Substrata: The Micro-Tunnel-Boring Machine that Cuts Utilities Costs by 60%

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I. Abstract

Substrata's electric Micro Tunnel Boring Machine (MTBM) brings the costs of tunneling down from $9.5 per millimeter of length per meter of diameter with existing technologies to $3/mm/m. Our Micro TBM is 0.5 meter in diameter and 4 meters in length and is capable of excavating a 0.5 meter diameter cylindrical, horizontal cavity for 30 meters underground. Micro TBMs have applications for infrastructure projects including laying tunnels for sewer pipelines, utility/electrical systems, and storm water drainage.

The global microtunneling market, projected to reach $1.2 billion by 2031 with a growth rate of 10.4%, reflects strong demand driven by urbanization, climate change, and supportive legislation such as the Infrastructure Bill. SubStrata's initial target market includes smaller-scale urban projects, such as fiber optics and utility extensions, with plans to scale to larger infrastructure projects in the future. Unlike competitors like The Boring Company, SubStrata focuses on compact, budget-friendly solutions tailored for smaller tunnels, making it a unique player in the market.

Our Micro TBM was selected to participate in the Not-a-Boring Competition, hosted by the Boring Company in March 2025 in Bastrop, Texas. The competition provided the SubStrata team a platform to showcase our innovation and compete against leading student teams worldwide. Our project received the "Rookie Award", given to the best team among the teams competing for the first time. Further, we were the only US team to dig on the first time.

Index Terms: tunneling, microtunneling, infrastructure, sustainability.

II. Introduction

Project Motivation

Our project is motivated by our desire to increase accessibility to non-disruptive tunneling technologies while also improving the financial viability of tunneling projects and environmental sustainability. In this high interest rate environment, it is critical that capital-intensive infrastructure projects can see cost reduction in order to generate a positive net present value and gain support from key decision makers. Reducing tunneling costs by a factor of three would be groundbreaking in the sense that more tunneling projects will become financially viable.

In addition, our design's simplicity is also able to reduce the number of parts by an order of magnitude from 5000 parts to under 294 parts. Our team was excited to take this innovation forward to share with the tunneling community at The Boring Company's Not-A-Boring Competition 2025 (NaBC) in Bastrop, Texas. There, we demonstrated our Micro TBM's ability to dig a tunnel of 0.5m in diameter. We were incredibly excited to be able to compete at NaBC as this gave us an opportunity to learn more about other innovative approaches taken by other universities around the world along with meeting leading engineers at The Boring Company and collaborating on safety check procedures.

Goals, Objectives, and Challenges

We have three key goals for our TBM. 1) Our 0.5 meter diameter TBM is designed to dig through clay that contains no rocks or large debris for a distance of 30 meters; 2) We also aim to be able to reuse most of our controls for future digs. We aim to salvage the key physical structure of the TBM and the electrical control system. Our objective is that we will only have to replace the cutterheads and the gear motor in the worst-case scenario; 3) Our most important goal is to be able to operate safely. We have developed a series of safety checklists on the electrical and mechanical front. We are closely following the safety procedures of the Penn Power Electronics Research Laboratory.

Given the interdisciplinary nature and scale of this project, our team has overcome a range of technical, financial, and administrative challenges. Since our project operates within a club under the senior design framework, we had to secure funding from multiple sources, including alumni, corporate sponsors, part sponsors, M&T funding, and senior design allocations. Additionally, we navigated logistical hurdles in securing a safe space for development and testing, including Prof. Lei Gu's lab and the NextFab facility in Philadelphia.

Reliability issues were another significant challenge, but with support from Siemens customer service and other vendors, we were able to resolve problems efficiently. Logistical complexities also arose due to the high cost and long lead times of many components, requiring extensive coordination with vendors and sponsors, which proved time-consuming and stressful. Furthermore, software compatibility posed difficulties, particularly with TIA Portal and Autodesk AutoCAD Electronics. To address this, we borrowed laptops from the university to ensure smooth operation. Despite these obstacles, our team successfully overcame each challenge, keeping the project on track.

