Technological innovation in the energy sector

Negative emissions plants, salt batteries, clay storage and floating wind farms

November 8, 2017

Producer
Claire Garney

Director
Alistair Taylor

The moonshot pursuit of "negative emissions"

A look at direct air capture and the negative emissions plant in Iceland

Scientists have been working on a process called "direct air capture" of carbon dioxide using machines that would pull thousands of times more carbon from the air than trees

The technology has not been at the forefront of the climate change debate because scientists were hopeful carbon emissions would come under control and thought the technology would be expensive to deploy

Investors in the technology include Bill Gates, Edgar Bronfman Jr., the late Gary Comer, Switzerland's Climeworks, Canada's Carbon Engineering and the U.S. company Global Thermostat

On October 11^{th}, a geothermal power plant in Iceland inaugurated the first system that does direct air capture to achieve negative carbon emissions. The plant operates at a pilot scale and converts 50 metric tons of CO_2 a year to stone

Direct air capture costs between $600 and $1,000 per metric ton of CO_2 captured from the air. Despite its costs, it is an important technology because there is no other way to deal with the CO_2 released by cars, ships and planes, and the world is on track to miss its emissions reduction target and goal of limiting global temperature rise to 2 degree

Most carbon capture systems depend on a process known as "reversible absorption" that runs a mixture of gases over a material to absorb CO_2 and then compresses the CO_2 and injects it underground

Sources Akshat Rathi, "The world's first 'negative emissions' plant has begun operation – turning carbon dioxide into stone," Quartz, October 12, 2017.

Three companies working on negative emissions projects

Efforts in Switzerland, Canada and the US to develop direct air capture technology

Climeworks

Achievements:

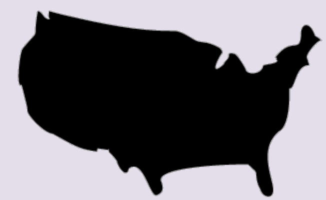
- Piloted a system that coats plastics and ceramics with amine, a chemical that can absorb CO_2
- Trying to bring the cost down to about $100 per metric ton of CO_2 captured
- Raised about $15 million in private investment
- Set up its first commercial unit near Zurich that captures about 1,000 metric tons of CO_2 to be sent to a nearby greenhouse, where crop yield has increased by 20%

Carbon Engineering

Achievements:

- Piloted a liquid system that uses calcium oxide and water to pull CO_2 from the air
- Trying to bring the cost down to about $100 per metric ton of CO_2
- Raised $15 million in private investment
- Waiting to scale up before it launches a commercial plant

Global Thermostat



Achievements:

