MELIUS RESEARCH

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HELIOGEN INC.

ATHN | $10.00

Buy | Target Price: $26

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What are the Biggest Ideas in Clean Tech?

Initiating Coverage of Heliogen with a Buy Rating

Heliogen's take on concentrated solar power aims to fix some very large, and previously unsolvable, problems in clean energy. The company targets decarbonization of industrial processes such as steel and cement making, which account for ~20% of global carbon emissions. The need is high: companies from miners to automakers have committed to lower carbon futures and cannot achieve them with intermittent electric supply from solar or wind. Nor can they do it efficiently with expensive industrial process heat converted from electricity. With its ability to provide green heat and 24-hour electric power, Heliogen has enough interest from its first customers to far surpass its five-year model. Unlike in other renewables, there aren't many others doing what Heliogen does. Once proven out at industrial scale and durability, growth potential is immense.

Taking on 15-20% of global carbon emissions is a large enough market for anyone, but the reason for our aggressive title is a little bit bigger still. Heliogen's technology is designed and suited to scale at both micro and macro levels. Software driven precision, assembly line production and standard process improvement applied to relatively simple products (mirrors and mounts) should drive the cost down continuously. Looking at the very big picture, some renewables have trouble scaling large enough to replace global fossil fuels. Hydropower is the obvious example: it is ~25% of global renewable energy, but can't really grow (most good rivers are already dammed). Photovoltaic (PV) solar is very cheap, and can scale well, but has intermittency/baseload issues, uses silicon from complex factories, and uses 10% of global silver to provide ~1% of global energy. Heliogen's inputs are software, steel, sunlight, glass, and gravel. None are in short supply.

Heliogen designs and manufactures a breakthrough, software-enabled, high precision concentrated solar power system. Though potentially transformational, the technology is easy enough to understand. Concentrated sunlight from mirrors heats up rocks, which retain heat well. Newly available code and computing power focuses thousands of cheap, factory-produced mirrors (heliostats) with much higher precision than in prior iterations of concentrated solar, achieving temperatures above 1,000°C, ~double prior designs. Higher temperatures in turn unlock transferable heat for industrial processes, a cheap form of storage, 85% capacity factor for electric power, and higher efficiency for hydrogen making or electricity.

The ideas that make it plausible are also simple. Mirrors can reflect up to 94% of sunlight, which can be converted to electrical energy at 37-50% efficiency, yielding more electrical energy than PV solar at 20-25%. High temps enable thermal storage (hot rocks) at ~$6/kWh vs. $200+ for electrical storage in batteries. Insulated rock tanks lose only 2% of the energy a day, solving intermittency. (Continued…)

New Solutions for Major Problems

Environmental and financial potential has attracted a high caliber team to this early stage (~pre-revenue) company. CEO Bill Gross has a strong track record as a successful entrepreneur, founding multiple companies directly. Through his creation and stewardship of Idealab he has been a part of over 150 new companies, with more than 40 acquired or IPO'd into public markets. Heliogen's head of manufacturing Andy Lambert comes over from SpaceX and BMW, its CFO Christie Obiaya from Bechtel, and its CTO Steve Schell comes with significant solar experience.

An open field. Heliogen is addressing one of the most fundamental problems in the world's decarbonization and energy mix, and there aren't many other solutions yet. There are dozens of companies pursuing new powertrains, electric vehicles, vehicle autonomy, ride sharing and so on. Many more work on various aspects of photovoltaic (PV) solar: utility scale, on rooftops of commercial buildings, home energy production and storage. Some large companies like Siemens are working on energy storage, including thermal storage, but without an efficient pathway from electricity yet. Chemical storage from batteries is a continual work in process, and thus far very expensive, though startups may come up with new pathways, such as the iron/rust battery recently previewed by Form Energy. However:

- Thus far there are no real solutions for making the intermittent solar and wind electricity generation into high capacity-factor electric power
- There are no real solutions for storage, which is a related problem, and
- There are few efficient solutions for delivering renewable heat to industrial customers. Making green hydrogen from electricity and then burning it is one currently available solution, but the end-to-end efficiency is inherently low, as it is with producing and then burning biofuel for heat.

If Heliogen's process works reliably at full industrial scale, demand won't be the problem. Mining probably uses 100 GW of installed capacity for processing of minerals and running mines, and just as much in mobile equipment, which could be an additional end market for green hydrogen in a decade or two. Many of those mines can't use solar thermal due to geography or space constraints, but even 25% would be 5,000 Heliogen modules. The company's five-year outlook has just under 200 modules in total installed. The goal is to build out slowly to prove out the design at scale, and then to accelerate towards the middle of the decade. The 2026 plan includes 120 modules and around $2.4bn in revenue; that won't even scratch the surface on demand.

Industrial processes are 15-20% of global carbon emissions, and mining is far from the largest emitter in that pool. Steel and cement making together account for close to 15% of global emissions. Both require heat as a significant input, and other renewable technologies don't supply direct heat, they make electricity; green electricity will already be in short supply for the grid.

Today, Heliogen is essentially pre-revenue. With first delivery in 2023, the business model will evolve from turnkey, project-based revenues, to selling equipment and technology to EPC contractors, to eventual licensing arrangements, with no clear limit on upside. The company's five-year financial outlook doesn't incorporate the eventual shift to licensing. The current focus is on translating the technology from testing to operations and beginning to build scale in the core components. That needs high involvement and control from Heliogen directly; the potential is very large, but will not materialize unless the first installations operate successfully.

Based on our assessment of Heliogen's projections, a 5MW module from Heliogen should cost customers on the order of $50mm today (though that's just a zero-scale

Key Numbers and Targets:

Mirrors reflect 94% *of sunlight onto target (PV solar captures ~20%)*

100 acre footprint*/5MW enabled by modular design, allowing for higher value "behind-the-meter" sites*

85% capacity factor *vs. 20-50% for PV and wind*

2% daily loss *in thermal storage*

Storage cost of $6 per *kWh-th a fraction of battery cost of $200 per kWh-e*

5 cents per kWh *electricity by 2026*

$2/kg green hydrogen *by 2026*

$120bn+ *annual TAM in industrial markets*

$1.8tn *annual TAM in clean energy* number not very indicative of the ultimate cost) and fall to closer to $30mm by the middle of the decade as early scale starts to build. That capital cost per peak watt is an order of magnitude higher than utility scale PV solar, but the more relevant comparison is on a cost per kilowatt-hour basis, since Heliogen includes overnight storage; through this lens, the cost is closer to parity, and the fact that Heliogen's solution will be able to produce power on demand makes those kWh more valuable. PV solar doesn't provide day and night power and cannot address the use cases Heliogen is attacking in industry.

By 2026, Heliogen's plan includes completing 120 towers in a year

By 2026, Heliogen's plan includes installing 120 towers in a year, or almost 600 MW, bringing in revenue around $2-2.5bn. That's still a tiny number relative to almost any energy market, including power needed to decarbonize mines, steel, cement, chemicals, or other industrial markets.

Inbound inquiries include need for power equivalent to more than 1,000 towers

Our estimates imply a need for as many as 80,000 towers, or 4,000 a year, in industrial markets. Energy markets are much larger

TAM estimates: industrial end markets we looked at need ~$2.5 trillion in investment, a $120bn annual opportunity for Heliogen. McKinsey, the IEA, and others have forecast global renewable markets need $8.5 trillion in investment by 2030, and $150bn for hydrogen. The starting point for Heliogen, though, is in markets where other technologies cannot reach. We took a slightly different approach, aiming to quantify the need in those higher value early industrial markets. Investment needed in mining, cement making, and steelmaking is on the order of $2.5 trillion. Green hydrogen for transport will take a decade+ to develop, while much of the end markets demand we lay out are needs that are present today.

We used detailed industry data to form that estimate, but it is a rough one. The number could be much larger than that, or it could be smaller, depending on things like land available at specific sites and suitability of Heliogen's heat. It doesn't really matter much; the numbers are plenty big no matter the detail. What *does* matter is that there are enough early customers to let Heliogen build real scale, into the billions or tens of billions. We think that there are, supported by both inbound inquiries to the company and by our estimate that just one or two mines could take all the modules Heliogen plans to build for the next five years. Once scale is achieved, the opportunity widens out into the whole energy market.

The goal is to beat fossil fuels in cost, first in high value, difficult applications, and eventually everywhere. The company's pricing model assumes customers will aim to get at least an 8-9% unlevered return on the investment. There's no real way to estimate this in general given customers' varying circumstances; some might be trucking diesel to remote areas at a high cost, others might have grids nearby with green power sources. The point, though, is that the company believes it can be cost competitive with fossil fuels. That is, in fact, a driving force for Bill Gross, who wants to see the technology spread wide and quickly. And without the need for subsidies.

As for the forecasts, Heliogen today is basically pre-revenue and is taking a steady, moderately paced approach to ramping up. It sees revenues in 2026 starting to gain scale, completing 120 towers and generating total revenue of $2.4bn, EBTIDA of $830mm at a 35% margin, and free cash flow of $433 million under the company's current estimates.

Valuation and Risks

In many ways the entire five-year forecast period is a proof of concept for a much larger opportunity

Trying to value Heliogen is a bit of a puzzle. If the technology works, the upside potential is extremely large. Growth for decades and few current competitors, in a high need application for companies and the world. The potential for shareholder value creation, in a multi-trillion-dollar market off a ~$2bn base valuation, is certainly into the tens of billions and possibly much more. However, the company hasn't yet built a full-scale installation. It has tested the components of one at its demonstration facility since November of 2019, but in the industrial world, and especially in the utility world, durability and uptime are critical, and some aspects of that are just hard to know until a product has spent years in the field. If the technology doesn't prove durable or reliable in its first few installations, the path to scale could be quite slow. Industrial customers tend to be slow adopters of technology anyway, often because durability needs time to prove out.

Heliogen's first material revenues won't come until 2023, and even by 2026 the company will still be in the early stages of building scale for a technology that we believe has trillions in addressable market. More and more companies are coming public before generating significant revenue, with hockey stick financials and no real costs to go on. In the case of Heliogen, the costs that the company incurs in the first five years' projects won't be all that similar to what the technology can do if thousands of units are cranked out in a year, and in many ways, the entire five-year forecast period is a proof of concept for a much larger opportunity, though one that should generate meaningful cash flow by year five.

The key milestones to de-risking will be putting up the first industrial installation and then seeing what problems crop up, and that won't happen for more than a year. Older versions of solar thermal encountered problems in keeping uptime high, and many underperformed promises meaningfully. Solving those problems, which often were related to molten salt or targeting, is something Heliogen has tried to address directly, but other problems could pop up with installations out in harsh climates for years.

