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Project Title	Calf-20 Metal-Organic Framework for Carbon Capture & Removal
Industry Partner	Svante Technologies Inc. & George Shimizu, University of Calgary
Industry Sector	Other Energy Intensive & Hard to Abate
Technology Pathway (Primary)	Carbon Capture & Storage / Utilisation
NIM Pillar	Technology Demonstration
Source	NIM Awards 2023
Description	Existing carbon capture technologies rely on chemical capture of CO2 by reactive liquids, an approach that has challenges of high energies to recycle and decay of the reactive liquid. A porous solid can separate gases by having one gas selectively condense inside. A challenge with post-combustion capture is that water from combustion will naturally condense before CO2. This nomination concerns a one-of-a-kind solid known as Calgary Framework(CALF)-20 made and patented by the Shimizu Group, that not only sorbs significant CO2, but remarkably, suppresses water uptake. The solid, also has exceptional stability to water, acid gases, and even steam. A powdered solid is, in itself, not a carbon capture system. The powder must be: 1. made into a stable form that allows for huge volumes of gas to permeate and then 2. placed in the engineered capture/regeneration rig that interfaces with the CO2 emitter. Svante Inc. are experts in these latter two domains. A unique aspect of their process is that the CO2 is removed from the solid directly with steam. This requires steam stability but also easy drying. The hallmark properties of CALF-20, excellent CO2 capture, steam stability, and water rejection, dovetail perfectly with the Svante process. The Shimizu group also found a way to make CALF-20 at ambient conditions leading to a second patent. Critical as deployment would need megatonnes of solid. Svante tapped the world's largest chemical manufacturer, BASF, to scale the solid and they have achieved 2.5 tonne batches. The synergy between material chemistry (UCalgary), process engineering (Svante) has enabled the first demonstrations of industrial carbon capture by the class of solids known as metal-organic frameworks. First from a Lafarge cement plant in BC. at a 1 tpd CO2 capture scale and then a natural gas steam generator in California at 25 tpd scale. Part of our story was published in the journal, Science, in 2021, downloaded over 27K times and cited over 180 times.
Innovations Employed	Prior to CALF-20, common perceptions were that a metal-organic framework would be either too unstable, too costly, unscalable, or all the above. CALF-20 was published in Science in December 2021 with academic and industry co-PIs. CALF-20 is the subject of two patents (composition and ambient synthesis) and was licensed to Svante for PCC. Demonstration at 25 tpd scale has been achieved. It is not overstatement to say

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	this has altered the landscape for research in solid CO2 capture but also for the academic and industrial perception of the class of compounds. It is the benchmark for the Metal Organic Framework (MOF) field and used to train AI methods as it excels in key metrics that were undervalued by earlier studies. Innovative breakthroughs are: 1. ability to physisorb CO2 in wet gas with suppression of water 2. benchmark stability to steam, acids; 3) scalability using green methods to 2.5 tonne scale; 4) two field demonstrations, now at 1 tpd and 25 tpd.
Dimension of Novelty	**Company & Country** It was new to Company, Country and International. Svante's structured adsorbent beds known as "filters" coated in CALF-20 MOF will be manufactured at Svante's new Centre of Excellence for Carbon Capture and Removal in Burnaby BC, where it will be able to supply 10 commercial sized carbon capture plants with enough filters to capture 1 million tonnes of CO2 per plant, per year, compounding annually
Innovation Collaboration	**In-house** **Cooperation with scientific institutions** Lower TRL at UCalgary, higher TRL at Svante Inc. **External Partners**
Intellectual Properties	"Calgary Framework-20 (CALF-20) - A Solid Sorbent for CO2 Capture", as designated by Licensor. Licensed to Svante Inc for CO2 capture. **Patent(s) and/or Patent Application(s) for Invention 1:** 1. US Provisional Application No. 61/776,223, "Metal Organic Framework, Production and Use Thereof" Filing Date: March 11, 2013 2. PCT Application No. PCT/CA2014/000204, "Metal Organic Framework, Production and Use Thereof", Filing Date: March 11, 2014 3. Australian Patent No. 2014231699 entitled, "Metal Organic Framework, Production and Use Thereof", Filing Date: Mar. 11, 2014, Issue Date: Apr. 19, 2018 4. Brazilian Patent No. 1120150218750, "Metal Organic Framework, Production and Use Thereof", Filing Date: March 11, 2014 5. Canadian Patent Application No. 2,904,546, "Metal Organic Framework, Production and Use Thereof", Filing Date: Mar. 11, 2014 6. Chinese Patent No. 201480014455., "Metal Organic Framework, Production and Use Thereof" Filing Date: Mar. 11, 2014, Issue Date: Mar. 19, 2019 7. French Patent No. 2971277 entitled, "Metal Organic Framework, Production and Use Thereof" Filing Date: Mar. 11, 2014, Issue Date: January 27, 2021 8. German Patent No. 602014074569.5 entitled, "Metal Organic Framework, Production and Use Thereof", Filing Date: Mar. 11, 2014, Issue Date: January 27, 2021 9. Indian Patent No. 319339 entitled, "Metal Organic Framework, Production and Use Thereof" Filing Date: Sept. 11, 2015, Issue Date: August 29, 2019

