MIT
Hyperloop

2021 Not-a-Boring Competition

Final Design Package (FDP)

January 2021

MITHyperloop.mit.edu

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Team Description

MIT has started a new Hyperloop team this year, named MIT Hyperloop III. Our team aims to prototype a Tunneling Machine which combines guided auger boring with a plasma exfoliation cutting head. Our team consists of about 20 MIT engineers and business professionals. Our engineers come from a broad array of disciplines—mechanical engineering, electrical engineering, computer science, and geophysics. Our business professionals come from the MIT Sloan School of Management and lead our efforts in fundraising, publicity, and marketing.

The concept of Hyperloop remains a promising technology for domestic transportation. The Hyperloop white paper released in 2013 brought publicity and focus to realizing scalable Hyperloop implementations. The SpaceX Hyperloop Pod Competitions brought academic institutions across the globe together to prototype Hyperloop pods. Through this venue, MIT had the opportunity to showcase award-winning designs with SpaceX. MIT Hyperloop I won Best Overall Design, Safety & Reliability, and Innovation Awards at the SpaceX-Hyperloop Competition I in 2016 for their magnetically levitated vehicle. MIT Hyperloop II won 1st Place in the US, the SpaceX Innovation Award, and the 2020 Edison Gold Award for Innovation in NextGen Logistics for their air-bearing levitated vehicle. Now, the Not-A-Boring Competition serves as an opportunity to explore innovative tunneling solutions to realize a Hyperloop ecosystem. Through this venue, MIT Hyperloop III is invested in the opportunity to explore scalable and cost-effective tunneling machines together with the Boring Company.

We would like to thank the MIT Edgerton Center and our sponsors for giving us their support in designing our Hyperloop Tunneling Machine.

Table 1: MIT Hyperloop III Team Roster

Team Member Name	Role
Maheera Bawa	Mechanical Engineer
John Poliniak	Mechanical Engineer
Rafael E. Olivera-Cintrón	Mechanical Engineer
Chille Bergstrom	Mechanical Engineer
Jordan Beer	Architect
Rion Motley	Architect
Isaac Lau	Electrical Engineer and Computer Scientist
Miles Kaming-Thanassi	Electrical Engineer and Computer Scientist

Tao Sun	Computer Scientist
Bhaskar Deo	Geophysicist
Logan Hester	Oil Field Drilling Engineer
Bobby Brown	Mechanic; Certified Welder
Deborah Navarro	Commercialization & Strategy
Phillip Davis	Certified Crane Operator; Welder; Class 7 (All Terrain) Forklift Operator
Brandon Etherton	Certified Crane Operator; Welder; Rigging; Crane Signals Person
Daniel Baskin	Certified Rigger; Fire Safety Certification; CPR and Military Medic; Welding Inspector
Katherine Liew	Project Manager
John McMaster	Senior Engineer
Michael Forsuelo	Senior Engineer

Design Description

MIT Hyperloop III proposes implementing a guided boring machine with plasma exfoliation. We will extend a Barbco Tribor 36, a well-vetted industrial machine, with a plasma cutting head. Our proposed Tunneling Machine (TM) differs from Tunnel Boring Machines (TBM). Tunnel Boring Machines (TBM) are a well-explored and conventional drilling technology. However, TBMs may suffer from a few limitations. TBMs often require millions of dollars per mile in terms of capital and operational costs. TBMs typically move on the order of 10^{-3} miles per hour. While the smaller tunnel diameter (0.5m) for the competition may reduce financial expense, we believe our solution both minimizes expense and optimizes tunneling speed. Herein, we describe our prototype Tunneling Machine (TM).

TM Top-Level Design Summary

Our proposed Tunneling Machine will build upon the Barbco Tribor 36 as an industrially-proven foundation. Barbco Inc. has been a leader in the underground construction industry since 1989. Over the years they developed over 11 patents, which have contributed to the Barbco Tribor system. Our team has been in discussions with Barbco about The Boring Competition. Their lead engineers agree with our vision that their existing technology, scaled up, could be an integral part of rapidly producing rural track, with no bottlenecks in production. Barbco and our team are in talks to develop new technology for the Barbco Tribor System, namely a contactless drilling plasma bit head.

The Barbco Tribor provides three functionalities: an auger boring machine, a guided boring machine, and a horizontal directional drill. We intend to use the auger boring and guided boring functionalities to mine through the strata. A Leica LDT-05 Theodolite will facilitate navigation. A Terex Crane RT 1045 will help load and unload heavy equipment. Our novel extension to the Barbco Tribor, the plasma cutting head, will help in cutting through harder strata. The shipping container offices will serve as the base of operations. The fabrication container will facilitate pipe welding and Tribor maintenance. See Figure 1 for a drill site overview. More detailed descriptions of each component are provided below.

