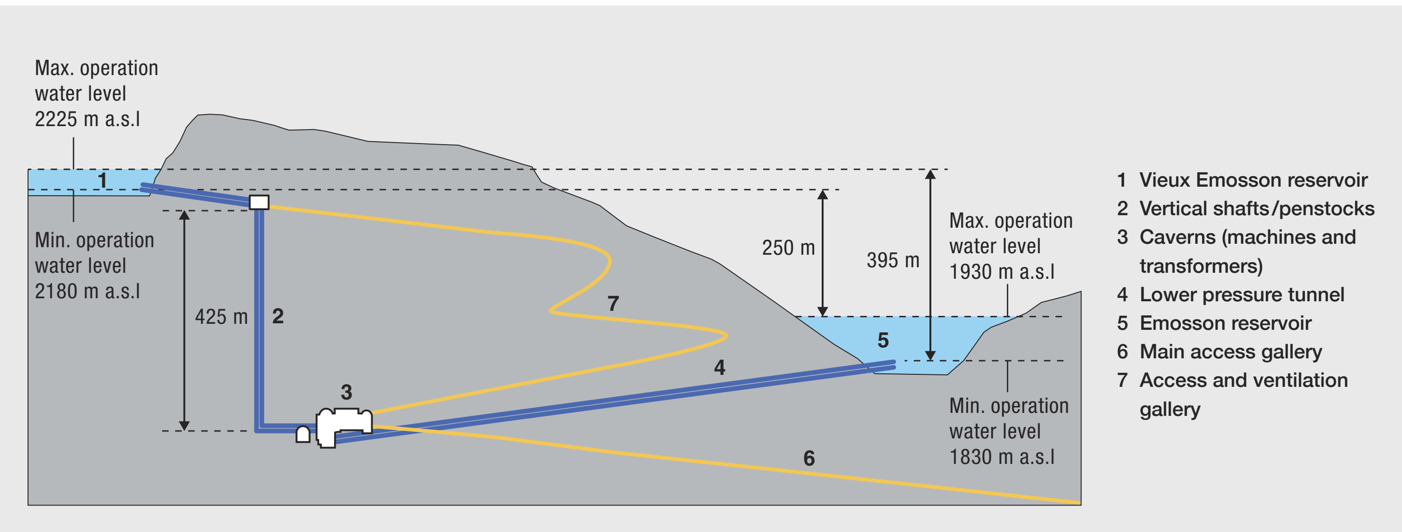
194 m: length of the underground turbine chamber

25 million m^3: capacity of Vieux Emosson reservoir ~ 20 hours of electricity

Building a plant in the Swiss alps

Pumped storage isn't appropriate for every environment: droughts, for example, can severely compromise the system's function. Hydropower technology can also affect sensitive ecosystems. And there must be a significant elevation difference for water to fall from: the greater the difference, the more energy efficient. But in areas with ample space, water, and mountains where a height difference can be exploited, pumped storage offers immense potential to compensate for fluctuations in power supply and demand. According to Australian National University, there are over 600,000 sites potentially suitable for pumped storage systems worldwide.

A good use case for pumped storage lies in Switzerland, which already generates nearly all of its electricity with carbon-free hydro and nuclear power. Around 60% comes from hydropower and an additional 35% comes from nuclear. Though the country has among the lowest carbon emissions in electricity generation worldwide, its ability to transition away from nuclear generation to renewables depends on large scale storage solutions. Bringing Nant de Drance online provides storage capacity, generates low carbon electricity, and adds system flexibility. The plant is crucial not only for stabilizing the Swiss grid but also for the European electric grid at large. For example, if a wind farm in Germany produces an excess supply, that energy can be transferred and stored at Nant de Drance.