III. Design and Methodology

Specifications, Requirements, and Constraints

Our Micro TBM is designed to deliver 4 kN of torque from our primary gear motor, powered by a 380V, 3-phase electrical supply. This power is provided through a variable frequency drive (VFD), which converts 240V single-phase input into 380V 3-phase output. The cutterhead structure, with a thickness of 2 inches, is designed with a safety factor of 3 to withstand the forces encountered during boring operations. Our propulsion system is designed to deliver 300 kN of thrust, sufficient to clear the full 30m distance, while maintaining a safety factor of 2.6. The propulsion mechanism consists of a screw jack system, powered by a 380V 3-phase motor, which also operates via VFD control.

The high-power system consists of the VFDs along with essential accessories, including braking resistors, circuit breakers, and power monitors. At full load, we expect a maximum current draw of 50A from the 240V power source.

For machine control, we are utilizing a Siemens S7-1200 PLC, which interfaces with sensors (power monitors, IMUs, proximity sensors, load cells) and actuators (VFDs, relays, and solenoids) through Modbus communication. To ensure seamless integration with Siemens automation, we employ a Modbus-to-Profinet gateway. Our system operates at a minimum communication frequency of 1Hz, ensuring real-time monitoring and control.

The operator interface includes a Graphical User Interface (GUI) displaying detailed parameter readings, real-time diagnostics, and system warnings. Additionally, the operator console features physical controls, including switches, potentiometers, and emergency stops for direct interaction with the machine. Safety is further enhanced through indicator lights, non-contact safety switches, and interlocks, preventing unauthorized or unsafe operations.

By combining robust power, propulsion, control, and safety systems, our TBM is engineered for efficient, safe, and precise tunnel excavation.

Iterations or Alternative Solutions

Mechanical iterations:

Alternative solutions for the mechanical components of the design consisted of propulsion methods. In order to push the TBM into the soil, we had to determine which method of propulsion we would use. We debated over using linear actuators or a screw jack and ultimately decided on using a screw jack given that it was more cost effective.

Our alternate solution would be to use linear actuators. Linear actuators tend to take lower loads than screw jacks. This implies that we would need multiple linear actuators in order to propel the TBM. With each linear actuator costing over $3,000 using four for instance would balloon our propulsion costs to over $12,000 dollars. Instead we decided to use a screw jack which costs us around $8,000-$10,000. We only needed one screw jack given that its mechanism is designed to handle larger loads than linear actuators, allowing us to achieve a mechanically more elegant and simple while also cost effective solution. However, to allow the screw jack to be used with the TBM, we had to design a thrust plate in order for the screw jack to apply a force to propel the TBM from the launch structure.

Electrical iterations:

Alternative solutions for the electrical system design consisted of the exploration of various control methods. We debated over using custom microcontrollers, PLC's or manual control. We decided on PLCs for their robustness and industry-standard, while other solutions are expensive, unreliable, or outdated.

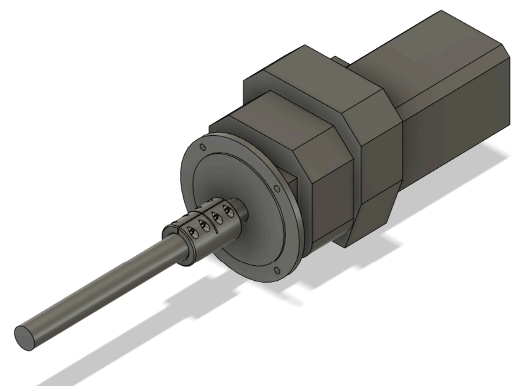
We decided to use a Siemens S7 1214 PLC for its combination of powerful computation ability and interconnectedness with a compact form factor. For instance, the device can handle multiple I/Os required, while simultaneously communicating with the computer as well as motor controllers with a variety of protocols, such as Modbus RTU or Profinet.