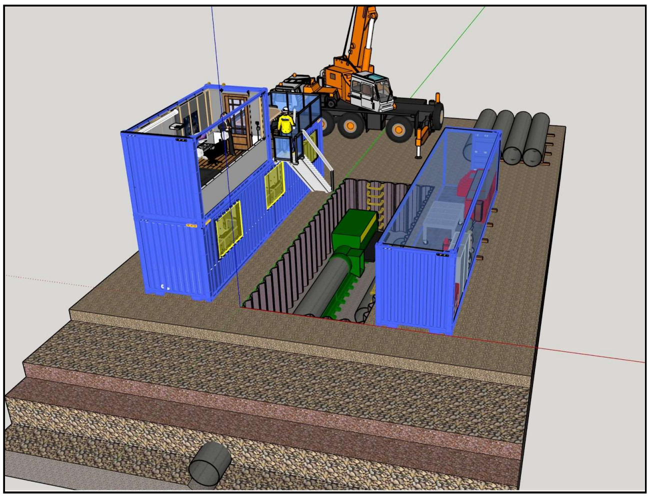


Figure 1. Drill Site Overview

Our novel extension to the Barbco Tribor is a plasma exfoliation head. The plasma head serves as a non-contact method to thermally disintegrate hard strata ahead of the bore liner, creating a kerf into which the liner can be advanced. The head itself consists essentially of concentric copper alloy tubes providing compressed air to cool the head, and working gas to generate plasma, surrounding a centrally located pair of tungsten electrodes providing both the ionization potential and the current source for the plasma channel. Compressed air will be supplied from the on site compressor at approximately 10 cubic feet per minute to provide cooling and working gas for the plasma tip.

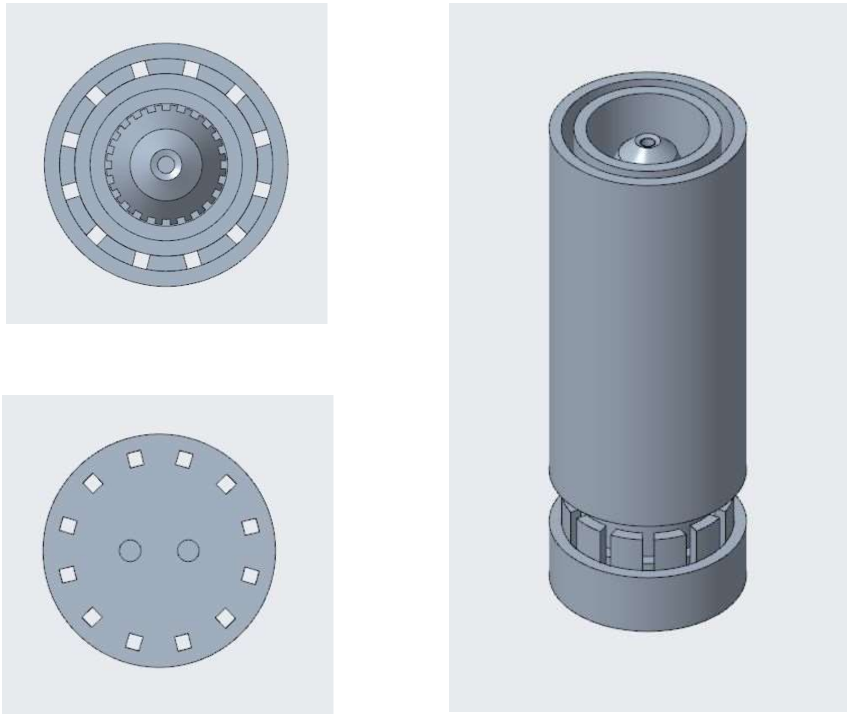


Figure 2: Plasma head: (top-left) front view; (bottom-left) rear view; (right) isometric view

The Plasma Head will consume up to 25kW (250A) at ~100V nominal supply, but the laser cavity requires approximately 20W (.002A) for 2 seconds at an electrode potential of approximately 10kV to initiate the plasma channel. At this power level, a single cutting will cut a 20mm deep and 15mm wide kerf in the bore face in under 2 minutes to accommodate the liner pipe advancement. It is expected that the Barbco Tribor will be able to advance the pipe through the expected Caliche lenses.

We will use a Terex Crane RT 1045 to load and unload heavy equipment. The RT 1045 crane will lift carbon steel pipe and the Barbco Tribor. More details can be found in our loading and unloading plan. The fabrication container will be the congregation point, where all of MIT Hyperloop's qualified team members will take directives from the command center. The qualified personnel will be responsible for preparing and welding the pipe according to the American Welding Society's (AWS) Welding Procedure Specification (WPS). The crane will have the lifting capacity and range to pick up and place the industrial equipment and containers for site setup and to load the 36" x .375" pipe for drilling operations. Our team's experienced and certified crane operators, rigging and crane signal team members will work with heavy equipment in compliance with the National Commission for the Certification of Crane Operators (NCCCO). Detailed lift plans can be found in the Loading and Unloading Plan section. Our experienced team members will also enforce industry safety standards to reduce any potential hazards on the site. Detailed safety assessments and protocols can be found in the Safety Features & Operations section.