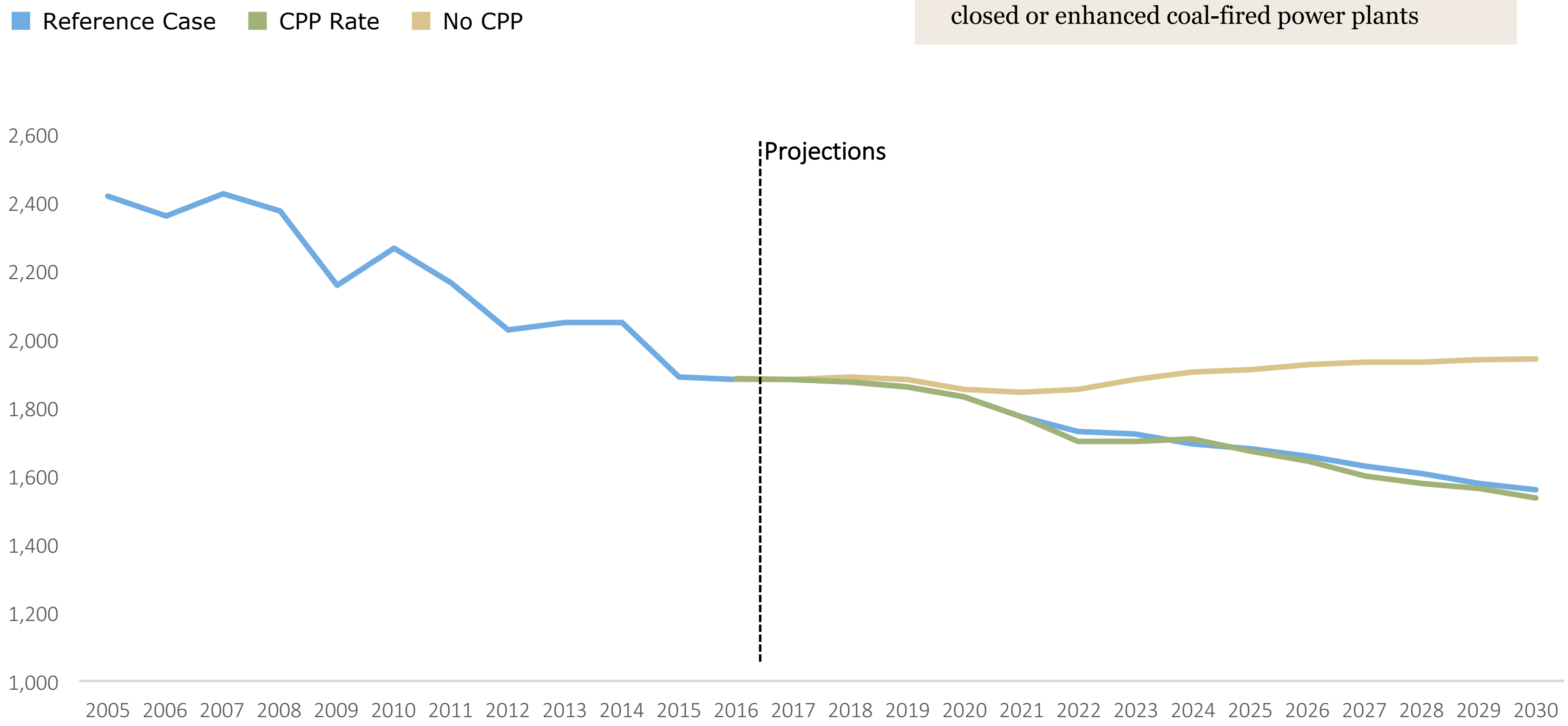
- Piloted a system that coats plastics and ceramics with amine, a chemical that can absorb CO_2
- Trying to bring the cost down to $50 per metric ton
- Received $50 million in private investment
- Launched a pilot plant at the Stanford Research Institute in Palo Alto, but the plant currently stands idle

Sources Akshat Rathi, "The world's first 'negative emissions' plant has begun operation – turning carbon dioxide into stone," Quartz, October 12, 2017.

Under the Clean Power Plan, the U.S. would reduce emissions at a greater rate than without the plan

Expected change in total U.S. emissions

In million metric tons



Estimates for greenhouse-gas emissions reductions under the Clean Power Plan were 32%, with most of the reductions coming from closed or enhanced coal-fired power plants

Sources: Energy Information Agency, 2017

Stanford researchers are developing a salt battery

A comparison between sodium and lithium batteries

Stanford researchers are developing a sodium-based battery that can store the same amount of energy as a lithium ion battery, but at a lower cost

The transition to renewable energy means there will be a higher demand for battery farms to store power and provide electricity at peak demand, low supply times

"Nothing may ever surpass lithium in performance, but lithium is so rare and costly that we need to develop high-performance but low-cost batteries based on abundant elements like sodium."