Other alternative solutions existed while deciding on our power system. We were debating between a 3 phase input or a single phase input. While a 3 phase input likely will give us more power to work with, it is also hard to access, only available in our advisor, Prof. Gu's lab. Alternatively, we chose a single phase 220V input, which is able to run off a wall plug and a transformer. This greatly improved testing efficiency.

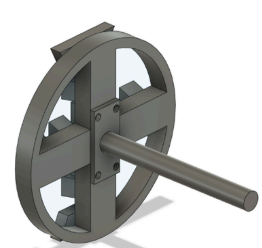
Technical Description and Approach

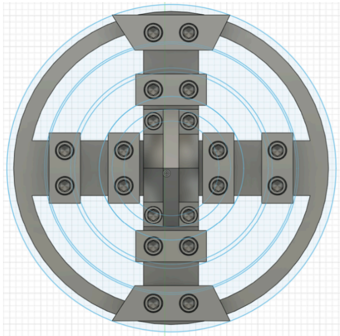
Mechanical: Our excavation system involves the use of an in-line gearmotor with extended shaft to deliver torque to our cutterhead.

Our main drive system features a 2700 Nm max torque gearmotor that runs at 10 RPM. We plan to run the motor at ~2400 Nm operationally. The calculations justifying this can be found in TBM Structural Analysis. The gearmotor features a 53mm keyed shaft, onto which we used a coupler to add an extended shaft of the same diameter. The length of this shaft was determined based on the length of the muck chamber with room for error. We are now using thin plates to adjust the cutterhead spacing as seen below.



Our cutterhead itself is designed with 6 "regular" cutters, 2 "edge" cutters and one center cutter. The cutterhead has been designed based on advice from previous entrants of the competition and our technical advisors in industry based on our experience with Bastrop soil conditions. The images below show our cutterhead with cutters bolted on it along with a front view which shows concentric circles of cutting that proves that the alternating cutters on parallel spokes cut the entire surface area of the cutterhead. The image also shows a circle larger than the frame diameter.





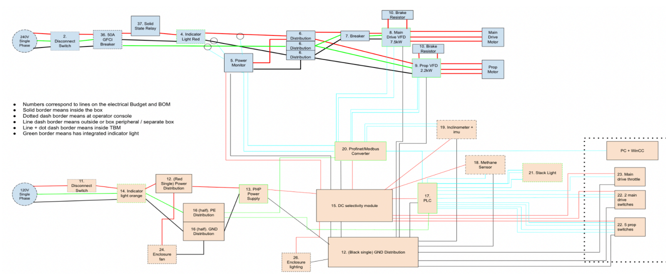
This is because our edge cutters scrape away more than the diameter of our tunnel to produce an industry-standard overcut. The extent of this overcut is a ½” thick ring. This puts the effective cut diameter to 21”.

Currently, for the machinery that drives our propulsion system, we are looking at a pipe-jacking system, where electric jacks propel the TBM from behind, allowing tunnel lining segments to be added continuously as the machine advances from a fixed position. Although we considered the gripper method, which relies on the TBM gripping the sidewalls to push forward, we ultimately chose pipe-jacking due to its seamless integration with the tunnel lining process, enhanced precision, reduced surface disruption, and superior stability given the ground conditions in Texas.

While we’ve considered it, we have decided against an indexing method to reduce points of failure along the pipe-jacking method and/or ease the manufacturability of our system.

In particular, our propulsion system used a single screw jack that interfaces with our thrust plate to push our TBM and the pipes forward. The screwjack we are proposing is an upright translating trapezoidal screw. The translating screw allows our screwjack to operate as a linear propulsion method, by not rotating and providing an upward thrust push. We also chose a specifically trapezoidal screw as those are better designed for low speed and high force applications, rather than the alternative ball screw which is more for high speeds and low forces. The screwjack for the job is the Joyce Dayton QS-21624 at 6mm per second we give the machine enough time to digest and vacuum out the incoming muck.