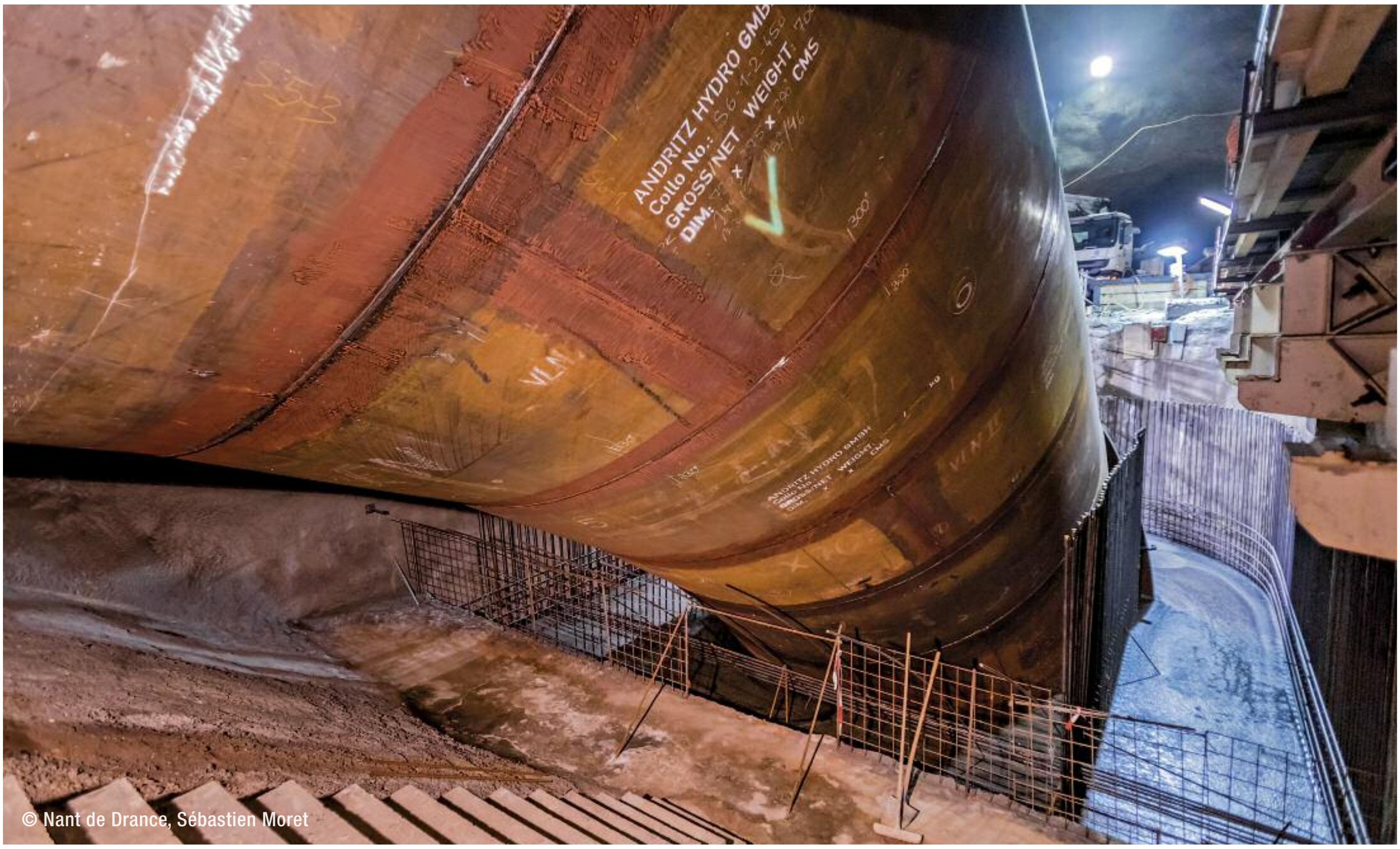


Two existing reservoirs with a significant height difference inspired this project in the Valais alps. The reservoirs are connected by a pair of gargantuan 2 km-long parallel conduits called "headraces". These include the 425 m high vertical shafts, some 7 m in diameter. The two pipes transporting water through the headrace, known as "penstock," are concrete-lined and reinforced with high strength steel in the areas of higher stress. Components exposed to the highest stresses use molybdenum-containing S690 QL1, a quenched and tempered steel. This includes the pipe elbows leading into and out of the vertical shaft, their flanges, and the reinforced distributors at the bottom of the shaft that supply the six turbines. Some of the areas of highest stress utilize S690 QL1 plate as thick as 130 mm, containing up to 0.7% molybdenum. Housings for the gates that help control inflow and outflow at either end of the headrace are also made with this steel. The force of the water crushing down is enormous – but heavy-duty plate steels can handle it. Especially if they're alloyed with molybdenum.