Boring operation is organized into five broad phases—Site Prep and Setup; Advancing the Bore String; Retraction/Loading; Cyclic Advancement; Shutdown and Surface Preparation. Site prep includes entry and exit pit excavation and laying in of the boring machine, pipe string segments, and auger accessories. Next, the boring machine is loaded with the first tunnel liner section, steering head, and auger. It is then powered up to begin advancing the tunnel. Eventually, as the first 20-foot section of pipe is advanced into the bore, a second section is prepped, the TM is reversed and idled, while the next section is loaded into the bore string and seam welded end-to-end to the previous section. The site then alternates between these two states—advancing under power and retraction/loading while idled, until each 15-foot bore segment is complete. Once the bore (and liner) reaches the target receiving pit, the auger is removed, the tunnel is cleared of any remaining debris, and road surface segments are laid into the liner in preparation for the drive-test segment of the competition.

TM Dimensions

Pit Dimensions

The pit dimensions are 14’x40’ with depth advised by geotechnical logs.

Terex RT 1045 Crane Dimensions

The Terex RT 1045 has a working radius of 3.3 feet. The Terex crane has a maximum main boom length, tip height, and hook height of 102, 108, and 100 feet respectively.

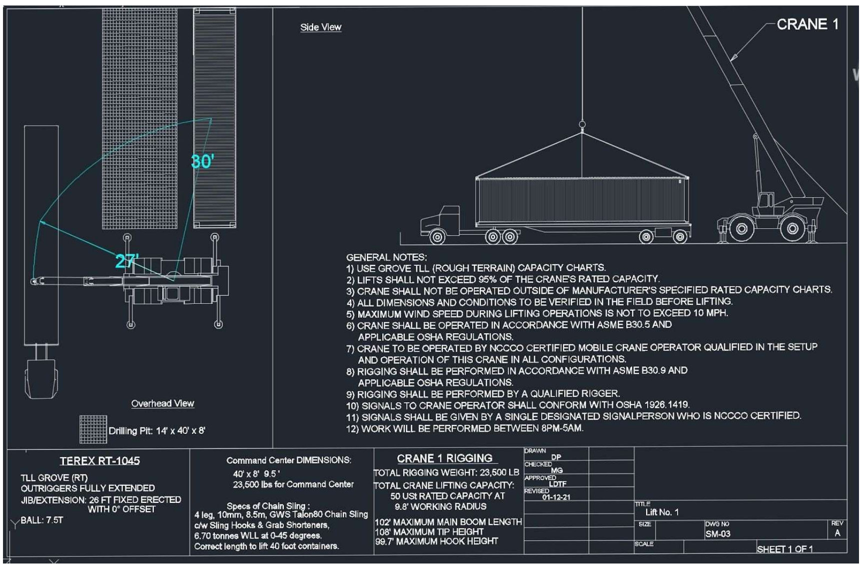


Figure 3: Terex RT 1045 Crane Specifications

Barbco Tribor Dimensions

The Barbco Tribor 36 has height, width, and length of 51.75”x48”x120”.

Pipe Dimensions

The Barbco Tribor 36 can push 36"x.375" pipe is 142.81 lbs. We may rescale the pipe diameter accordingly.

TM Mass by Subsystem

Terex RT 1045 Crane Mass

The Terex RT 1045 has a rated capacity of 44 tons. The Terex RT 1045 has a mass of 31 tons.

Barbco Tribor Mass

The Barbco Tribor 36 weighs 33,950 lbs.

Pipe Mass

The 36”x.375” pipe is 142.81 lbs. Each 20’ segment weighs 2,856.2 lbs. The total 100’ of pipe weighs 14,281 lbs.

TM Power Source and Consumption

Terex RT 1045 Power Source & Consumption

The Terex crane is powered by a QSB6.7 Diesel Engine. The rated power supply is 230-550 horsepower.

Barbo Tribor Power Source & Consumption

The Barbco Tribor 36 is powered by a 300 horsepower diesel engine.

TM Plasma Exfoliation Head Design and Function

The Plasma Exfoliation Head operates on the same principles as many other plasma cutting technologies. To cut material, rock in this case, a plasma discharge is initiated between the material and the plasma head, and the plasma affects thermal energy transfer to the material in its path. The plasma's high temperature helps to restrict the heat-affected zone close to the material being melted and disintegrated—very little material beyond the cut kerf is heated appreciably, even in materials with high thermal conductivity.

The extant plasma technologies differ in the means of arc generation and transfer to target substrates. Transferred-arc plasma cutters treat the material as part of an

electrical circuit, thus requiring the target to be electrically conductive.
Non-transferred arc cutters generate a plasma discharge, which is generally blown towards the target by the working gas supply.

In the current Plasma Exfoliation And Cutting Head (PEACH), we utilize a split central electrode to serve double-duty. Initially, the conductors are treated as electrically separate for the generation of an atmospheric nitrogen laser discharge. This laser discharge ionizes the air between the electrodes and the target substrate. After this short series of laser discharges (up to 2 seconds), the electrodes are then treated electrically as a single conductor supplying the plasma heating current. Please see Figure 2 above for a schematic overview of PEACH.

In other designs, the plasma is heated with microwaves generated by a magnetron. A pulsed power supply is used to simultaneously initiate and heat the plasma discharge with a fast rise-time, high voltage, and high power electrical pulses (typically repeated at tens to thousands of hertz).