Electrical: Our full schematic is seen below. The electrical system in our TBM is designed to be safe and simple to assemble in an enclosure, test, and operate.



Our only control unit on our machine is the Siemens S7-1200 1214C PLC. As shown in the one-line diagram, the PLC unit aggregates data sent in from each sensor, displays it on an HMI panel and a computer monitor, compares their current values with their expected ranges, and alerts the operator if there’s a discrepancy. Based on the operator’s input, the PLC reacts accordingly, such as adjusting the speed of the motor through the VFD or shutting down the TBM. The PLC system also reacts automatically, such as turning the indicator lights on given current machine state (error, running, de-energized), or shutting down the system by the shunt-trip given unsafe conditions (like if methane detected, for example).

Communication is happening via Profinet and Modbus RTU.

Project Standards and Design Impact

Engineering standards have been consistently applied through part and material selection. Our standards include but are not limited to: 1) ¾"-16 bolts, ASME B1.1 standard (selected using shear stress failure mode analysis); 2) AISI (American Iron and Steel Institute) 4130 Steel (chosen for material yield strength). We selected this standard of steel since it is cost effective and allows us to apply a higher factor of safety; 3) Standard 120 VAC, one phase outlet (NEMA 5-15) National Electrical Manufacturers Association; 4) We adhered to University of Pennsylvania Power Electronics Laboratory Standard Operating Procedures for our testing safety standards.

The Boring Company also provides a long list of safety precautions that have been incorporated into our system in the form of fail-safe hardware and software. This includes emergency stops implemented at multiple levels including a relay, switch, and breakers in case any of our I/Os exceeds warning levels. It also takes two steps to start the machine–an e-stop and relay–and then finally engaging the main motor.

Further, our team has been following strict safety guidelines throughout the building process. This includes wearing personal protective equipment such as gloves, safety glasses, and steel-toed boots around mechanical assembly. We also have a buddy system in place when working with high-power equipment. For the competition, we followed a Standard Operating Procedure involving safety checks before, during, and after operating the TBM. We had various verbal and hand signals in place at every point of operation to ensure that all members of our TBM team were safe.

Technical Conclusion

In summary, the technical design of Substrata's Micro TBM integrates a robust mechanical drive system and a safe, efficient electrical control framework. The engineering approach emphasizes cost-effective innovation, reducing complexity while ensuring operational reliability through rigorous testing and adherence to established safety standards. Mechanical elements like the gear motor-driven cutterhead and single screw jack propulsion are optimized for both performance and simplicity. On the electrical side, the use of a Siemens S7-1200 PLC alongside comprehensive sensor integration and safety interlocks ensures real-time monitoring and control. Together, these systems formed a cohesive, pioneering solution for accessible, non-disruptive tunneling, setting a strong foundation for our demonstration at the Not-A-Boring Competition.

IV. Results & Discussion

We successfully built a micro tunnel-boring-machine for the Not-a-Boring competition, hosted by The Boring Company in March 2025. Our machine is 60% cheaper than current tunnel-boring machines. In fact, our solution is as cheap as open-cut methods, but without the use of jackhammers. Further, we've built a fully-electric micro TBM, which eliminates diesel emissions on-site.

After diligently raising more than $50k from sponsors and UPenn alumni, we built a tunnel-boring machine proven to work on-site. At the competition, we dug a tunnel of approximately 1.5 meters in length. The main issue we had was that our main drive motor burned. Had we bought a more powerful (and more expensive) motor, we're certain that this wouldn't be an issue. Although our propulsion system did work at the competition, another key takeaway is that we should have used more than one screw jack. For example, having three screw jacks forming a triangular shape at a significant distance away from the pipe's center would have made our micro TBM withstand more rotational forces.