So the end market potentials are large: TAM in the tens to hundreds of billions on industrial power, and trillions in clean energy. Customers want the product; there aren't other solutions in some cases. But the likelihood of success is hard to estimate. That doesn't stop some clean energy plays, like QuantumScape trading at a $11bn+ valuation ($20bn+ valuation a few months ago, or $9bn+ valuation a few weeks ago).

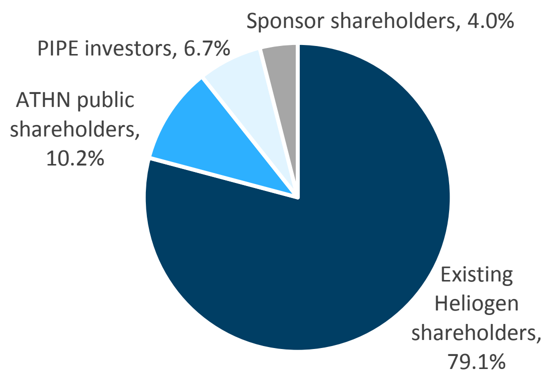
This initiation of coverage assumes the merger with ATHN, a SPAC, occurs, and takes no view on ATHN itself. We apply our price target to the ATHN ticker, which is the currently available way to invest in Heliogen (again, under the assumption that the merger is completed, which is not a certainty).

Athena Technology Acquisition Corp (NYSE: ATHN), a SPAC or special purpose acquisition company, entered into a business combination agreement with Heliogen in July of this year. Pro forma, post-merger share structure has the entity 79% owned by existing Heliogen shareholders (including 36mm in outstanding Heliogen stock options and unvested RSUs), 10% by ATHN public shareholders, 7% by PIPE investors, and 4% by ATHN founder shareholders, assuming no SPAC share redemptions. The post-merger ticker is expected to be HLGN, with shares trading on the NYSE.

Assuming the $10 share price, ATHN would merge with Heliogen at a pro forma EV of ~$2.1bn, adding up to $385mm cash to the combined company's balance sheet for a market cap of ~$2.5bn. Pro forma diluted shares outstanding would be ~246mm, including 36mm in outstanding Heliogen stock options and unvested RSUs but excluding ~8.6mm in public and private warrants (exercisable at $11.50/share on the later of 1) 30 days after completion of the business combination or 2) 12 months from the closing of the ATHN IPO, i.e. March 16th, 2022), again assuming no redemptions by the SPAC's public shareholders.

Our Price Target: If we apply a 6.5 multiple to Heliogen's 2026E revenue, and discount back three years at 15%, we would get an EV of ~$10bn and a target price of $40. All that really means is that if Heliogen can get to a profitable $2bn+ revenue stream, it will be worth a lot given the long growth runway. Probably more than 6-7x revenues, in fact. The trick is to estimate the odds of getting there. Our $26 target takes 6.5x 2026 revenues, discounts to 2023 at 15%, and applies an additional 40% discount.

Figure 1: Heliogen Pro Forma Ownership Structure



Source: Company data and Melius Research

Figure 2: Illustrative Pro Forma Valuation

Pro forma valuation ($mm, mm shares)	
Price per share	$10.00
Pro forma diluted shares outstanding	245.7
Pro forma equity value	*$2,457*
Pro forma net debt (cash)	($385)
Pro forma enterprise value	***$2,072***

Source: Company data and Melius Research

Risks

Concentrated solar doesn't have a successful history. Early projects had no storage, and thus were not competitive. Then, some concentrated solar systems used molten salt as a storage medium, which proved to be difficult to handle and prone to causing downtime. Most projects were massive in scale, and thus massively underperformed when single points of failure like molten salt containment arose. Molten salt is good for storing heat, but can freeze if temperature drops too low, or degrade if temperatures are too high. Bill Gross has decades of experience in solar (including successful exits of EI Solutions to Suntech and RayTracker to First Solar, and also an unsuccessful exit of concentrated solar company eSolar), and Heliogen's CTO/Chief Engineer does as well. They've spent much of the past 5+ years working to design Heliogen's offering to avoid some of the past issues: the invention of closed-loop tracking (patented) improves mirror accuracy, with the goal of improving performance and reducing cost, and the use of solid media (rocks, sand, or ceramic) to store the heat avoids the freezing problems of molten salt that have plagued concentrated solar in the past. That does not mean the solutions will be problem free, though.

There are many reasons energy transitions take so long to accomplish. Among them is durability, which can often only be proven out after years of testing. In the industrial world, it's common to see customers be incredibly conservative on equipment choices, and it's common to see new platforms even from huge companies with lots of experience fail or have hiccups in production or design that take several years to work out.

Heliogen's product is simpler than some of the examples we have in mind—new engine or gas turbine platforms, for example. And Heliogen's software-based approach perhaps allows for faster corrections and iterations of the technology. But the product will need to stand up to the weather (rain, high winds), corrosion, and other possible issues for many years.

If Heliogen's first towers run into issues, the ramp to 2026 could be pushed out, and investor patience for the idea could evaporate.

Though we think the upside potential is very large, the downside scenario is zero: if the technology fails to prove out reliability and durability, it won't be useful in either industrial or energy markets. We continue to advocate a portfolio approach when buying emerging clean tech companies; there will likely be big winners along with ideas that don't work at all, and visibility at early stages is low.

Tackling the Big and Unsolvable Issues

There are few bigger problems in the world than the ones Heliogen aims to address. Modern civilization is built on cheap and convenient fossil fuel energy—which is fundamentally concentrated and stored sunlight—that is easily transported and easily converted to heat or electricity. The carbon released from that conversion (the burning of fossil fuels) is dangerous to modern civilization, but a large and abrupt reduction in the use of fossil fuels, without another form of energy replacing it, would be as well.

Just as petroleum in particular is hard to replace due to its dual roles as a highly efficient energy carrier and as a highly concentrated energy source, coal has uses that are hard to replace with renewables. Coal provides energy dense heat to industrial processes. Today's renewable energy sources, photovoltaic solar and wind, produce electricity, not heat. That electric output can be converted to heat, through simple resistance as in an electric stove or by making hydrogen and then burning it, but both methods are inefficient in terms of end-to-end energy conversion.

The IEA's Net Zero by 2050 has a very material assumption buried inside, that the world can somehow double the historical trend in energy efficiency in the global economy, such that we can have a larger economy, with a larger and healthier population, while using 11% less energy in 2050 overall relative to today. That's not easy to envision; efficiency has not inflected upwards like that in the past, and historically, it has been very efficient to extract and burn fossil fuels. It is even harder to envision if renewables like photovoltaic solar and wind make electricity, which then needs to be converted to hydrogen at a loss, and then burned.

A large part of the 15-20% of global emissions that come from industry come from burning coal for heat, to melt iron, process limestone, crack hydrocarbon chains. Also challenging are electricity demands in remote areas. A mine needs to run 24 hours a day in order to leverage the huge capital installed, and it cannot use intermittent power from today's renewables. The same holds true for many other industrial processes. Decarbonizing industry is one of the largest challenges around, added to decarbonizing the rest of the world with cheap and clean energy.

Heliogen's method of concentrating and storing sunlight has benefits that touch on several of these unsolvable problems at once. Its efficient path to collecting that concentrated sunlight leads to other efficiencies in storage, use, and conversion. Near-24-hour renewable power with a target 85% capacity factor. Overnight, or multi-day, energy storage. Green industrial process heat for cement, steel, mining, and petrochemicals. Thermal storage at ~$6 per kWh-th instead of $200/kWh-e as with batteries. The outflows of these capabilities apply to utility scale energy generation and could mitigate some of the energy price spikes and crises that we are seeing with natural gas in Europe today. Green hydrogen at an affordable price, produced by a more energy efficient method, can power not just industrial processes, but freight transportation as well. And solving industrial heat addresses 7-10% of global emissions that have no other solution.

Technology is needed to solve these problems. Decarbonizing industry, or solving intermittent power, seemed like an impossible problem based on tech from a decade or two or three ago. With Heliogen, and hopefully dozens of other companies in other spheres, technological advancements and political timing are combining in ways that were not possible in the past. Heliogen wants to compete favorably with fossil fuels, driving change through profitable investment more than mandates. The commitments by customers and companies will help kickstart that change, though.

If it works, Heliogen will be addressing a multi-trillion-dollar market that will grow for the next 50 years. There are few opportunities we know of that are larger or more important.

Management

The leadership team here has more than a decade of experience in solar, and in concentrated solar specifically. They've spent that decade, and more before it, thinking about how to make this technology scalable and repeatable, and about how to solve some of the hard technical challenges to make it possible.

Leadership also has significant experience in contracting large energy projects, both in sales and in financial oversight. Heliogen will start out as a technology company that needs to manage projects as well. Early success can unlock demand that has no near-term limits, but early failures could cause years of delays, a difficult concept in an early-stage company. Experience at the CFO and business development levels is key.

The cost curve on PV solar has fallen perhaps 30% for every doubling in scale, though that may be starting to hit limits as scale has been achieved and input costs can't be reduced to zero. Heliogen needs to see costs fall more like 15% for every doubling, and in many ways the task is easier. Heliostats are mirrors that can be repositioned, and they are basically glass, a reflective coating, and steel. The technology doesn't need factories for wafer production, nor complex interlay of copper, silicon, cadmium, and all the other things that go into PV solar panels. It's talent in this cone of development is just as important and impressive, nonetheless.

CEO Bill Gross has been an entrepreneur for four decades, starting as a teenager funding his undergrad at Caltech with a solar product. He founded Idealab, a pioneering incubator that has produced more than 150 start-ups with over 40 successful exits via IPO or acquisitions. Idealab has incubated solar projects in the past, including some that are precursors to Heliogen's technology. eSolar was a concentrated solar thermal project a decade ago, with Gross, CTO Steve Schell and others exploring different ways to make factory producible, cheaper solar thermal power, and working on targeting as well. The cameras and computing power didn't exist then to do what Heliogen aims to do now, but the ideas have been in development for years.

CFO Christie Obiaya was previously CFO and head of strategy at Bechtel Energy. Bechtel executes on billions of dollars in large projects ranging from nuclear to LNG to transmission to renewables. Though in a decade Heliogen may be a licensing company with some manufacturing of core components, all that matters over the next five years is making sure projects go smoothly, and for that it will need close coordination with the engineering and construction companies (like Bechtel) that perform the actual installations. Obiaya's background includes engineering and business degrees from MIT.