In all cases, the goal is to separate the tool head from the heat source—heating of the substrate is partly Ohmic heating from the supply current being shunted to ground by the substrate. However, the bulk of the heating comes from the recombination of plasma species at the substrate-plasma interface, resulting in a very high thermal gradient. The plasma reaches thousands of degrees on one side of the interface and the substrate mostly resting at ambient temperature on the other side of the interface. The immense, rapid-onset stresses induced by this heating tend to remove more material than could be directly vaporized or melted with the available power if supplied in a more isostatic manner.

The key to the effectiveness of plasma cutting, or any of our cutting methods employed in boring, is to limit the amount of energy deposited but also to limit the amount of material into which that energy is deposited. As with the auger boring machine and pipe rammer, only the material that actually intersects with the pipe wall path itself is imparted with any significant portion of the machine’s energy, while the bulk material within that boundary is simply augered out in bulk, at much lower energy.

By utilizing very high temperature plasma, in a very narrow kerf, thermal losses are minimized so that the bulk of our power supply energy gets deposited in material that needs to be removed. Very little creeps uselessly into the surrounding substrate during the cutting process.

The laser cavity power supply consists of a bespoke digital controller driving a modified commercial inverter power supply. The mains voltage is rectified and pulsed at approximately 20khz, feeding a small flyback mode transformer with 110 or 220V square waves which are then stepped up to 6-10kV (no load). Due to the power supply's internal capacitance, no additional capacitive storage is required, and this power supply can directly drive the atmospheric laser cavity. In practice, as we move from prototype to commercial unit, a triggered spark gap will be employed for faster, more reliable switching of the laser supply.

A second inverter power supply similarly rectifies and pulses mains current, but in this case the voltage is stepped down from 120 or 240 to approximately 90V. Power control is effected through PWM control of the MOSFET switch feeding the step-down transformer, which provides power control, rather than discrete current or voltage control. In practice, PEACH should be run as close to maximum power as is practical, with as fast a traverse speed as possible, while the PWM controller serves as a power-limiting feature mostly for thermal protection. In the production unit, multiple temperature sensors will provide feedback to the controller, allowing the controller to prevent thermal damage to the plasma head itself. Low voltage sense lines will also be provided to check for short circuit conditions (head obstructions, groundwater, etc) and at least one pressure transducer to ensure adequate airflow to the plasma head before and during operation.

At these power levels a single cutting head will cut a 20mm deep and 15mm wide kerf in the bore face in under 2 minutes. It is expected that the Barbco air hammer will be able to advance the pipe through the expected Caliche lenses, with the plasma-cut kerf reducing the force required to split the material.

The plasma bit technology is described in greater detail in the below patents.

https://patents.google.com/patent/US3467206A/en
https://patents.justia.com/assignee/ga-drilling-a-s

TM State Diagram

The broader boring phases—Site Prep and Setup; Advancing the Bore String; Retraction/Loading; Cyclic Advancement; Shutdown and Surface Preparation—are explained in greater detail below. These broader boring phases may be used to infer a formal state diagram.

Site Prep and Setup

As the system is composed of several distinct elements supplied by third party contractors and manufacturers, setup and prep must largely abide by the requirements for each individual machine's established procedures. The boring machine itself, as manufactured by Barbco, requires a pit approximately 3 feet deeper than the tunnel to be bored, and wide enough to accommodate the machine itself—in our case we project a finished entry pit of at least 20' by 60', with the major axis aligned to the bore, to accommodate the machine, and the auger, pipe, driveshaft extensions, and several sets of replacement parts. This is done so that the Terex RT 1045 crane can be idled and/or powered off during the boring operation. Initially, these components will be delivered to the dig site with the expected assortment of heavy equipment, and then rigged and lowered into the entry pit with the overhead Terex crane. Once all equipment has reached its final location, crew members can enter the pit, the TM is fueled, and initial checks of normal operating parameters are made before loading of the first pipe section, steering head, and connection of the auger.

Advancing the Bore String

The pipe, now loaded in the boring machine with the steering head attached to the leading edge and auger head and drive shaft inside, is advanced to, then into, the bore face, using the hydraulic rams located at the rear of the TM. The entire TM, and pipe assembly, is pushed forward by these rams. When additional propulsive force is required (due to the variable aggregate composition of soil strata), the air hammer can be engaged to provide percussive driving force. At the same time, the hydraulic rams continue to advance the bore string, much like driving piles. This changeover in propulsion modes and control of the auger speed are affected by a human operator with a control panel, located on the surface. As boring resistance decreases, the air hammer can be deactivated and the steady-state hydraulic drive resumes as the primary motive force.

Retraction/Loading

As the bore liner advances and the TM nears the bore face, additional pipe segments must be loaded into the string to enable further advancement. At this point, the TM is idled, and then reversed under minimal hydraulic pressure to return to its start position, and idled again while a new auger drive shaft segment, and liner pipe section, are loaded in front of the TM. These operations are performed remotely, with the pipe assembly being lifted by the Terex crane from above and the idling and reversal of the TM controlled by the remote operator. Once the next segment is in place, the pipes are seam-welded end-to-end. This may require personnel in the pit, in which case the machine can be completely powered down until the welder's exit the pit and restarted to advance the bore string again.