The SubStrata team is very proud of the awards we received at the competition. We shipped our heavy machine to Bastrop, Texas, and were the only US team to dig on our first try. Further, we were the smallest U.S team and budget to participate in the competition. Lastly, and perhaps most importantly, we were recognized as the third best team overall and received the "Rookie Award", given to the best team amongst those competing for the first time. Given the success of our innovative and affordable machine, The Boring Company stated: "If we were to build a TBM for the competition for the first time, this is how we would have done it."

V. Business Case

Currently, the process of laying pipes for sewage drains or electrical wiring beneath urban streets is both highly disruptive and expensive. The most widely used method, known as open cut, involves excavating a trench by digging up road surfaces and other infrastructure. One of the closest examples was the replacement of pipes under 34th Street, where half of the road was closed for one entire year. The MTBM manufacturer market is quite fragmented, with companies such as Herrenknecht AG, Komatsu, E-BERK, The Robbins Company, and Akkerman Inc, manufacturing a wide range of TBM sizes. Only the latter two are based out of the USA, in addition to The Boring Company, and the smallest diameter these firms manufacture are 48 inches, indicating a market opportunity for our product.

Microtunnelling offers a less invasive solution. Instead of excavating the surface, a small tunnel boring machine is used to create the necessary underground pathway, allowing pipes or wiring to be installed without the need for open trenching. Microtunneling, while quieter and non-disruptive, is prohibitively expensive—costing approximately three times as much as open cut (~$9.5/mm/m).

We designed the main drive system that eliminates steering in order to cover shorter distances quicker. By simplifying the design and operational processes of TBMs, we can make this method more affordable and accessible. Our largest competitive differentiation lies in our ability to ⅓ the cost of digging, driving more excavation volume and value for our customers. Key stakeholders in this project include infrastructure construction companies that are constantly seeking more efficient machines and processes, as well as city authorities and private landowners who would benefit from the minimal disruption of trenchless construction.

a. Value Proposition

Urban infrastructure is essential for modern utilities like water, electricity, and telecommunications. Currently, most infrastructure is constructed via traditional open-cut methods, involving digging an open trench, laying pipes or wires, then covering the trench. This is costly, time-consuming, and highly disruptive. Because large-scale excavation is required, impacts such as road closures, disruption of communities, and noise pollution make open cut methods far from ideal.

Micro-tunnel boring machines offer a less invasive alternative, only requiring entry and exit pits on the surface. However, their high cost—averaging $9 per millimeter of diameter per meter of tunnel—limits their use. Combined with overhead costs, for instance, a 500mm diameter tunnel could cost $150,000 per 30 meters, making MTBMs impractical for smaller projects in budget-constrained urban areas. SubStrata's initiative to develop a new micro-TBM addresses these challenges by simplifying design and operation to lower costs, aiming at $3 per millimeter per meter. To do this, we focused on simplifying the electrical systems of the machine, including power systems, controls, safety, and navigation. Further, our fully electric MTBM eliminates the need for diesel, which accounts for up to 22% of operational costs in open-pit mines.

Affordable micro-tunneling can revolutionize urban development by enabling efficient, sustainable infrastructure installation with minimal disruption. By reducing the barriers to trenchless construction, this innovation can fill a market gap, benefiting municipalities, private developers, and utility companies. Expanding access to micro-tunneling technology will improve infrastructure projects across the United States, enhancing urban living and sustainability in our communities and beyond.

b. Stakeholders

Due to the complexity and size of our project, many stakeholders are involved in order to make our project a success. Testing our prototype presents significant risks to: our students, residents, property owners of the test-site, the University of Pennsylvania, the environment, and our sponsors. We are aware of the magnitude of our project and how complex it may be to control all electromechanical components that it is composed of. Failure in keeping our machine under control can cause significant impact to the safety and wellbeing of individuals and property owners involved. Furthermore, damage caused by our project would also result in the loss of funds and time.

We would like to highlight Substrata's commitment to keeping all of our stakeholders safe and well. On a less physical level, we will also continue to honor the donations we have received from alumni and corporations who have been making our dream come true.

c. Market Research:

The global microtunnelling market is expected to reach $1.2 billion by 2031. This is a product of the strong growth that this market is experiencing; according to Business Research Insights, the growth rate of the global microtunnelling market is projected to be 10.4%. Leaders in engineering and consulting like Stantec have been calling this industry "the next big thing in civil engineering."