CTO & Chief Engineer Steve Schell has past experience at eSolar as well as in other tech startups, including in 3D printing and robotics. Concentrated solar has a bumpy history as an industry, with lots of potential but lots of engineering hiccups that kept it from coming to fruition. Heliogen's design and strategy aims to avoid some of the most obvious. Some examples: molten salt is a tricky medium, but higher temperatures were needed to use rocks for thermal storage. Heliogen can do that, eSolar could not. Targeting has been an issue for efficiency, and that has been a focus for Schell and Gross for a decade.

SVP Production & Supply Chain Andy Lambert comes over most recently from SpaceX, where he had led manufacturing of the rockets, and from BMW, where he'd led manufacturing for the Mini. Time will tell what the true cost potential is for Heliogen, but to get to 5 cents per kWh of electricity delivered, or $2/kg green hydrogen, the company needs to cut its current initial planned costs by more than half. Those initial costs aren't representative of much of anything…prototype scale, really. As the first projects are built, though, costs will need to come down. Lambert's manufacturing experience is extensive, both in the auto world, building on decades of learnings around Lean and continuous improvement, and in the start-up world, where SpaceX has performed engineering miracles that have transformed launch costs and the opportunities in space. In one illustration of the potential cost downs, he likened Heliogen's heliostats to a car door—steel and glass—rather than to the overall complexity of a car.

Tom Doyle, Chief Commercial Officer had previously been at BrightSource, a concentrated solar thermal company, and was CEO of Renew at NRG. NRG has 23,000 MW of capacity delivering energy to 6 million customers around the US. Tom oversaw the renewables portfolio and placed $7bn+ in renewable capital. He also oversaw the world's largest concentrated solar power project.

Other members of the team are equally impressive: Chief of Staff Thomas Patrick from Deutsche Bank was CEO of DB USA and Co-Head for Americas of the Corporate and Investment Bank; Head of Strategy Vikas Tuteja comes from McKinsey and Ford. Essentially, the collected expertise in technology, financial management, EPC, manufacturing, and solar sales as well as design is quite well suited to the needs Heliogen will have as a maturing company. The talent level is high, attracted perhaps by the scope of this opportunity to both improve the world and build a business with no clear limit on potential.

Heliogen has agreed to merge with Athena Technology Acquisition Corp, a SPAC. Athena is a female-led entity, with its leaders formerly entrepreneurs and senior executives across technology and finance. Our report assumes the merger goes through and expresses no opinion on the transaction itself.

Heliogen's Technology and Products

The ideas are simple enough, as we noted on the cover. Sunlight is concentrated with mirrors, which heats up gravel (or sand, or ceramics, but basically rocks). From there, the concentrated energy can be 1) converted to electricity, via a standard steam turbine process or a high-efficiency supercritical CO2 process, 2) converted to hydrogen, where there are advantages that we will cover later, or 3) be used as process heat for industry. Each of the three products—near-24-hour power, green hydrogen, and green heat—have advantages vs. other renewables, and in some cases unique capabilities. Power will probably be the major product for the first several years though; it is easy to drop in as a replacement for other electric generation. Replacing cement kiln heat from coal with Heliogen green heat might take more on-site engineering, and swapping out coal for green heat and hydrogen in steelmaking even more so.

Software-based targeting enables the entire set of opportunity, design choices, and cost reduction

The technology to get there is cutting edge, though. A Heliogen 5 MW module will use 40-60,000 mirrors, all consistently aimed at a small target up to 1,000 feet away. The company does it with cameras on the target tower that scan the field of mirrors continuously, measuring the brightness of each mirror simultaneously, and then adjusting the aim to maximize energy on the target. That trick of figuring out exactly where each mirror is aimed is not a simple one.

The processing power to perform the task wasn't available until around 2017, when GPUs (graphics processing units) came along…GPUs can be on the order of 100x faster than the older CPUs at certain tasks. That power, along with software controls and a decade of experience in testing and programming, is what enables the system to work. Heliogen's "closed loop" system means the mirrors are constantly adjusted to aim at the target, as opposed to older "open loop" tracking systems that used pre-programmed adjustments and knowledge of the sun's position and movement through the sky to move the mirrors.

Closed Loop Tracking and Why it is Needed

Accuracy to 1/30th of a degree brings efficiency and high temperatures…

That level of precision would be quickly lost without constant recalibration

The movement of the earth and the sun's position in the sky is easy enough to calculate with high precision, so one might think you could set up the mirrors to follow that path in the sky without needing all the computing power and software calibration. That's what **"open loop"** tracking is. A heliostat (concentrated solar power mirror) or PV solar panel can be programmed to follow the sun and collect maximum energy fairly easily in principle.

The reality, however, is different, since wind, weather, heat/cold, earthquakes, rain, soil moisture and expansion, and so on can all change the aim of a mirror, or the shape of the ground on which the heliostat (mirror) is mounted. Setting up the mirror to track the sun without recalibration will lead to losses, as various mirrors are thrown slightly out of alignment over days, weeks, or years.

"Closed loop" tracking puts a feedback loop between the target and the panel. In other words, it measures whether the sun is reflecting properly onto the target and sends adjustments to the heliostats if not, bringing them back on target. Heliogen's system aims with extreme precision: it can bring the target up to 1000°C, and then tilt a few mirrors away if the temperature gets to 1003°C, or bring more on focus if it drops to 996°C. Without these corrections, the panels would gradually fall further and further out of alignment with the target, and the power generated would also be less predictable or consistent.

The other benefit to closed loop tracking is less obvious: it allows for a cheaper design for the heliostat mounting. If the system is open loop, aiming to have the mirrors track the sun and reflect onto target over months and years, it needs to stay in exactly the same place, for months and years. That means the mirrors have to be mounted very securely, in a concrete base for example. The design choices around that need drive others, e.g. larger mirrors, larger mounts, and a system that requires a lot of effort around installations. Heliogen's design replaces complex, expensive mounting hardware with software.

One last benefit of the technology and the closed loop tracking is that it can be updated over time. A large installation of historical solar thermal is likely to get a little worse every year, even with some expensive manual recalibration. Heliogen can do the reverse: get a little better every year with software and over the air updates, enabling better efficiency, higher temperatures, or other improvements.

The competitive moat surrounding Heliogen's technology is a mixture of patents, trade secrets, and many years of work in the space to solve problems. The company has six patents granted, 13 pending, and perhaps two to four dozen more that may be filed. The patents cover various aspects of the imaging/vison and tracking systems, as well as aspects of the heliostat design. The patents aren't the only protection; the team has been working on aspects of concentrated solar for a long time and is keeping some of the IP as know-how and trade secrets. Years of labor and programming go into the system design as well, so replicating it would take significant time and effort. And if the moat comes from technology at the start, scale will begin to add to it if the modules prove out in full industrial scale usage.

Underlying the simple ideas, enabled by the technology, are also design choices that we think will prove to be powerful over time. Choosing a technology path that is centered around modular units, scale that allows behind-the-meter installations at industrial facilities, and factory production are all ideas that reach forward decades and enable large potential. Effectively, the technology and design are both factors, working in harmony based on the following principles:

- Software allows for the precise control of thousands of small mirrors, with the reflected energy hitting a very small target several feet across.
- Precise control allows for higher temperatures, above 1,000°C.
- Higher temperatures allow for steam to be generated for process heat in industries like steel and cement, or mining.
- Higher temperatures enable more efficient hydrogen production, with solid oxide electrolyzers and some of the input energy coming from heat rather than electricity.
- Higher temperatures allow for more efficient electricity generation from supercritical CO_2 turbines instead of conventional steam turbines.
- Higher temperatures make thermal energy storage possible; gravel at 1,000°C has well more than twice the useable energy stored as at 500°C, and it's the same rock. Molten salt historically topped out at 600°C or so.
- Small mirrors allow for factory production of components, with the potential to bring down the cost curve massively. The mirrors are just glass, steel, and a reflective coating.
- Smaller mirrors allow for easier installation, potentially automated in the future.
- Smaller mirrors and closed loop tracking allow for less expensive mounting. Concentrated solar in the past used large, heavy, durable installations in an attempt to reduce cost.
- The modular design, much smaller in area per module than most large solar installations, allows for "behind-the-meter" applications, so industrial customers can replace retail pricing on electricity with internal power generation.

Efficiency Advantage and How it Flows into Products

We've portrayed the scope of this potential as very large in industrial markets, and much larger still as it moves into utility power generation. Right now, we want to talk about why that massive scope is plausible. Potential efficiency is much higher than for solar PV, as much as triple if heat is the end product, but there are also advantages in electricity generation and hydrogen production.

The fact that concentrated solar power starts with collecting 94% of the solar energy as it hits the ground is the simplest way to think about why Heliogen might be able to deliver on some of these transformational potentials. The targeting technology and temperatures explain most of the rest.

- **Electric power generation:** high efficiency enabled by collecting more sunlight. Modest losses in conversion to electric due to high temperatures and low losses in thermal storage. Thermal storage with rocks is cheap as well, perhaps $6/kWh-th or so versus $200/kWh-e+ for batteries. 5 cent per kWh renewable power through day and night is the goal.
- **Industrial heat:** the advantages here are greater, for customers with the right sunlight and space. Concentrated solar builds heat effectively. Software targeting and closed loop tracking at Heliogen have achieved temperatures more than double that of molten salt systems, which makes heat transfer more efficient. The design, in small modular installations, can fit near many industrial footprints, unlike older concentrated solar that was utility scale.
- **Green hydrogen**: it takes about 50 kWh input to make green hydrogen, but not all of that input needs to be electricity. Heat can supply some of the energy, and Heliogen collects heat with high efficiency. Solid oxide electrolyzers, which can only operate at high temperatures, can output hydrogen more efficiently as well.

Concentrated solar captures more photons/ wavelengths of light

It starts out with 4-5x the energy collected versus PV: 94% of the inbound sunlight reflects off the mirror towards the target

For perspective, photovoltaic solar efficiencies range from the low teens to the mid-20 percent range, and higher for some low volume specialty designs. That is, of the solar energy striking the panel, something like 20% might be converted to electricity. There are fundamental limits to how high this can go, with the simplest being that the cell doesn't capture all wavelengths of light; some photons might be too energetic, some not enough.

Figure 3: Photovoltaic Solar Efficiencies

PV Technology		Cell Conversion Efficiency	Module Conversion Efficiency
Crystalline	Monocrystalline silicon (Si)	27.6%	24.4%
	Multicrystalline Si	23.3%	20.4%
	Multi-junction Gallium arsenide (GaAs)	47.1%	38.9%
Thin film	Cadmium telluride (CdTe)	22.1%	19.0%
	CIGS	23.4%	19.2%
Emerging	Perovskite	25.5%	17.9%
	Organic	18.2%	11.7%

Source: University of Michigan and DOE

Concentrated solar simply reflects the light rather than converting it to electricity. It reflects most wavelengths and so captures a greater portion of the sun's energy. For Heliogen, mirrors have around 94% efficiency in reflecting inbound solar energy. There are some minor losses in the design of the field of mirrors—at certain angles of the sun, some of the mirrors might shade out others—but almost all of that is successfully reflected towards the target.