Cyclic Advancement

The TM, and site in general, cycle between Advancement and Retraction/Idle Loading states with each 20-foot section of the pipe until the string breaches the inbound wall of the target receiving pit.

The Terex RT 1045 crane will facilitate the 20’ section of pipe's loading cycle onto the Barbco conveyor system. The crane will be operated by the certified crane operators, mechanics, and rigging experts on the team. The 20’ sections of 36”x .375” pipe will be delivered from Bakersfield by Kelly Pipe. The Kelly Pipe truck will drive underneath our Terex crane system and be offloaded into our fabrication container area and zone. Welding operations will be coordinated at the fabrication container. We may consider Path Robotics for automated welding as resources, time, and coordination allow.

Shutdown and Surface Preparation

Once the liner is advanced through the receiving pit's inbound wall, either the personnel can remove the auger by pulling it through to the receiving pit, or the TM can retract the entire auger string back into the entry pit in 20-foot increments. This effectively reverses the procedure used for advancing the bore string, but at much lower power levels in a no-load condition. Once the bore is cleared of debris, the TM is used to push the driving surface segments into place. The Tunneling Machine only needs to be retracted to its start position and powered down to enable safe entry of the proposed drive test vehicle.

TM Navigation Mechanism

We will utilize a Leica LDT-05 to enable theodolite line of sight for guided boring. Theodolite guidance systems are fairly common in the field. The combination of the Leica LDT-05 with the Barbco Tribor 36 will require manual adjustments. The theodolite provides corrections which can be applied to the steering system on the Tribor machine to maintain bore track and grade. These measurements are made continually as the bore string is advanced, both for accuracy and safety of the bore trajectory. In a piloted system, the pilot bore is completed with a theodolite, while the main bore follows the pilot back to the receiving pit. However, in a pilotless bore, the theodolite sights down the bore string from the sending pit and provides live guidance for the liner advancement via optical reticle.

Figure 4: Leica LDT-05 Theodolite

TM Propulsion Mechanism

Our team will start with initial site preparation and set-up. The pit is excavated to approximately 14’ by 40’ and a depth of 8 feet. Similar dimensions are excavated for the receiving pit. The floor of the pits are leveled with the aid of a laser. Laser-level ensures a flat datum surface for subsequent measurements and alignment of the boring machine. A piling is driven near the rear of the entrance pit to anchor the machine. The piling can accommodate the forces exerted on the bore string and Tribor. A half inch steel plate is welded to the piling. The Tribor 36 exerts over 500,000 lb of push on the bore string. This maximum force is expected to be sufficient for driving the bore string through various soil conditions. The force required to advance the string increases incrementally through the course of the boring operation. Note that our 20 foot sections of 36” OD pipe weight approximately 2856.2 lbs. Next, the boring machine is placed via crane onto the leveled pit floor. The track sections are likewise loaded via crane. Both the boring machine and track sections are checked for alignment prior to loading with the first tunnel liner section, steering head, auger, and first driveshaft section for the auger. Self-test and walkaround inspection is followed by power-up to begin advancing the tunnel. Eventually, as the first 20-foot section of pipe is advanced into the bore, a second section is prepped, and the drive is reversed and idled. At this point, the next section of pipe and auger drive shaft is loaded into the bore string, and the pipe seam welded end-to-end to the previous section. These welds, as well as the welds on the piling back-stop, will comply with (AWS) American Welding Society D1.1 Structural Steel Code Book. Our structural welds will be completed with Lincoln 7018 rods. The site then alternates between these two states—advancing under power and retraction/loading while idled. These two alternating states repeat in roughly 15-foot stages until the 100-foot bore is complete. Once the bore and liner reach the target receiving pit, the auger is retracted and the tunnel is swept of any remaining debris.

Propulsion for the Barbco Tribor system is delivered via two separate electric over hydraulic circuits. The primary is by means of rack and pinion design. The secondary is through two cylinders on centerline with the rotary. The rate of penetration is subject to ground formation in terms of hardness, abrasiveness, water content, etc. The hole diameter and the weight of the equipment in the hole involves the friction on the items in the hole during the drilling process. The rate of penetration is subject to how fast cuttings are removed.

Barbco has many patents breaking down its tech for horizontal drilling and boring of tunnels. Please see https://patents.justia.com/assignee/barbco-inc for relevant patent information.

Figure 5: Barbco Tribor

Tunnel Lining Installation Method

Traditionally, TM-based systems excavate a tunnel and then line it with either pumped concrete or pre-cast concrete panels. An auger-equipped pipe jacking system allows virtually all the high-energy machinery to remain stationary, and on the surface (in our specific embodiment, in an easily accessible sending pit). This ensures that the bore string will not need to be withdrawn in the case of most system errors or failures.