Some of the key growth factors behind this significant spur are large-scale infrastructure projects driven by climate change and urbanization. Additionally, government spending and legislation including the Infrastructure Bill and the Inflation Reduction Act have been catapulting the microtunnelling market into new heights.

As mentioned in the value proposition section of this paper, there truly are multiple applications for MTBMs. It's key to highlight that the world doesn't just need big tunnels for large infrastructure projects. In fact, when we consider areas from transportation, energy, mining to telecommunication, all of these continuously rely on tunnels that are smaller than 4 meters in diameter. Imagine how much more affordable connectivity access would be if fiber optics were installed using MTBMs instead of open-cut methods—plus, the added sustainability benefits of minimizing community disruption and preserving the landscape.

d. Customer Segmentation:

Our primary customers are construction contractors, as we would spend our initial years leasing our MTBMs for a variety of projects. In the future, we see opportunities to vertically integrate and take on construction contracts ourselves from institutions such as local governments and municipalities.

In the short-run, we see bigger feasibility of addressing the customer segment of smaller-scale urban projects. These include telecommunications projects – like installing fiber optics networks – or utilities – like extending energy lines. We believe that addressing these smaller-scale projects would better align with the technology that we are currently building, given that our MTBM has a diameter of 0.5 meter. This dimension is suitable for projects that require smaller cables or tubes, and both telecommunications and utilities fit into that category.

In the long-run, however, we are excited to scale the dimensions of our microtunnel-boring machine, increasing its diameter close to 4 meters. This would allow us to target a second customer segment of larger-scale infrastructure projects, including transportation and energy. These areas typically require bigger tools and materials given the sheer need of having to encapsulate bigger cables or allow for human access underground.

e. Competition

Within the world of tunnel-boring machines, the leading innovator is The Boring Company. The company has been undertaking significant infrastructure projects and have already amassed a healthy amount of attention worldwide from the media. That being said, The Boring Company undertakes projects that are in general larger than the ones that SubStrata will take on. Our final prototype in March had a diameter of 0.5 meters, which is significantly smaller than The Boring Company's tunnels, which can have a diameter of up to 6 meters. We don't see the Boring Company as a competitor because, in fact, they are some of the biggest supporters of student-run microtunnelling projects. In March 2025 we participated in their Not-a-Boring Competition in Bastrop, Texas.

Our most direct competitors were the other teams participating in the Not-a-Boring Competition with us. These were students from other US universities as well as from European institutions. For example, over the last few years, the German team of the

Technical University of Munich (TUM) has been quite consistent at winning the horizontal dig.

The MTBM manufacturer market is quite fragmented, with companies such as Herrenknecht AG, Komatsu, E-BERK, The Robbins Company, and Akkerman Inc, manufacturing a wide range of TBM sizes. Only the latter two are based out of the USA, in addition to The Boring Company, and the smallest diameter these firms manufacture are 48 inches, indicating a market opportunity for our product.

f. IP

We are currently not pursuing IP protection in this project at this time; however, it is an opportunity we would seek to explore in the future.

g. Revenue Model

We will begin operating with a leasing model, with potential to expand via vertical integration and take on construction contracts with our own equipment like TBC does. Our revenue model is based on excavation volume, which leads to the formula: Revenue = Average length dug × Average diameter × Price per mm of diameter per meter of length. Given that it took us ~6 months to manufacture a TBM (amid administrative and part sourcing hurdles), we have outlined projections for our TBM manufacturing capabilities through 2030 below. We arrived at the number of construction projects we take on by assuming each project uses two TBMs and applied an average of one year per project from estimates given by the 2023 North American Microtunneling Job Log. We assumed we would take on 25% of projects in 2025 and applied an extremely conservative growth rate of new projects in future years, leaving plenty of room for revenue expansion. We arrived at average project length by examining past microtunneling excavations such as utility tunnels in locations including Houston (~700 m), Denver (~1200 m), and San Diego (~1400 m). The industry average is around $9.52 cost / mm / m. The cost to manufacture our TBM is about ⅓ of this, and we will be charging roughly $6.00 / mm / m, beating our competitors on price and allowing us to drive volume at a great margin (more details in the cost section).