That target is a collecting tower that absorbs the focused heat delivered by the thousands of heliostats. 80-90% of the energy reflected off the mirrors reaches the collection point as heat. From there, the insulated rock storage vessel can hold the heat with minimal losses.

Electric power with higher efficiency than PV solar? Steam turbines are perhaps 37% efficient, and the high temperatures achieved by Heliogen have the potential to make that higher; steam turbine efficiency is limited by issues as steam cools, but with higher temperatures, supercritical CO2 can be used as the fluid instead of steam. Therefore, the overall efficiency when converting to electricity probably comes out higher than with most PV solar, measuring from the potential energy coming to earth as sunlight that is transformed into electricity.

The costs when Heliogen gets to large scale may be low, but the bigger advantage is the elimination of intermittency. That's something PV solar will struggle to ever do. For example, even with PV panel capacity being extremely cheap, converting PV electric energy back to heat for thermal storage would produce huge losses, and it would not be capturing the full spectrum of light.

Figure 4: Starting With 94% of the Energy Allows for Higher Efficency

Mirror		Shade effect		Target heat loss		Heat storage		Turbine		Electric power
94%	x	90%	x	85%	x	95%	x	37%	=	25%

Source: Melius Research

Continuous electric power is a product that other renewables cannot deliver, and it will have large applications for many industrial markets. For some, such as remote mine sites, there are no other choices; some mines make electric power from fossil fuels today. For others, the modular design, with a relatively small footprint, means the other two products Heliogen can deliver, heat and hydrogen, have some unique advantages and higher efficiencies.

Unique, efficient solution for green process heat:

30-40% of cement CO2 emissions are from fossil fuels for heat…wind and PV don't provide heat

20%+ of emissions from steel making are from fossil fuels for heat

>10% of emissions from mining are for process heat

Green Heat: A Cheaper Path than Hydrogen Fuel for Industrial Process Heat

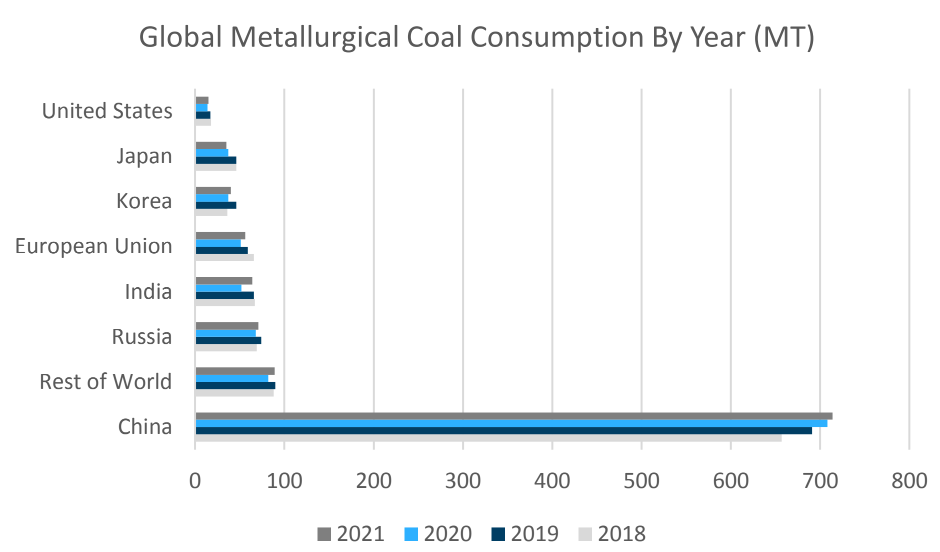
Industrial processes like steelmaking, cement making, mining, petrochemicals, and more use process heat as a part of production. Steel making is the obvious example: about 1.1 billion tons of metallurgical coal per year gets fired off in the production of steel. Cement is one of the biggest carbon emitters in the world; some of that is because cement starts with limestone (calcium carbonate) as an input, but around 30-40% of the emissions from cement are from fossil fuels to heat the process. Mining is another early target for Heliogen: environmental reports suggest process heat might be in the range of 10-20% of the energy used in mines.

There's no immediately obvious way to get process heat without burning fossil fuels, biomass, or Heliogen's modular concentrated solar product. Companies definitely need a solution. Auto and truck makers, from Volvo to Mercedes-Benz, have committed to using green steel in vehicles and have already started sourcing it. But the solution—using hydrogen instead of fossil fuel for heat to make steel—is expensive.

Green hydrogen is expensive not just in dollars per kilogram, but in energy, since it needs to be made with clean renewable energy to start with, and since it takes ~50 kWh of electricity input to make a kilogram of hydrogen. Using hydrogen for heat is even more expensive…there are efficiency losses to contend with. PV solar starts out at 20% efficiency, then losses from converting to hydrogen might be 30%+, losses for transport might be 10-20%, and so on. All that just to burn it is a lot of steps with losses.

ArcelorMittal, a Heliogen investor, has said that burning hydrogen for heat to make steel might raise the cost 60% in its German facility, and others have cited 20-30% cost increases from green steel. That's an expensive green premium that can be cut very sharply by using industrial process heat from Heliogen. Heliogen can simply concentrate sunlight to make heat, skipping the conversion to electric, the conversion to hydrogen, and then back to heat.

Figure 5: Met Coal for Steelmaking: ~8% of Global Carbon Emissions, Without Any Current Green Solutions



Source: IEA and Melius Research

Green Hydrogen: More Efficient Production, Cheaper Cost

Heliogen can deliver electricity, green heat, or hydrogen. Any source of electricity can make hydrogen: the process takes something like 50 kWh of electricity and an electrolyzer to split water into hydrogen and oxygen. Green hydrogen is currently quite expensive, though, even with clean energy sources like solar and wind beating out fossil fuels and nuclear on electricity cost. One reason is capacity factor: solar puts out extremely cheap electricity for a few hours a day, and nothing at all for 12 hours or more. That leaves an expensive electrolyzer sitting idle most of the time.

Green hydrogen cheaper than diesel?

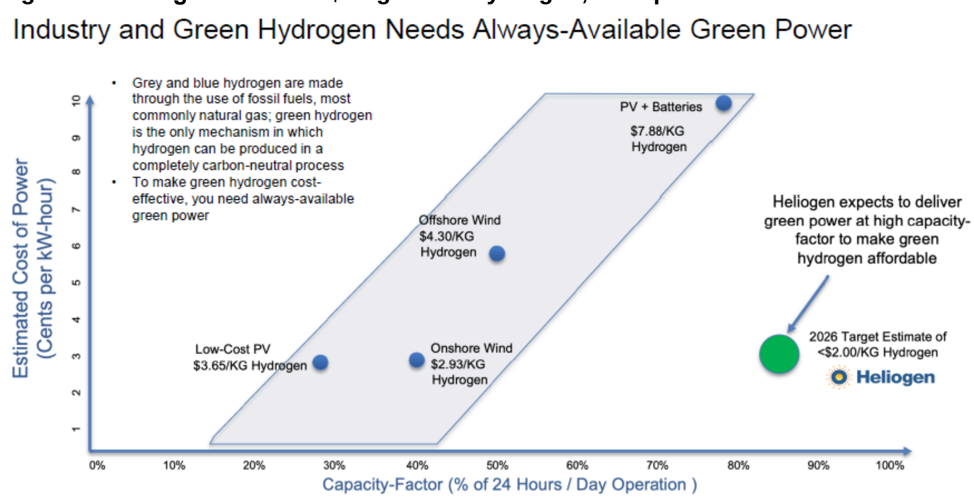
***24-hour power** levers the capital intensity of the electrolyzer*

***Efficiently made heat** can be used as an input, replacing ~30% of the electricity*

***Solid oxide electrolyzers** only work at high temperature, but are more efficient than other kinds*

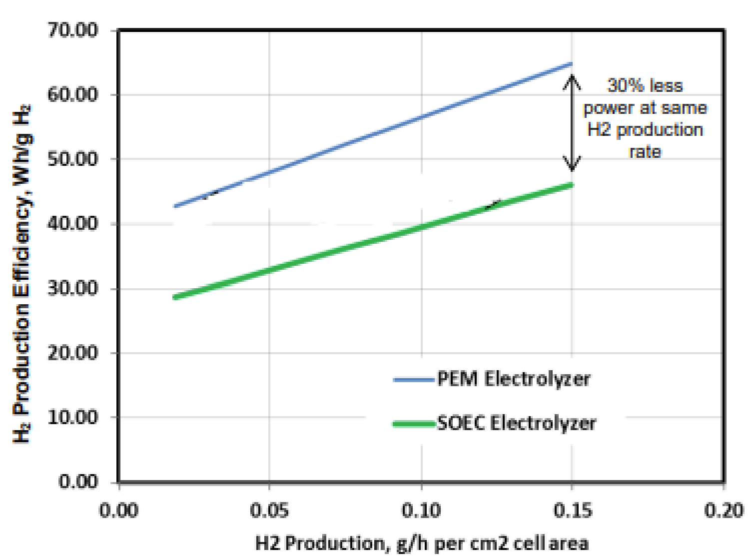
Heliogen has three advantages here that work in combination. Delivering power (from thermal storage and a turbine) consistently throughout the day and night leverages the capital cost of the electrolyzer. Using heat as an energy input instead of electricity leverages the efficiency of the mirrors and heat retention. And solid oxide electrolyzers, which work only at high temperatures, produce more hydrogen with less energy.