The benefits of utilizing a steel bore liner are not limited to convenience. The speed advantage comes directly from the limited cross-section of strata with which the bore string directly interacts. Energy density is maximized by limiting the total energy required to advance the bore string to pushing the liner solely. Therefore, the power density is maximized. With the swarf excavated by an internal auger under comparatively low power, long bores can be completed by a single machine, or broken up into segments with minimal surface-access excavation required. With multiple bores being completed simultaneously, long tunnel strings can rapidly be constructed with minimal surface impact—with proper planning, the entry and exit pits can be positioned to coincide with expected surface access.

Steel, being ductile, is much more resistant to catastrophic failure under seismic loads than concrete. Crack propagation, assuming proper temper and alloy composition, is less of a concern with steel than traditional construction materials like concrete. While concrete can support several thousand pounds per square inch of compressive and shear forces, even low alloy carbon steels can routinely support significant tensile loads in excess of 70,000 psi. Steel’s electrical conductivity and magnetic permeability permit relatively easy fault monitoring and nondestructive testing.

Further, as concrete relies on carbonates and hydration reactions to form solid structures, and is only partly recyclable or reusable, largely as an aggregate filler. On the other hand, a steel tunnel presents a unique opportunity (depending on the steel mill's power source) to produce fully recycled, fully recyclable, and carbon-neutral to carbon-negative structures. Since carbon is the chief alloying element in most steels, the material itself serves as a carbon sink during manufacture.

Lining Storage and Delivery System

Our bore liner consists of 20’ sections of pipe, which are pushed in as the primary component of the boring string.

Soil Removal System

Soil Settlement/Heave Calculations and Estimations

This section is not directly applicable—The liner advances with bore face, obviating the need for mud or pressure balance concerns, as the earth pressure is supported before material is removed from the bore.

Excavation and Earth Pressure Balance

As above, Earth Pressure Balance is achieved via direct action of the advancing liner, with no unsupported, unlined bore extending ahead of the advancing liner.

Soil Transport System

The internal auger transports soil from the bore face back to the machine, where it is discharged via chute to the side of the TM.

Predicted TM Thermal Profile

The Barbco Tribor 36 has been well-vetted by industry. We are working with Barbco to obtain thermal profiles for the Tribor.

Predicted TM Trajectory

The tunneling trajectory will be heavily influenced by the strata. The rate of penetration depends heavily on the strata type. Please see Figure 6 for the Ground Conditions Chart corresponding to the Barbco Tribor.

GROUND CONDITIONS CHART

	Wet Runny Sand	Wet Stable Sand	Dry Sand	Dry Clay	Wet Clay	Small Gravel
Auger Speed	Slow	Fast	Slow	Optional	Optional	Optional
Rate Of Penetration	Fast	Fast	Slow	Optional	Optional	Optional
Cutting Head	BBC-25 Sand	BBC-25	BBC-25	BBC-25	BBC-25	BBC-35
Wing Cutters	No	No	No	Yes	Optional	Yes
Head Position	Inside	Inside	Inside	Flush	Flush	Outside
Bentonite	Yes	Yes	Yes	Yes	Yes	Yes
Water Inside	No	No	No	Yes	Yes	Yes
Band	Yes	Yes	Yes	Yes	Yes	Yes
Bore Continuous	Yes	Yes	Yes	Optional	Optional	Optional
Clean Casing	Pack	Pack	Pack	Clean	Clean	Clean
Pit Base	Concrete	Stone	Optional	Optional	Stone	Optional
Backstop	Concrete	Concrete	Concrete	Steel	Steel	Steel

	Hard Pan	Large Gravel	Small Boulders	Soft Solid Rock	Hard Solid Rock	Land or Railroad Fill
Auger Speed	Slow	Slow	Slow	Slow	Slow	Cautious
Rate Of Penetration	Medium	Slow	Slow	Slow	Slow	Slow
Cutting Head	BBC-75 BBC-CT2	BBC-35	BBC-75	BBC-35	BBC-45 BBC-50	BBC-35
Wing Cutters	Yes	Yes	Yes	Yes	Yes / No	Yes
Head Position	Outside	Outside	Outside	Outside	Outside	Outside
Bentonite	No	No	No	No	No	No
Water Inside	Yes	No	No	No	Yes	Yes
Band	Yes	Yes	Yes	Yes	Yes	Yes
Bore Continuous	Optional	Optional	Optional	Optional	Optional	Optional
Clean Casing	Clean	Clean	Clean	Clean	Clean	Clean
Pit Base	Optional	Optional	Optional	Optional	Concrete	Concrete
Backstop	Steel	Steel	Steel	Concrete	Concrete / Steel	Concrete

Figure 6: Ground Conditions Chart for Barbco Tribor 36

Anticipated boring speeds will be on the order of feet per minute as industry experience suggests. Based on the supplied geological data, we can expect somewhat faster boring speeds at depths greater than 6 feet, and especially below 8 feet: soil moisture content seems to rise significantly with depth, and deeper strata do not appear to contain Caliche lenses, which can slow the boring process considerably depending on the hardness. We do not expect significant deviation from a straight-path, but with a steering head we can accommodate upwards of 6-7 degrees off-axis per 20’ pipe section as conditions demand.