<u>**Revenue Build**</u>	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
TBMs Manufactured	2	3	4	5	6	7
Total TBMs on Hand	2	5	9	14	20	27
ossible projects (2 TBMs / project, 1 yr each)	1	2.5	4.5	7	10	13.5
% of projects taken on	25.0%	25.5%	26.0%	26.5%	27.0%	27.5%
Number of construction projects	0.25	0.6375	1.17	1.855	2.7	3.7125
Average project length (m)	1100	1100	1100	1100	1100	1100
Average tunnel diameter (mm)	500	500	500	500	500	500
Revenue / mm of diameter / m of length	6	6	6	6	6	6
Total revenue	$825,000	$2,103,750	$3,861,000	$6,121,500	$8,910,000	$12,251,250

h. Cost

The cost of manufacturing the TBM will be accounted for as a capital expenditure, listed under the PP&E section of our balance sheet and expensed yearly as depreciation. The part cost to build our TBM is estimated to be around $60,000, and we have applied a very conservative estimate of 2% more cost efficiency in manufacturing each year, driven by our capability to negotiate equipment sourcing contracts and ask for bulk discounts, with huge potential to reduce the cost beyond our numbers. Our TBMs will be depreciated over a useful life of about 4 years initially, backed by research indicating that most industry-grade TBMs have a 10,000 hour design life, divided by a 7-9 hour workday and 360 working days a year. As the quality of our assets increases, the useful life will also improve, which we have modeled via a 2% increase in lifetime each year. We have modeled with a depreciation waterfall to demonstrate the income statement impact of our CAPEX (including parts cost, wages, and miscellaneous costs) each year, listed under operating expenses. For the sake of simplicity, we have modeled SG&A and R&D as a percentage of revenue, however there is most definitely a fixed cost component in these expenses, allowing significant opportunity for future margin expansion. Further, according to McKinsey, R&D accounts for less than 1% of revenue in the construction sector. We believe that our R&D investment as 5% of revenue will enable our competitive advantage and lower costs, passing on savings to our customers. After a 21% corporate tax rate, we arrive at a positive profit margin by 2026.

Income Statement	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Revenue	$825,000	$2,103,750	$3,861,000	$6,121,500	$8,910,000	$12,251,2
Depreciation of CAPEX	$690,000	$1,499,047	$2,334,903	$3,115,228	$3,996,804	$4,995,1
SG&A (15% of revenue)	$123,750	$315,563	$579,150	$918,225	$1,336,500	$1,837,6
R&D (5%)	$41,250	$105,188	$193,050	$306,075	$445,500	$612,56
Operating Income	-$30,000	$183,953	$753,897	$1,781,972	$3,131,196	$4,805,8
Tax at 21%	0	$38,630	$158,318	$374,214	$657,551	$1,009,2
Net Income	-$30,000	$145,323	$595,578	$1,407,758	$2,473,645	$3,796,5
Profit Margin	**-3.64%**	**6.91%**	**15.43%**	**23.00%**	**27.76%**	**30.99%**

CAPEX	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
BOP TBMs	0	2	5	9	14	20
New TBMs built	2	3	4	5	6	7
Part Cost to Build Each TBM	$60,000	$58,800	$57,624	$56,472	$55,342	$54,23
Wage and Misc Cost	$400,000	$400,000	$400,000	$400,000	$400,000	$400,0
Total CAPEX	$920,000	$1,376,400	$1,830,496	$2,282,358	$2,732,053	$3,179,6