**Chemical engineer Zhenan Bao,
one of the engineers on the Stanford project**

The sodium-based battery would cost 20% less than a lithium ion battery with the same storage capacity. Lithium costs about $15,000 a ton to mine and refine, where as a sodium-based electrode material costs just $150 a ton

The project increased the energy efficiency of sodium-ion batteries by 87%, while still costing 20% less than lithium-ion batteries with the equivalent storage capacities

Stanford's salt is a positively charged ion (sodium) attached to a negatively charged ion (myo-inositol)

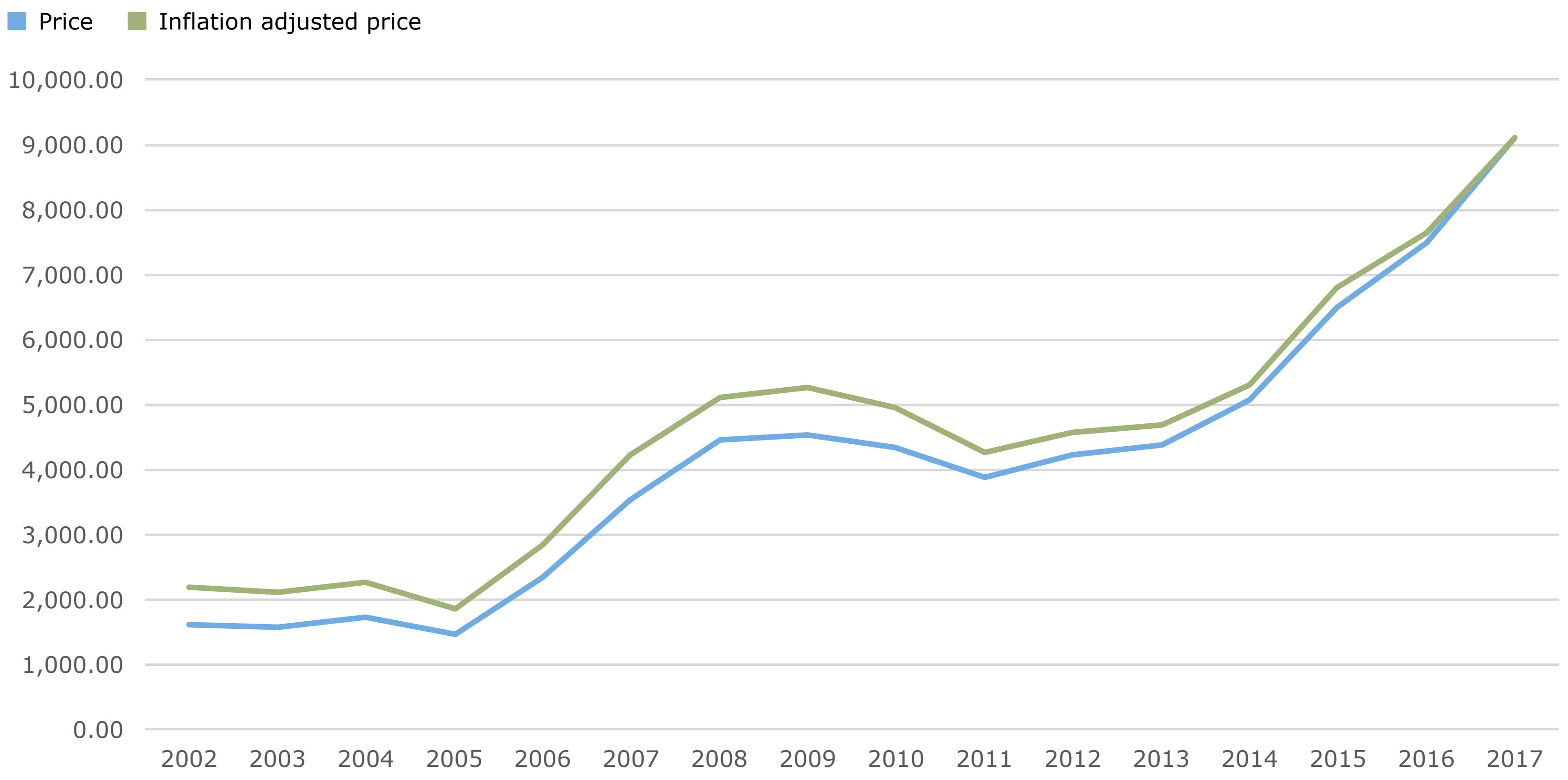
In theory, sodium should be able to hold more power than lithium, but it is less capable of maintaining a continual charge and discharge cycle so it has been less applicable in grid-scale applications