Figure 6: Heliogen's Goal is $2/kg Clean Hydrogen, Cheaper than Diesel



Source: Heliogen

Figure 7: Solid Oxide Electrolyzers Make More Hydrogen with Less Power



Source: DOE and FuelCell Energy

TAM: Reliable, Continuous Power for Industrial Markets

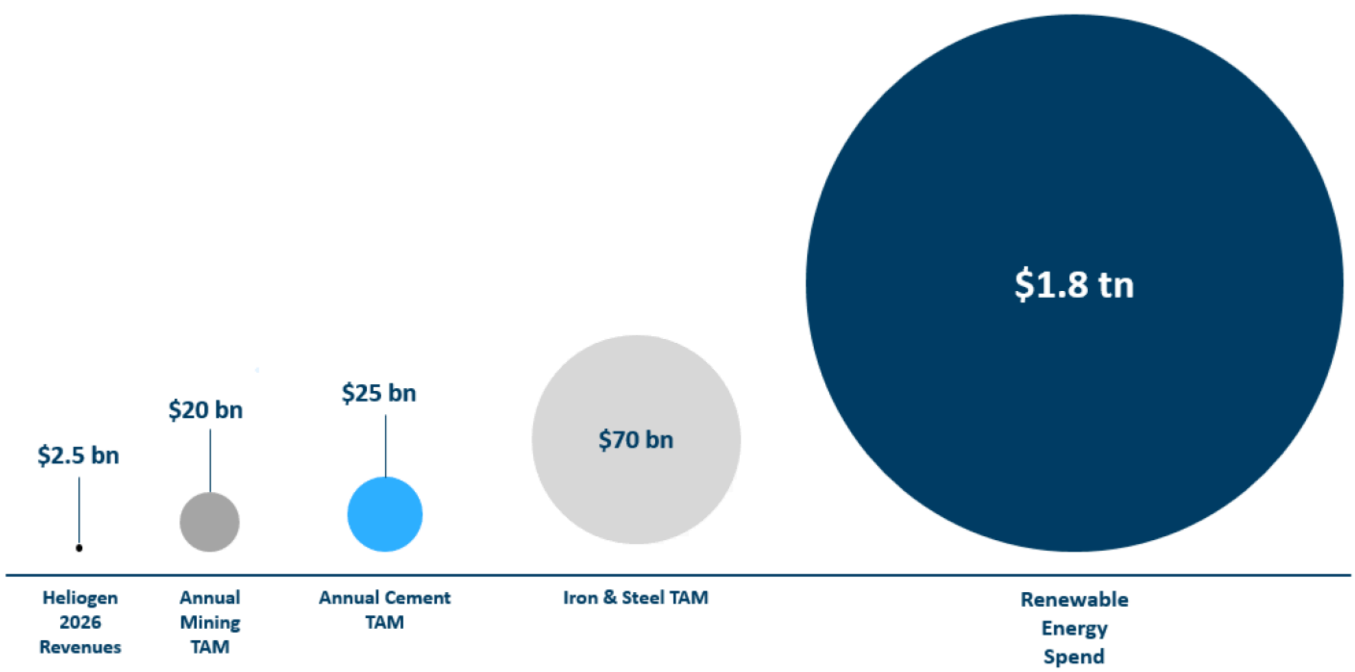
Replacing fossil fuels' roles in the world is, well, one of the biggest end markets in the world, with trillions in spending needed annually for a decade. The IEA's Net Zero by 2050 framework calls for annual clean energy spending to triple to ~$4 trillion by 2030 and be sustained from there. A lot of that spend is for batteries and clean transportation, but renewable energy spending needs to rise to $1.8 trillion annually by 2030 and $1.2 trillion in 2050.

Our look at end markets and TAM is not meant to be precise; the numbers are so large that the precision doesn't matter much. Our primary goal was simply to verify our intuition that the 15-20% of global carbon emissions from industry would mean the market is extremely large. That is well supported by a bottom-up look. We also looked at geography, reducing the available market to narrow in on sunny areas with adequate space to deploy Heliogen's solution. We have solid estimates in mining, but a little less so in cement, so we took a bigger haircut there.

The result? Industrial companies in the three markets we looked at—mining, steel, and cement—could spend north of $2.5 trillion on Heliogen modules, and profitably so if the power produced is as cheap as forecast. To oversimplify, that would translate to an annual TAM of ~$120bn assuming a 20-year life on Heliogen modules. Over time, Heliogen would have a profitable, rising annuity on maintenance/software updates and upgrades as well that we are not including. Again, that number may be materially understated if sunlight and space available are more widely available than we estimated, and it doesn't include chemicals, aluminum, or other large industrial use cases.

With the scale built from high value customers in industrial, Heliogen could also move into the still much larger energy market.

Figure 8: Heliogen Annual TAM Estimates



Source: Industry data and Melius Research

Mines: ~$400bn Need, Annual TAM of $20bn

$200 billion for mineral processing electricity and heat plus $200 billion for electric/hydrogen-powered mobile machines, or $20 billion annually assuming a 20-year life of a Heliogen module.

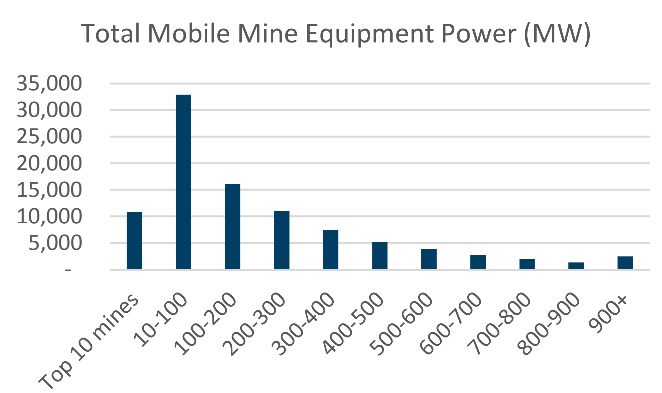
We'll start with mining, since that's an early source of demand for Heliogen, an area well suited for its solution, where the top miners have committed to net zero, and an area we know well. Mines are often in remote areas. They are capital intensive and need nearly 24-hour power to maximize throughput. And they have space for installations.

Global surface mines use on the order of 100 GW in power capacity to process ore. For context, that's something like 10 New York Cities' worth of power output. Our estimate doesn't capture underground mines, though there are a lot of underground coal mines, gold mines, and others. That power is used for mine operations and mineral processing, and the mines use a similar amount of power in the form of mobile equipment: tens of thousands of mining trucks, thousands of shovels, bulldozers and so on to dig and carry the ore.

We got to that estimate using mobile equipment power. There are more than 35,000 big mining trucks running globally, with power output ranging from half a megawatt per truck to over three megawatts. In total, the truck fleet power is ~57 GW, and trucks are around 60% of equipment in global surface mines. There are around 1,300 surface mining sites in the world, but as with most things, an 80/20 rule applies to size: the top ten mines have about 10% of the global installed power, and the top 100 have about 40%.

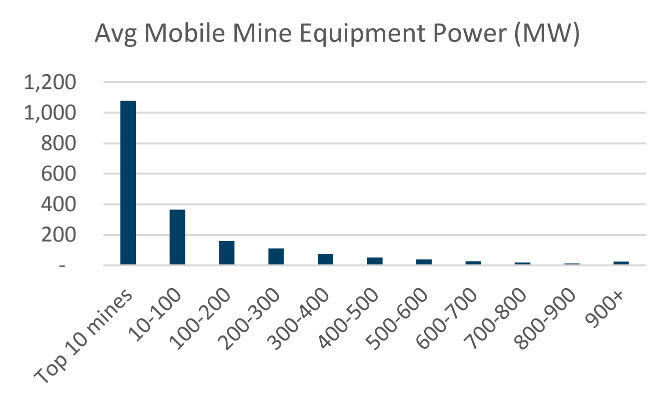
That means the top few dozen mining sites in the world could keep Heliogen busy for a long time. The average mobile equipment power at one of the top ten mines is a gigawatt, about what's needed to power a small city. The top 100 mines still average close to 400 megawatts. Heliogen's modular power comes in 5 MW increments, which implies that a single large mine could take all the power in Heliogen's 2026 plan. There are lots of mines, and lots of markets besides mining.

Figure 9: ~100 GW of Mobile Equipment Power in Mines



Source: Parker Bay and Melius Research

Figure 10: Big Mines Mean Big, Efficient Project Sites



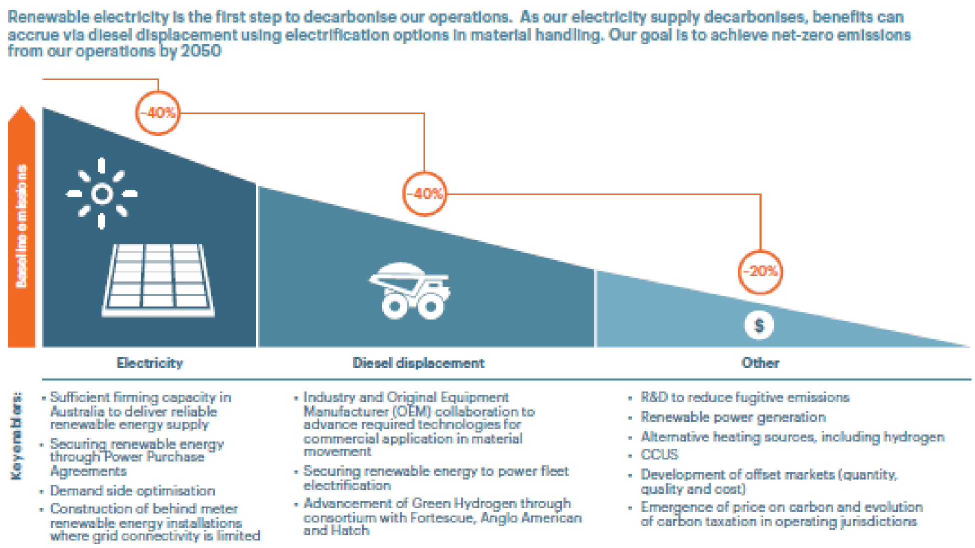
Source: Parker Bay and Melius Research

Why do we equate mobile equipment power, currently almost all diesel, to the power mines could get from Heliogen to use for mineral processing? One answer, for a decade in the future, is mining trucks will need to work on lower carbon alternatives to diesel. The industry has committed to switching away from diesel over time; it is a difficult task, since diesel is a beautiful energy carrier, but projects have started already. CAT and BHP announced an initiative to try electric mining trucks in mines, and since batteries obviously cannot run a 3 MW load for very long, those trucks will be charging on electricity supplied by the mine, running on a trolley system. Future trucks might use hydrogen or ammonia as well.

The other reason is that mine power is split 50/50 between mobile equipment and power for mineral processing and other operations, according to the International Council on Mining and Metals, a leading industry organization, and supported by environmental reports from large miners. That 50/50 split covers "scope 1" emissions, or direct emissions from assets owned by the mine. Scope 2 would include purchased grid electricity, which could also be a market for Heliogen to address.