Predicted Vibration Environments

We do not expect significant down-bore vibration under normal boring conditions, but operation of the hammer for hard-strata environments presents the potential for relatively large impulsive loads transmitted along the entire bore string. We will iterate with Barbco engineers to better understand vibrational performance of the Tribor when encountering hard strata.

TM Launch and Receiving Structures Design Cases

As our Tunneling Machine does not itself move down the bore, the receiving pit only serves to expose the downbore end of the finished tunnel to surface access. Retraction of the auger involves simply reversing the hydraulic ram actuation and removing 20 foot sections of auger shaft at a time.

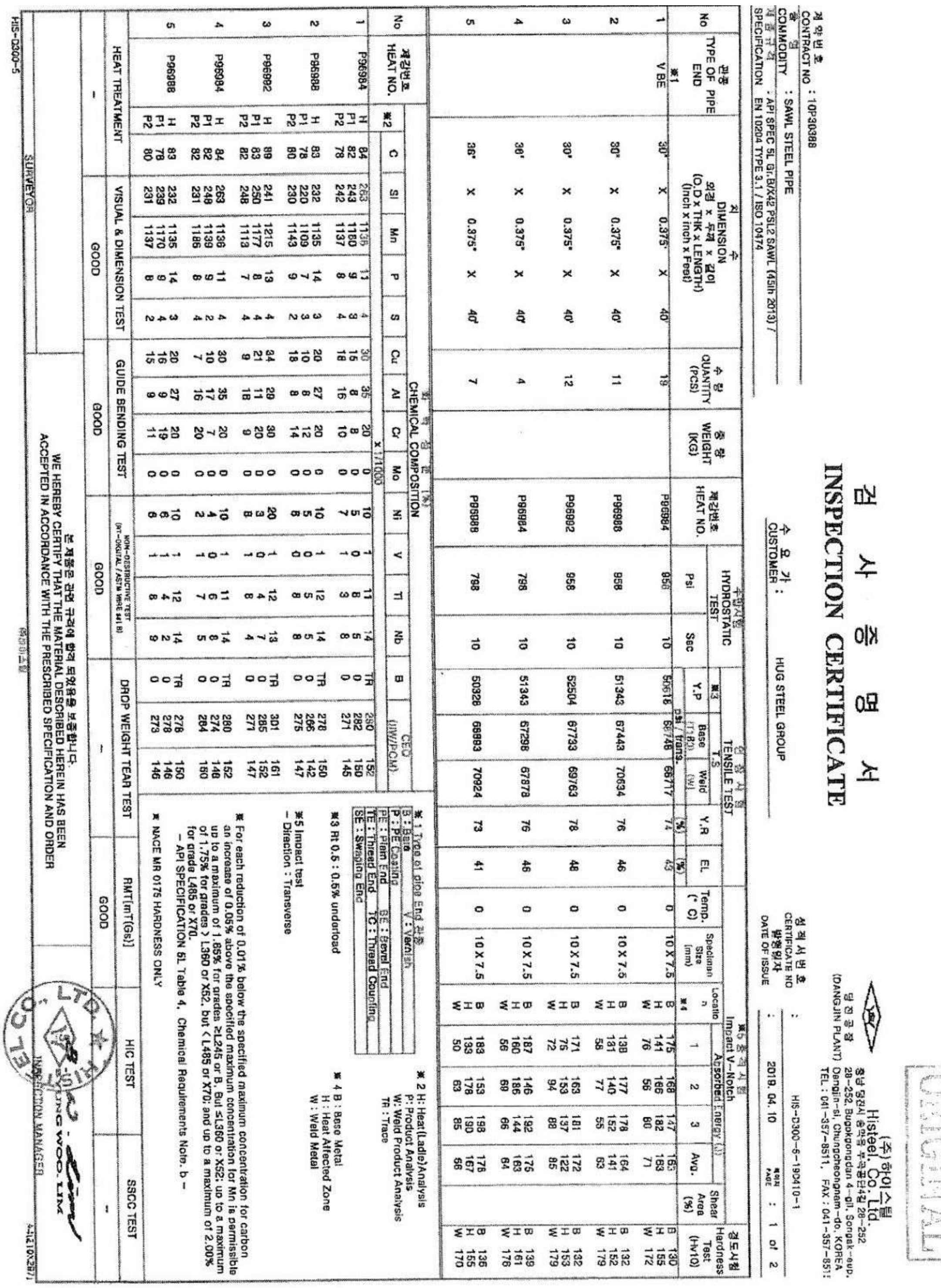
Initial Launch Loads

The Tunneling Machine experiences near-zero loads as the bore is initiated. Only a moderate force is required to advance the pipe to and into the bore face. Most of the loads experienced at this point are solely due to the inertial mass of the pipe and nominal friction on the support system. The soil composition dictates frictional loads as the bore advances. Frictional losses necesitate increases in propulsive force, up to a maximum of approximately 500,000 lb of pushing force available from the hydraulic rams. Additional percussive force is made available from the internal hammer as used for advancing through harder strata. Torque loads are also reacted by the machine base, as applied to the auger head, up to a maximum of 60,056 ft-lb of torque.