Sources: Tom Abate, "A Stanford battery based on sodium may offer more cost-effective storage than lithium," Stanford News, October 9, 2017; Cole Latimer, "Salt could supercharge storage batteries," The Sydney Morning Herald, October 16, 2017.

Cost of lithium has risen significantly since 2011

Average annual lithium prices, 2002-2017

In dollars per metric ton



Sources: "Lithium," Metalary.com, 2017.

What's old is new again as scientists look to ancient technology for energy storage

MIT researchers have been studying how firebricks can be used to support carbon-free energy. The theoretical system called Firebrick Resistance-heated Energy Storage (FIRES) uses bricks to store excess energy from wind farms as heat, and then the heat would be used directly or turned back into electricity

Firebricks are clay bricks first used by the Hittites 2,000 years ago. It is a brick made of refractory ceramic material that, if insulated properly, can retain heat for long periods of time. Firebricks are extremely resilient and can withstand temperatures up to 3,000 degrees Fahrenheit

Researchers say the energy storage system almost was created in 1917, but there wasn't as much demand for energy storage as today. The project is still in its theoretical stage, and the team is looking at possible solutions such as making the firebricks themselves electrically conductive and methods for turning the heat absorbed by the firebricks back into electricity

"At times, it is more efficient for energy producers to give energy away for free or even pay consumers to take their power plants' generation than to curtail production because the shutdown and startup of the plant may cost them more."

— Jeff Bladen, market services executive director for the Midcontinent Independent System Operator, on why storage is necessary for generation firms' bottom line