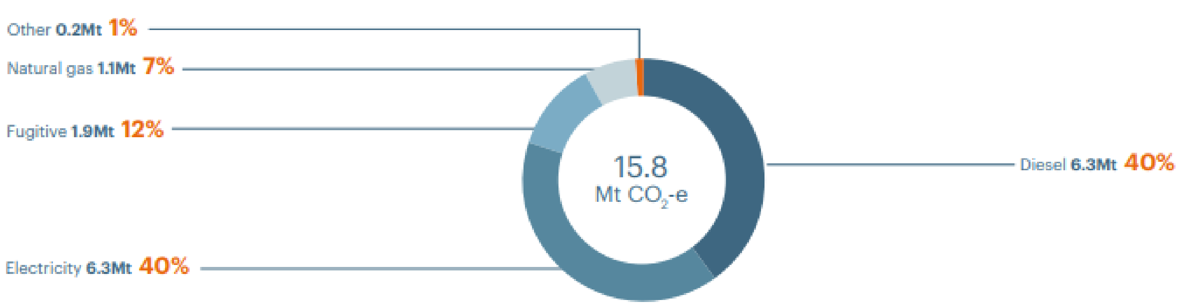
Process heat is a product Heliogen can deliver very efficiently if the local geography fits right. BHP says process heat is about 7% of its emissions, Rio Tinto says 14% of direct emissions and those from purchased energy come from process heat.

Figure 11: BHP: 40% of Emissions from Vehicles, 40% from Electricity



Source: BHP Climate Change Report 2020

Figure 12: BHP Carbon Emissions: Electricity and Diesel Each 40%, Process Heat ~7%



Source: BHP Climate Change Report 2020

The other things needed to use Heliogen's solution are space, sunlight, and maybe commitment to decarbonization. That "maybe" is in the sentence because Heliogen may well provide a cheaper solution than fossil fuels or local grids, thus not requiring the decarbonization commitment. Industrial operations tend to be risk-averse, however, and the decarbonization push will kick off a transition that may prove to be cheaper for the mines as well.

In October 2021, the world's top miners pledged to reduce direct and indirect carbon emissions to Net Zero by 2050. Many miners have earlier and often more aggressive goals, but the coordinated statement out of the industry association (International Council on Mining and Metals) and its members is a clear and simple statement. The signatories represent almost half of the global mining and metals industry, and all the large global leaders.

Figure 13: Leading Global Miners Pledge Net Zero by 2050

Source: International Council on Mining and Metals

__Reality check:__ Our mining annual TAM estimate of $20bn is in the same ballpark when compared with $100bn in annual industry capex.

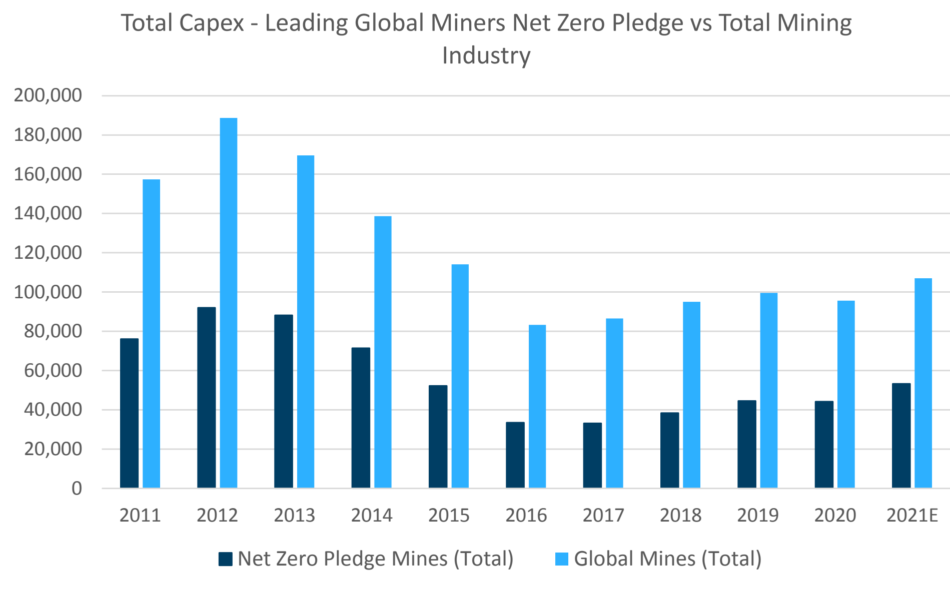
One major difference is that __this__ capital spend reduces operating expenses…solar power doesn't use fuel. Global mining COGS is more like $800bn annually

The signatories of that pledge account for about 45% of global mining capex, though our TAM assumes all mines eventually decarbonize.

Global mining capex figures, having peaked at over $180bn back in 2012 and probably above $100bn annually today, also help cross-check the reasonableness of our market size estimate. $20bn annually for green power is a lot relative to the capex pool, but it is the right order of magnitude.

Solar power also differs from a natgas plant, coal plant, or diesel engine power for that matter, in that there is no fuel cost. The capex may be high, but the opex would start falling immediately. Cost of goods sold for public miners across the world is on the order of $800bn annually.

Figure 14: Signatories to Net Zero ~Half of Global Public Mining Company Capex

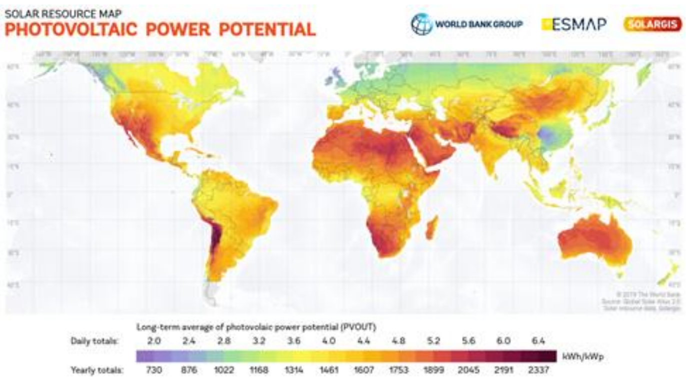


Source: FactSet and Melius Research

The final factor is geographic suitability. To use a Heliogen module, the mines would need sunlight and space. Both are generally present, and Heliogen can probably address half the global mines where there is enough sunlight, and probably at least half of those have enough space to put in solar.

Global mining sites overlap fairly well with solar potential, with concentration in the US Southwest, Australia, Brazil, Chile and South Africa…mines are often in desert areas with less cloud cover. We used an assumption that 50% of mine sites would have suitable solar resources, based on comments from a leading miner.

Figure 15: Solar Potential -> Latitude and Clouds



Source: World Bank Group

Figure 16: Global Surface Mines

Source: Parker Bay and Melius Research

As for space, well, it is often not a problem at mine sites. Our TAM estimate assumes about 2/3rds of mines with sunlight will have suitable land to install solar modules, also in keeping with comments from a leading miner.

Figure 17: Olympic Dam in Australia, One of the World's Largest Mines

Source: Google Maps

Figure 18: Rio Tinto's California Mine, an Early Partner

Source: Google Maps

Cement: $500bn Need, $25bn Annual TAM

Cement manufacturing accounts for about 7% of global carbon emissions. For perspective, the cement industry makes about 4.1 billion tons of cement annually, or about a thousand pounds for every person on the planet. When mixed with sand, gravel, and water to make concrete, the weight is 8x higher: ~four tons for each person globally. That huge volume is what makes it such a large carbon emitter.

Why is cement such a big emitter?

Global consumption is about 1,000 pounds per capita…*about 3x as much as gasoline by weight*

50-70% of that is from the limestone source material: limestone is calcium carbonate, and the carbon is released in processing to make cement. That emissions source will have to be addressed by other means. But much of the rest of the emissions comes from fossil fuel energy input, largely to heat the kilns used in cement making. 2-3% of global emissions is a big number, and that's the simplest way to think about this TAM. We also looked at it with cement industry data.

Cement factories use and source power in a few ways. According to a report by the Cement Sustainability Initiative, global cement factories use about 500,000 GWh of power from on-site production. Assuming 24/7 power generation, that equates to almost 60 GW of installed capacity for on-site generation. That's not too much less than the global mines at something like 100 GW of onsite power. The cement numbers are going to get a lot bigger, though.

Global cement power installed capacity:

~60 GW on site production

~130 GW purchased from outside capacity

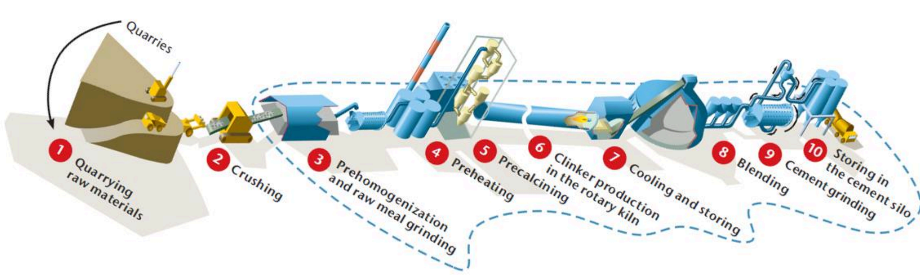
~1,000 GW equivalent in thermal energy from fossil fuels

Cement factories also use power from other sources, such as local grids. The equivalent capacity needed for outside power is another 130 GW. That's not as direct a target market for Heliogen, but it's a possible one. The numbers still get a lot bigger than that, however, since most of the energy use is for heating limestone, not power to run the machines.

Thermal energy used in cement making is about 10x the power numbers above. Cement factories can sometimes use organic waste, fossil fuel waste, or biomass instead of fossil fuels, but globally close to 90% of the thermal energy is from fossil fuels (Europe has replaced a lot more than that, moving from almost 100% fossil fuel in 1990 to just over 50% today). Sticking with the global number, thermal use is around 10x the other power uses. We are going to play fast and loose with some conversions here, since comparing heat to electricity requires some assumptions on how you want to count it, but basically the thermal energy is equivalent to 1,000 GW of capacity, a huge number. We'll apply a rough but large downward correction factor when thinking about TAM for Heliogen later.

These are huge numbers: 1,200 GW is big when a single Heliogen module is 5 MW, **so we'll show a quick sanity check**. The global installed capacity of electricity, at 9,700 GW, is around ten times our thermal number. Global electricity represents about 20% of global energy use and 40% of energy emissions because of the waste in conversion. Cement "capacity" is equivalent to 10% of global electricity capacity. 10% times the 20-40% of total emissions that are from electricity seems close enough to the 2-3% of global carbon emissions that we started with.

Figure 19: Cement Making Uses Process Heat To Get Kilns up to 1,400°C



Source: Cement Sustainability Institute

1,200 GW of capacity is equivalent to 240,000 Heliogen towers, or 12,000 a year assuming a 20-year life (Heliogen 2026 plan: 120 towers). Again, a lot of that capacity won't be addressable, either because it's too far north to get consistent sunlight, or because the facilities won't have hundreds of available acres nearby to install the modules.