Inside a reinforced distributor. It divides each large diameter penstock into three branches, feeding one turbine each.

What makes the steel strong?

When the required yield strength of a plate steel surpasses 500 MPa, molybdenum becomes important, especially for thicker plates. When quenching a steel plate after heat treating at high temperature, the center of the plate cools more slowly than the surface, a phenomenon that becomes more pronounced as steel sections become thicker. This variation in cooling is problematic because it results in inconsistent steel strength across the thickness. Molybdenum is very valuable in thicker steel plates because it helps to homogenize the steel's strength profile across the thickness of the plate.



The massive penstock is reinforced with high strength steel in the areas of highest stress like the elbows.

Molybdenum is therefore a key hardening element in high-strength penstock. The steels involved in pumped storage plants are thick plates that need to be exceptionally hard, strong, and tough, but also weldable. Molybdenum helps heavy duty steels develop an ideal balance between hardness and toughness. Strength usually comes at the expense of toughness, a measure for a material's ability to absorb impact. Imagine a piece of glass, something very hard, also needing the properties of something highly shock absorbent like rubber. Strong steel can be tempered – a form of heat treatment – to increase toughness, but then the material usually loses some of its desired strength. Molybdenum, however, largely prevents the loss of too much strength during tempering and maintains toughness. During tempering, molybdenum precipitates by itself or jointly with other elements such as chromium and micro alloys, to form what are known as "nanosized carbides", which are essentially very hard, microscopic particles in the microstructure. These microscopic particles dispersed in the microstructure are responsible for secondary hardening. When steel is heated and cooled according to carefully designed time-temperature schedules, its microstructure can be adjusted to a wide variety of phase constituents, grain sizes, and other structural features resulting in wildly different properties. Molybdenum plays a major role in controlling the phase formation and particularly promoting strong microstructures.

Installation of a pump turbine. The turbine blades are made of martensitic stainless steel, containing 0.3–1.0% molybdenum.

Nant de Drance: excellent energy efficiency

With its 900 MW of installed generation capacity, around as much as a typical nuclear reactor, the Nant de Drance plant is one of the most powerful in Europe. It operates at over 80% efficiency – among the highest achieved in pumped storage power plants, and far above traditional thermal power plants. For example, coal-fired plants average just over 33% efficiency. They can also take hours to reach full operation. Nant de Drance, on the other hand, can start up in two minutes and go from pumping to generating in less than five minutes, so it can react to any spike in demand or drop in supply almost instantaneously.

Because Nant de Drance will so greatly improve the Swiss grid's ability to react to rapid changes in power supply and demand, the country's famous railway system, SBB, became a shareholder in the project. SBB's trains are fully electrified, requiring as much electricity as Switzerland's largest city, Zurich. However, power demand for the rail system varies dramatically throughout the day, peaking to several hundred MW in the early morning when locomotives all over the country power up nearly simultaneously. Demand also surges every half hour when trains leave the stations according to the synchronized train schedule.

But where exactly is all the massive equipment hidden within the pristine peaks of the Swiss Alps? Well, the entire plant is built inside a mountain. Hiding so much of the storage plant's structure within the mountain not only preserves stunning views of the Alps, but also reduces its impact on the local ecosystem. Over 17 km of tunnel were dug into the mountain using a huge tunnel boring machine. One 5 km tunnel leads to the gaping subterranean engine room, where the turbines are housed. Though it's 600 m below ground, the room is so large, the Leaning Tower of Pisa could comfortably fit inside! Most of the welding of the massive steel pipes and other components took place on site in caverns. The construction of the plant spanned 14 years and operation began in July 2022.

The world's transition to clean energy will be challenging. The inherent variability of supply requires massive energy storage systems. However, solutions are developing, and some are already available, like hydropower storage. Nant de Dance is an example of successful large-scale energy storage, made more reliable and longer lasting through the special properties of molybdenum-alloyed high-strength steels. Once again, molybdenum is instrumental in a technology poised to meet the world's energy demands more sustainably. (Karlee Williston)