A ceramic pump could also be used for storage

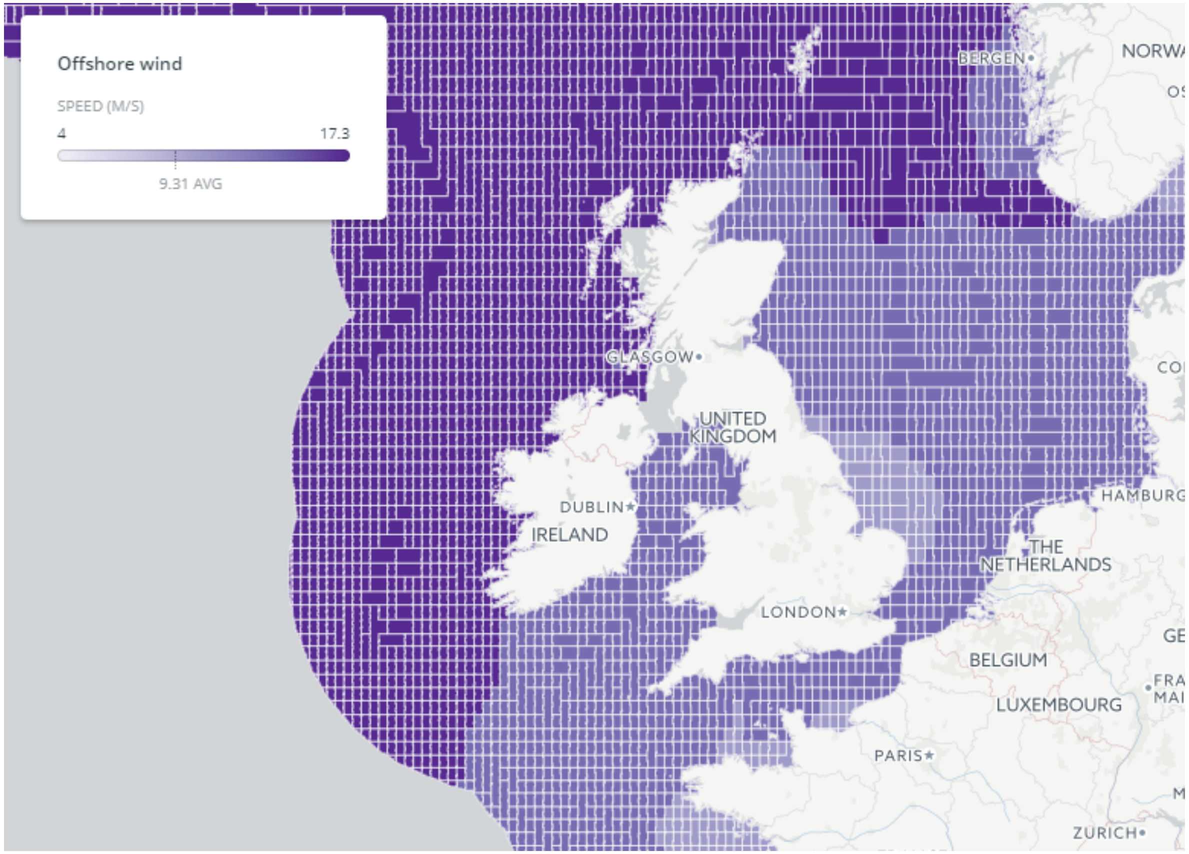
- A research collaboration between Georgia Tech, Stanford and Perdue universities used new composite materials, diamond tooling, precision machining and seals made from graphite to strengthen ceramic
- This strengthened ceramic was used to create a pump that can withstand heat of up to 1,400 degrees Celsius and be used in a heat transfer system
- The thermal storage system would use liquid metals like molten silicon to store and transfer heat energy that would later be converted into mechanical or electrical energy
- A prototype operated successfully for 72 hours using molten tin at an average temperature of 1,200 degrees Celsius
- Research for the thermal energy grid storage system received $3.6 million in funding from ARPA-E

Sources: James Temple, "Ceramic pump that takes the heat promises cheap, efficient grid storage," Technology Review, October 11, 2017; Allee Manning, "MIT researchers propose and ancient technology to store clean energy," Inverse, September 6, 2017.

Floating offshore wind farms allow access to stronger wind further from the coast

*Note: 9.31 m/s is the worldwide average

Offshore wind speeds around Scotland



Source: "NREL Global Offshore Wind GIS Data," National Renewable Energy Laboratory of the Department of Energy, February 23, 2015.

Floating wind farm off of Scotland begins delivering electricity

Key elements of the offshore wind project

In October, the world's first floating wind farm, located off the coast of Scotland, began delivering electricity to the grid

The Hywind project was built by Norwegian Statoil ASA and Masdar Abu Dhabi Future Energy Co.

"Knowing that up to 80% of the offshore wind resources are in deep waters where traditional bottom fixed installations are not suitable, floating offshore wind is expected to play a significant role in the growth of offshore wind going forward."

Irene Rummelhoff, executive vice president, New Energy Solutions Business, Statoil

The farm includes five turbines floating 25 km off the coast of Peterhead near Aberdeen and has the capacity to generate 30 MW of power

The project cost about $263 million to construct, and was supported by 2.5 renewable obligation certificates (ROCs) from the British government that pay about £140 per MWh

Offshore wind has increased wind speed and reduced complaints from neighbors, but until now it has been limited to areas with relatively shallow seas. Floating farms open up markets in Japan, the west coast of the U.S. and the Mediterranean

The Hywind project uses Statoil's Batwind lithium devices that hold 1 MWh of power to store electricity generated by the project

Source: Anna Hirtenstein, "World's first floating wind farm begins operating in Scotland," Bloomberg, October 18, 2017.