Global cement plants could use ~$3 trillion in Heliogen modules

Adjusting for sunlight, space available, and a 20-year lifespan leaves:

Annual TAM of $25bn, or closer to $65bn including China

We'll make one adjustment before trying to adjust for geography and space. Perhaps 90% of the demand for clean energy for cement is from heat. A 5 MW Heliogen tower can put out 5 MW of electricity, but recall that the turbine used to turn heat into electricity might only be 37% efficient; it can put heat out with much greater efficiency, delivering ~13 MW of thermal power per module.

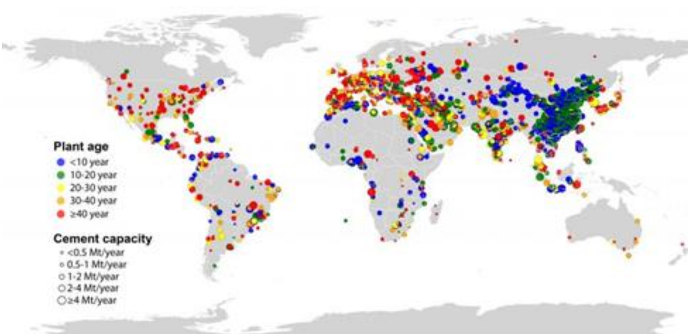
That means the TAM would be about 5,500 towers a year before adjusting for geography and space limitations. If the modules cost customers $30mm by 2026, that's an annual TAM of ~$170bn. The geographic haircuts to that potential need to be quite large, however. China and India are over 60% of global cement production, and might not be customers, due to lower solar potential or other reasons. If we assume Latin America, North Africa, the Middle East, and Australia all have good sun and are good markets, that's about 22% of cement production. Adding in Southern Europe and parts of the US probably gets us close to 30%.

Knowing how many factories have hundreds of acres available for Heliogen modules is not simple, but cement factories don't tend to be in dense urban areas. Cement factories are often located near limestone mines, to save transport cost, though they are probably not as remote as some other mines due to the benefits of being near population centers when transporting the heavy finished product.

We used an estimate that 2/3rds of mines have adequate space to install Heliogen modules in our mining TAM. For cement plants we will assume a lower number, closer to half.

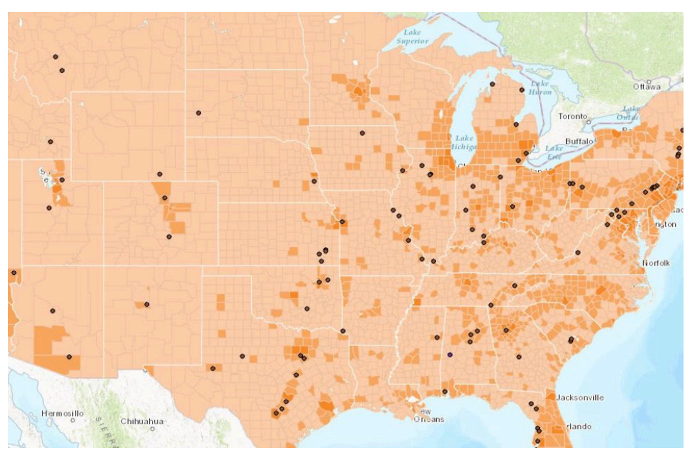
That leaves an addressable opportunity on the order of $25bn annually if we exclude China, or closer to $65bn including it.

Figure 20: Global Cement Factories: LatAm, Africa, Southern Europe, Australia, Parts of Asia Have Good Sun



Source: Global Infrastructure Emission Database

Figure 21: US Cement Factories vs. Population Density: More Common in Rural Areas



Source: Data Basin

Steel: $1.4 Trillion Installed Base Need, $70bn Annual TAM

Steelmaking represents as much carbon emissions as all global on highway freight transportation…

…from roughly 550 large plants

Reducing the carbon output of steel is one of the most difficult problems the world needs to solve. Iron and steelmaking consume 8% of global energy, according to the IEA, and account for 7-8% of carbon emissions from the global energy system (excluding emissions sources like agriculture). That's equivalent to the total emissions from all global freight transportation.

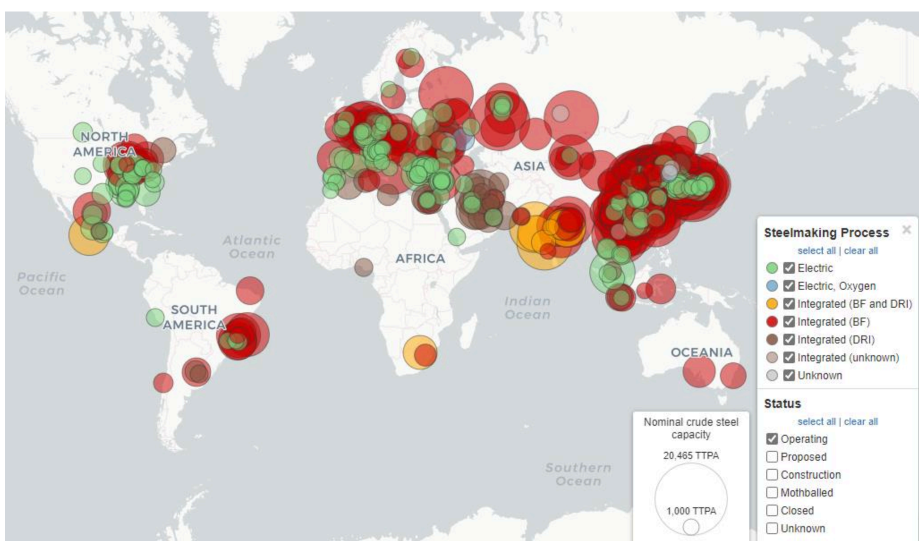
For context, the world burns around 7.7 billion tons of coal annually, about 2,200 pounds for every person alive. The bulk of it used as thermal coal to make steam for electric power generation. PV solar, wind, and nuclear are all green substitutes that could be used. That's a massive challenge, though, as the solar and wind intermittency becomes a major issue, one that Heliogen might help with someday. But there's nothing impossible about replacing that coal burn, it just takes time, money, and infrastructure. PV solar is cheaper than coal in many parts of the world today, so it's not necessarily even a costly trade.

About 1.1 billion tons of that global total is metallurgical coal, which is used in making steel. Just like with cement, the carbon emissions come from more than just heat. Carbon plays three roles in steel making: a heating agent, a reducing agent, and a small amount for making steel alloys (carbon steel). Heating is fairly obvious: blast furnaces use pulverized coal to get to temperatures on the order of 1000°C. Some of that heat might be replaced with Heliogen's green heat.

Reducing simply means taking the oxygen out. Iron ore is more or less rusty iron, in other words, and it needs to be closer to pure iron to make steel. Iron mined globally is generally iron oxide. Carbon from coal bonds with oxygen, leaving pure iron and releasing CO_2. That process can't be replaced simply by adding heat, but it is possible to reduce the carbon emissions by using hydrogen as a reducing agent instead of carbon. Hydrogen bonds with the oxygen to make water instead of CO_2.

There are 553 steel plants in the world today, according to Global Energy Tracker. China dominates, but there is a reasonable amount in other good geographies. And depending on the application, Heliogen might also send green hydrogen thousands of miles by pipeline as opposed to providing locally produced heat or electricity.

Figure 22: Global Steel Plants



Source: Global Energy Tracker

One way to think about the market in steel is to look at the energy content of that 1.1 billion tons of met coal used. Energy content of coal varies, but met coal used for steel might have 8 MWh of energy per ton, making the total amount burned annually equivalent to about 9 billion MWh. We are going to play fast and loose with conversions again here, since we are starting with energy content (MWh or kWh are often used when referring to electricity, but they are basically measures of energy) and not working with electricity, but dividing by 365 days per year and 24 hours a day, that 9 billion MWh of energy equates to something like 1,000 GW of capacity.

That's a very big number, about as much energy as our cement market, and it might take 80,000 Heliogen modules to replace the coal (instead of the Heliogen 5 MW electric output, we are assuming ~2.5x that amount of energy put out in the form of heat).

McKinsey suggests that replacing the heating value of coal in blast furnaces might reduce carbon output by 20% or so, equivalent to 16,000 Heliogen modules. But since coal is used for both heating and reducing, we will look at each factor separately.

Replacing the reducing function, the other 80% of coal's carbon output in steelmaking, is clearly needed as well, and hydrogen can do that. We looked at two estimates of the hydrogen needed to replace the reducing carbon in a ton of steel, and just like with the met coal numbers above, the result is quite large. On the order of 100 to 130 million tons of hydrogen would be needed (replacing something like 800 million tons of carbon). With a Heliogen module able to produce 850,000 kg (850 metric tons) of hydrogen a year, the demand would be on the order of 120,000 to 150,000 Heliogen modules. The installed base of such towers, at $30mm each, would be close to $5 trillion, and the annual market for Heliogen assuming a 20-year life would be $250bn or so.

Should we haircut the market size for sunlight limitations, suitable land around the steel mills, or other factors, like the attractiveness of selling tech products into China? Perhaps, since steel mills are less likely than mines and cement factories to have miles of excess land around, and they are subject to the same limitations with sunlight. However, hydrogen can replace both the heat value and the reducing value of the coal, and hydrogen can be shipped in from other places. With that in mind, we will adjust to take out China, which we believe will not be an early Heliogen market due to issues with technology transfer. China is close to 60% of global steel production, but ~70% of blast furnace production.

That still leaves a need for ~45,000 modules; at ~$30mm each, that equates to an installed base opportunity of $1.4 trillion, and an annual market of $70bn assuming a 20-year life for the modules.

In some ways, the above is an underestimate. The steel sector has emissions from sources other than met coal. Electric arc furnaces, which don't use as much coal, produced about 30% of global steel in 2020. And the blast furnaces that do burn coal, and the factories around them, also use electricity, a lot of it for compressors to blow air. Coal represents perhaps 90% of emissions from the blast furnace process, but the other 10% is still a lot. So the total need for green energy, and green reducing agents (hydrogen instead of carbon), is larger than that very large met coal figure, by at least 50% or so.

The raw numbers sound large, and they are, but they won't be realized soon and aren't even the most important outflow of thinking about steel. Steel making is complex, and changing large, capital intensive, complex industrial processes is not a short or easy process. It's not likely that the installed base will adopt new technology quickly, even with economic incentive.