Useful life of asset		4.00	4.08	4.28	4.50	4.72	4.96
Depreciation Waterfall for CAPEX							
	2025	$230,000	$230,000	$230,000	$230,000		
	2026		$337,353	$337,353	$337,353	$337,353	$26,988
	2027			$427,287	$427,287	$427,287	$427,287
	2028				$507,394	$507,394	$507,394
	2029					$578,444	$578,444
	2030						$641,153
Depreciation Expense		$230,000	$567,353	$994,640	$1,502,033	$1,850,477	$2,181,265

VI. Conclusion

Substrata's micro-tunnel-boring machine represents a significant step toward cost-effective and sustainable tunneling. By engineering a lean and fully electric TBM capable of delivering powerful performance with a simplified, first-principles design, we address both the technical and economic barriers that have limited microtunneling's wide adoption. Our 0.5-meter TBM reduces tunneling costs from $9.5 to $3.00 per mm of tunnel dug per meter of diameter – an unprecedented advancement that positions our system as a promising player for urban infrastructure development.

Through iterative mechanical and electrical design, we developed a solution that met the technical requirements of the Boring Company's Not-A-Boring Competition and that laid the groundwork for commercialization in the long-term. From the integration of a gearmotor with high torque and a screw jack propulsion system to a complex PLC-based control program, our TBM uniquely merges performance, safety, and modularity. The successful construction of our TBM demonstrates our team's ability to bring engineering innovation into real-world application.

Beyond the competition, our vision for SubStrata is grounded in creating a long-lasting impact in the urban infrastructure industry. With a sound and appealing business model and strong engineering foundations, we intend to revolutionize how cities build underground infrastructure for telecommunications, utilities, and much more. This project has not only strengthened our technical capabilities, but has also prepared us to become future leaders in sustainable engineering and infrastructure innovation. Further, the success of our fundraising efforts in the realms of $70k underscores how we have communicated our project's vision effectively – a skill that is essential for an outstanding engineering professional. The SubStrata team was ecstatic to compete in the Not-A-Boring competition in March 2025, and is now even more ecstatic for what lies in the future of microtunneling.

VII. Ethical Concerns

Our TBM is incredibly complex with ethical considerations regarding the environment, safety, and adhering to the will of our sponsors.

Our project requires sourcing parts from all over the globe. Together, we combined mechanical and electrical parts along with software from North America, Europe, and further a field in Asia, requiring shipping by air, land, and sea. We sourced parts from Italy, Germany, Austria, China, Japan, and more. The reason we chose to globally source our parts was as a result of cost optimization. It is unfortunate that minimizing cost and maximizing quality does not always lead to minimizing our carbon footprint. If given a higher budget, we would like to source components from nearby manufacturers that produce components that meet the specifications and our needs.

In addition to keeping our large budget in check, we also have to ensure that we are respecting the will of our sponsors and donors. SubStrata is extremely grateful for the support of the UPenn ESE department, the M&T Program, and all of our sponsors and donors who have made this dream a reality.

Despite high expectations, we also have to ensure that we protect the will of our supporters and ourselves. Safety has and will always be our number one priority. Ensuring that we follow the safety protocols of the Penn Power Electronics Research Lab will prevent and minimize the possibility of equipment damage, injury, and loss. Our project involves significant amounts of electromechanical parts which pose potential danger if handled incorrectly or without the correct safety procedures. In addition, testing and controlling our equipment is important in order to minimize loss and property damage. We work with facilities like NextFab, the senior design room, and the Penn Power Electronics Research Lab. For the competition, we installed safety procedures such as having a lock system that only the TBM driver can operate, ensuring that only authorized operators are able to control the equipment.

VIII. Acknowledgements

We would like to acknowledge and thank our sponsors for their continued support in the project. In particular, Penn ESE has been a great contributor both financially as well as technically, helping our team move closer to the final goal. We would also like to thank our other sponsors, like Siemens, PPM or Human Capital. Without them, we would have not been able to get this far.