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	10. Italian Patent No. 50201000016970, "Metal Organic Framework, Production and Use Thereof" Filing Date: Mar. 11, 2014, Issue Date: January 27, 2021 11. Japanese Patent No. 6586366 entitled, "Metal Organic Framework, Production and Use Thereof" Filing Date: March 11, 2014, Issue Date: September 13, 2019 12. Korean Patent No. 10-2057165 entitled, "Metal Organic Framework, Production and Use Thereof" Filing Date: October 8, 2015, Issue Date: December 12, 2019 13. Spanish Patent No. 2971277 entitled, "Metal Organic Framework, Production and Use Thereof" Filing Date: Mar. 11, 2014, Issue Date: January 27, 2021 14. Swiss Patent No. 2971277 entitled, "Metal Organic Framework, Production and Use Thereof" Filing Date: Mar. 11, 2014, Issue Date: January 27, 2021 15. United Kingdom Patent No. 2971277 entitled, "Metal Organic Framework, Production and Use Thereof", Filing Date: Mar. 11, 2014, Issue Date: January 27, 2021 16. United States Patent No. 9,782,745, "Metal Organic Framework, Production and Use Thereof" Filing Date: Sept. 11, 2015, Issue Date: Oct. 10, 2017 *****Svante exclusively licensed and owned patents and applications for CALF-20
IP Links	**"Metal Organic Framework, Production and Use Thereof"** Australian Patent AU2014231699 Canadian Patent CA2904546 US Patent US20160016148
Timetable & Progress	System proven in operational environment. Technology available for consumers (TRL 9) Svante launched Project CO2Ment, a 1 tonne per day pilot capture plant at Lafarge Holcim's Richmond Cement Plant in Richmond, BC, Canada in 2019 as a first of a kind approach to carbon capture from a cement kiln using Svante's filters. In the spring of 2023, Chevron and the DOE launched a second of a kind capture plant at their Kern River oil field in Southern California featuring Svante's CALF-20 MOF filters. Both projects are continuing to test and operate today. Research began on this specific MOF in 2012. Svante development of their rotary adsorption machine began in 2016. The implementation of CALF-20 in the Svante system began in 2018. The Shimizu group works exclusively on MOF development. Svante works on the process engineering side. CALF-20 was studied in Calgary and a compositional patent filed in 2014, followed by a second patent in 2018 on a better synthesis. Svante, beginning with their previous incarnation, Inventys, had developed their rapid temperature swing process. Svante worked with CALF-20 since 2014 and took a license in 2018.
Financing (Public/ Private)	Funding Public • Alberta Innovates Strategic Research Project • Natural Science and Engineering Research Council of Canada CREATE Training Program

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	• US Department of Energy GRANT NAME
Finance Links	Alberta Innovates Strategic Research funding Natural Science and Engineering Research Council of Canada CREATE Training Program
Project Phase TRL	TRL 9
Problems to be Solved and Risks to be Managed	Prior to CALF-20 no MOF had been employed for a large-scale application and certainly not one with a harsh environment and scale requirements like flue gas capture. MOFs were regarded as academic curiosities stemming from lower stability, low scalability and cost of the family. End testing by UCalgary/Svante showed benchmark stability (500K steam cycles, weeks in flue gas) and an ambient condition synthesis that has now been scaled to 2.5 tonnes. From the molecular level, a remarkable aspect of CALF-20 is the ability physisorb CO2 with high capacity and selectivity over even water up to 40% humidity. With 178 degrees difference in boiling point, one would not expect CO2 to condense before water but sorption of water is actually even suppressed. This is a unique feature of this compound and countered existing thinking in CO2 sorbent design. Svante exploited the molecular features to synergize with their rapid cycling, temperature/steam regeneration process. This included making laminate forms that had the same exceptional properties as the powders and optimizing the process cycles leading to progressive 0.1 tpd, 1 tpd and 25tpd demos.
Preliminary or Final Results Achieved	Svante has been testing and optimizing this MOF in the lab and in the field at Chevron and Lafarge and has shown extremely positive results. The technology has proven to have fast kinets, high capacity for CO2 and resistance to SOx, Nox and other impurities in industrial flue gas. Additionally, the company's structured adsorbent beds coated in CALF-20 have a high selectivity for CO2 over water -an important component in the technology's competitive advantage over other traditional capture technologies. Further, because the technology has not shown to emit fugitive toxic chemicals and doesn't require chemical plants added onto a capture plant, Svante's use of CALF-20 is more environmentally responsible by design, as compared to traditional, state-of-the-art approaches.
CO2 Emissions Reduction Potential - Implementation and Future Market	Once Svante's manufacturing facility in Burnaby is complete, it will be able to provide enough filters to capture 10 million tonnes of CO2 at commercial carbon capture plants each year - compounding annually. This manufacturing capability, coupled with Svante's world-leading partnerships built across the CCUS value chain will enable emitters worldwide to capture and remove CO2 emissions in an environmentally responsible way, and potentially significantly reduce the cost of capture per tonne. This technology can make a drastic impact on the world's efforts to reach net-zero, as it can be applied across industries, including but not limited to cement, steel, oil & gas, pulp & paper, fertilizer, lime, petrochemicals, aluminium, ethanol, and more.

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Market Positioning	Svante can address 90% of the carbon capture and removal market, with applications for various concentrations of CO2 found at industrial sites, including lime, steel, fertilizer, cement, ethanol, oil & gas, pulp & paper, and more. The company is also working with GE Gas Power to develop a solid sorbent that can capture CO2 in an economically sustainable way from natural gas combined cycles (gas turbines).
Project Location	Canada
Project & Technology Links	Article in Science journal 374 - pages 1464 -1469 (2021) 17th December 2021 Third Party Testimonials
Technology Links	Svante - CALF-20: A carbon capture success story Science Article