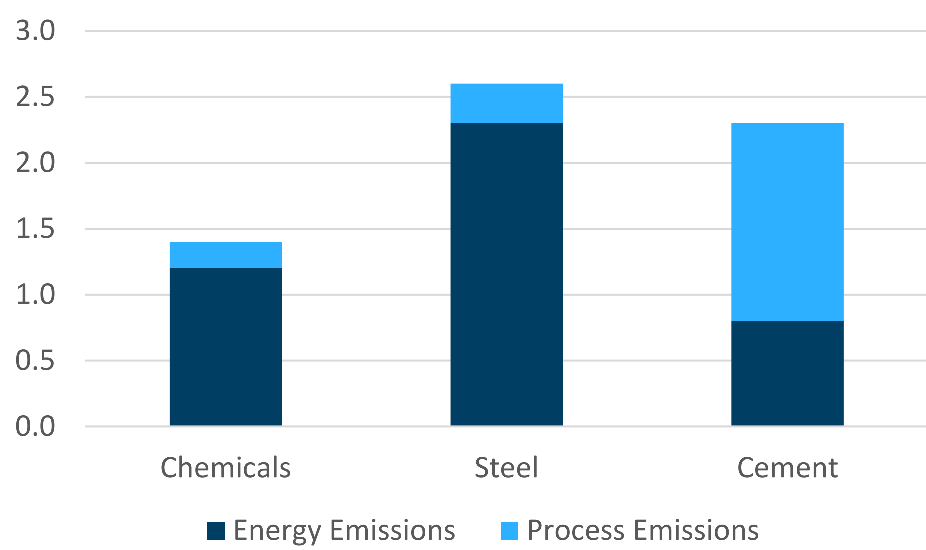
What is interesting, though, is that just like for mines, the steel mills are massive facilities, and there aren't that many of them. To oversimplify, a need for 50,000 modules for the ~350 plants outside of China equates to about 140 modules per plant. In other words, much like in mining, a decision by a large player like Arcelor Mittal could see much of Heliogen's five-year plan taken up by one or two steel factories.

There are other industrial end markets besides mining, cement, and steel. We focused on them as a starting point, and as some of the larger sources of emissions that need to be addressed. But lots of industrial processes use heat and steam. Heliogen's design, with modular 5 MW installations that take up ~100 acres or so, should be applicable to other large industrial plants as well.

For example, the petrochemical industry uses huge amounts of energy, about 60% of the total for steel or cement. In fact, Heliogen's first revenues are from Woodside Energy, in the oil and gas space. The Middle East has invested heavily in refining and petrochemicals over the past decade…Saudi Arabia does not lack land or sun.

Aluminum smelting is also extremely energy intensive; much of the value of aluminum is embedded energy. A lot of that energy is internally generated rather than purchased from the grid: 55% globally according to the IEA. Aluminum accounts for roughly 2% of global emissions from energy use. It also makes extensive use of continuous power from hydro (and even geothermal).

Figure 23: Direct CO2 Emissions from Heavy Industry Sectors by Category, 2019 (GtCO2)



Source: IEA and Melius Research

Financials and Valuation

As with many companies coming public via SPAC, often earlier stage than traditional IPOs of decades past, Heliogen's financials imply a steep ramp over the next several years. The ramp isn't what worries us, though, at least not from the demand side. We're convinced that the markets are huge and that the problems customers face are not readily solved by anything on the market today. Perhaps more important than that, the demand is starting out strong. Just one or two customers, such as Rio Tinto (announced collaboration underway) and Arcelor Mittal (announced investment and collaboration underway), could cover the demand across the forecast period at just one or two of their many sites. Heliogen has announced only one revenue relationship so far (with Woodside Energy in Australia), but the inquiries are strong, for projects that would take multiple thousands of towers versus the 120 that Heliogen has in its 2026 plan.

Inquiries aren't orders, and we don't mean to imply so. But there's ample need for what Heliogen wants to supply, and customers realize it. The risks we see are more along the lines of getting the first projects up and running, and running at high uptime. That's a bit harder to predict, even if the company has intensively tested multiple aspects of translating the test facility, with 400 mirrors and a tower, up to full scale with 40,000 mirrors.

The revenue ramp is designed partly to address those issues and partly to provide Heliogen with the flexibility to price appropriately based on what costs turn out to be in full scale installation—and probably what the value turns out to be as well. Rising energy costs is a dramatic event this year that makes Heliogen more attractive economically.

The revenue model will change over time. At first, Heliogen controls the project, and is partnering with EPC contractors for the installation. Heliogen's management has plenty of experience to provide valuable management and oversight (CFO Obiaya's tenure as CFO of Bechtel Energy, the company's largest business, and Chief Commercial Officer Tom Doyle as well, from decades spent in renewable energy development and leadership). Heliogen will book revenues on the entire project and report based on percentage of completion for projects that should take over one year to install. Later, Heliogen could have a more hands-off approach, not standing in as a project manager but selling to EPC companies. Ultimately, the model should evolve to a licensing business, with lower revenues but higher margins. The financial assumptions aim to provide customers with an 8-9% unlevered return; to be competitive with current, non-green solutions in other words. We are not taking any different views from Heliogen's own forecast at this time.

Figure 24: Heliogen Annual Financial Forecasts

($mm except modules)	2021E	2022E	2023E	2024E	2025E	2026E
New modules installed	-	-	3	15	57	120
growth, y/y %		nm	nm	*400%*	*280%*	*111%*
Revenue	$8	$24	$197	$569	$1,414	$2,396
growth, y/y %		*200%*	*721%*	*189%*	*149%*	*69%*
EBITDA	($29)	($59)	($92)	($114)	$287	$831
margin	*nm*	*nm*	*nm*	*nm*	*20%*	*35%*
Capex	$10	$15	$34	$36	$56	$97
% of sales	*125%*	*63%*	*17%*	*6%*	*4%*	*4%*
Free cash flow	($40)	($70)	($132)	($183)	$84	$433

Source: Company data and Melius Research

Valuation is tricky, as we noted. If the modules in 2023 go up on time and produce at 85% capacity factor, with the sort of demand and backlog we expect would result at that time, we would expect the value to be in the $10 billion+ range. If the product proves to be as cheap and as effective in diverse applications as we currently expect, perhaps tens of billions. If the technology and scale provide a durable moat in a market of hundreds of billions, well, the upside is larger still.

As of today, we have the opportunity to invest in a company that has not yet delivered a commercial module. It is going public in part to accelerate that curve, to provide transparency to potential customers, and to provide a strong balance sheet that can readily finance the kind of investment needed, in both factory and project finance.

There are a number of potential powers in solar power and clean energy. Heliogen is fundamentally different in some ways. It is aiming to provide a service that no one else does at present. That's different from solar peers, where a number of companies compete in a space with a little less technology differentiation (which is not to say Heliogen will definitively remain differentiated, but the technology certainly starts out so). In some ways, Heliogen might be more similar to a company like QuantumScape, with potentially transformational technology driving large opportunities years out. QuantumScape carries an EV around $10bn, depending on the day, for a market opportunity in the $20bn range today, and which analysts think will be on the order of $200-250bn in 2030. Heliogen's market exists today, not just in 10-20 years: tens to hundreds of billions that could be sold right now if the solution works.

The market is willing to pay a very high multiple on that, 50x revenues 5 years out, though those revenues are small relative to QS' opportunity. SolarEdge and First Solar trade around 6-7x more mature 2021 revenues, with some unique technology.

If we apply that range of ~6.5x revenue to Heliogen's 2026, and discount back three years at 15%, we'd get an EV of ~$10bn and a target price of $40. All that really means is that if Heliogen can get to a profitable $2bn+ revenue stream, it will be worth a lot given the long growth runway. Probably more than 6-7x revenues, in fact. The trick is to estimate the odds of getting there. Our $26 target takes 6.5x 2026 revenues, discounts to 2023 at 15%, and applies an additional 40% discount.

Figure 25: Comparable Companies and Valuation Framework

		Valuation (USD)			Sales (USD)						EV/Sales					
Ticker	Name	Current Mkt Cap	Net Debt	Enterprise Value	2021E	2022E	2023E	2024E	2025E	2026E	2021E	2022E	2023E	2024E	2025E	2026E
SEDG	SolarEdge Technologies Inc	$18,666	($369)	$18,297	$1,969	$2,670	$3,250	$3,677	$4,322	$5,149	9.3x	6.9x	5.6x	5.0x	4.2x	3.6x
QS	QuantumScape Corp	$11,028	($985)	$10,043	$0	$0	$0	$10	$35	$181	nm	nm	nm	989.5x	288.2x	55.5x
FSLR	First Solar Inc	$10,997	($1,267)	$9,731	$2,803	$2,746	$3,509	$4,118	$4,240	$4,134	3.5x	3.5x	2.8x	2.4x	2.3x	2.4x
BEPC	Brookfield Renewable Corp	$6,692	$12,705	$19,397	$3,273	$3,473	$3,655	n/a	n/a	n/a	5.9x	5.6x	5.3x	nm	nm	nm
ORA	Ormat Technologies Inc	$4,404	$947	$5,351	$660	$791	$897	$1,010	$933	n/a	8.1x	6.8x	6.0x	5.3x	5.7x	nm
JKS	JinkoSolar Holding Co Ltd	$2,768	$1,922	$4,691	$6,550	$8,302	$8,969	$10,811	$12,510	$18,419	0.7x	0.6x	0.5x	0.4x	0.4x	0.3x
REGI	Renewable Energy Group Inc	$2,486	($143)	$2,343	$3,066	$2,753	$2,676	$3,298	$3,102	$3,286	0.8x	0.9x	0.9x	0.7x	0.8x	0.7x
CSIQ	Canadian Solar Inc	$2,330	$1,254	$3,584	$5,478	$6,642	$6,808	$7,034	$7,246	n/a	0.7x	0.5x	0.5x	0.5x	0.5x	nm
SOL	ReneSola Ltd	$547	$75	$622	$92	$134	$126	n/a	n/a	n/a	6.8x	4.6x	4.9x	nm	nm	nm
	Simple avg										*4.5x*	*3.7x*	*3.3x*	*143.4x*	*43.2x*	*12.5x*
	Revenue weighted average										*2.7x*	*2.3x*	*2.1x*	*1.8x*	*1.7x*	*1.4x*
					Melius estimates											
ATHN	Heliogen Inc	$2,455	($385)	$2,070	$8	$24	$197	$569	$1,414	$2,396	258.7x	86.2x	10.5x	3.6x	1.5x	0.9x

ATHN Price Target (2023):	
Target EV/Sales	30.4x
Target EV	$5,990
Net debt (pro forma)	($385)
Target mkt cap	*$6,375*
Dil. shares (pro forma	245.7
Target share price	$26

Source: FactSet, Visible Alpha, company data and Melius Research

Figure 26: Heliogen Valuation Math

Heliogen 2026E revenue	$2,396
EV/sales	6.5x
Implied EV, 2026	*$15,574*
Discount rate	15%
Implied EV, 2023	*$10,240*
Net debt (cash), pro forma	($385)
Implied market cap, 2023	$10,625
Diluted shares, pro forma	245.7
Probability discount	40%
2023 price target	$26

Source: Melius Research

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