Receiving Loads TM Structural Design Cases

Soil and Overburden Loads

Hydrostatic pressure tests for 36”x0.375” pipe at 40’ section length demonstrate structural integrity up to 798 psi at 10 sec. This is consistent with the strength requirements and test ratings for pipe in oil and gas well conditions going to significantly greater depths than our proposed tunnel bore. Please see Figure 7 below for Inspection Certificate details.



ORIGINAL

(주)하이스틸
Histeel. Co. Ltd.
충남 당진시 송악읍 부곡공단4길 28-252
당진공장 (DANGJIN PLANT) 28-252, Bugokgongdan 4-gil, Songak-eup, Dangjin-si, Chungcheongnam-do, KOREA
TEL : 041-357-8511, FAX : 041-357-8515

검 사 증 명 서
INSPECTION CERTIFICATE

계약번호 CONTRACT NO : 10P30388
품명 COMMODITY : SAWL STEEL PIPE
제품규격 SPECIFICATION : API SPEC 5L Gr.B/X42 PSL2 SAWL (45th 2013) / EN 10204 TYPE 3.1 / ISO 10474

수요가 CUSTOMER : HUG STEEL GROUP

성적서번호 CERTIFICATE NO : HIS-D300-6-190410-1
발행일자 DATE OF ISSUE : 2019. 04. 10 페이지 PAGE : 1 of 2

No	관종 TYPE OF PIPE END ※1	치수 DIMENSION 외경 x 두께 x 길이 (O.D x THK x LENGTH) (Inch x inch x Feet)	수량 QUANTITY (PCS)	중량 WEIGHT (KG)	제강번호 HEAT NO.	수압시험 HYDROSTATIC TEST Psi	Sec	인장시험 TENSILE TEST ※3 Y.P	T.S Base (T18D) psi / trans.	T.S Weld (W)	Y.R (%)	EL (%)	※5 충격시험 Impact V-Notch Temp. (°C)	Specimen Size (mm)	Location ※4	Absorbed Energy (J) 1	2	3	Avg.	Shear Area (%)	경도시험 Hardness Test (Hv10)
1	V BE	30" x 0.375" x 40'	19		P96984	958	10	50616	66748	66717	74	43	0	10 X 7.5	B H W	175 141 76	168 166 56	147 182 80	163 163 71		B 130 H 155 W 172
2		30" x 0.375" x 40'	11		P96988	958	10	51343	67443	70634	76	46	0	10 X 7.5	B H W	138 131 58	177 140 77	178 152 55	164 141 63		B 132 H 152 W 179
3		30" x 0.375" x 40'	12		P96992	958	10	52504	67733	69763	78	48	0	10 X 7.5	B H W	171 75 72	163 153 94	181 137 88	172 122 85		B 132 H 153 W 179
4		36" x 0.375" x 40'	4		P96984	798	10	51343	67298	67878	76	46	0	10 X 7.5	B H W	187 160 56	146 186 69	192 144 66	175 163 64		B 139 H 161 W 176
5		36" x 0.375" x 40'	7		P96988	798	10	50326	66893	70924	73	41	0	10 X 7.5	B H W	183 133 50	153 178 63	198 190 85	178 167 66		B 136 H 155 W 170

화학성분 (%) CHEMICAL COMPOSITION

No	제강번호 HEAT NO.	※2	C	Si	Mn	P	S	Cu	Al	Cr	Mo	Ni	V	Ti	Nb	B	CEQ (IIW)	CEQ (PCM)
										x 1/1000								
1	P96984	H	84	263	1136	11	4	30	35	20	0	10	1	11	14	TR	280	152
		P1	82	243	1160	9	3	15	8	8	0	5	0	8	5	0	282	150
		P2	78	242	1137	8	4	18	16	10	0	7	1	3	8	0	271	145
2	P96988	H	83	232	1135	14	3	20	27	20	0	10	1	12	14	TR	278	150
		P1	78	220	1109	7	3	10	8	12	0	5	0	5	5	0	266	142
		P2	80	230	1143	9	2	18	8	14	0	8	0	8	8	0	275	147
3	P96992	H	89	241	1215	13	4	34	29	30	0	20	1	12	13	TR	301	161
		P1	83	250	1177	8	4	21	11	20	0	3	0	4	7	0	285	152
		P2	82	248	1113	7	4	9	18	9	0	8	1	8	4	0	271	147
4	P96984	H	84	263	1136	11	4	30	35	20	0	10	1	11	14	TR	280	152
		P1	82	248	1139	9	2	10	17	7	0	4	0	6	8	0	274	148
		P2	82	231	1186	8	4	7	16	20	0	2	1	7	5	0	284	150
5	P96988	H	83	232	1135	14	3	20	27	20	0	10	1	12	14	TR	278	150
		P1	78	239	1170	9	4	16	9	19	0	6	1	4	2	0	278	148
		P2	80	231	1137	8	2	15	9	11	0	6	1	8	9	0	273	146

※1 Type of pipe End 관종
B : Bare V : Varnish
P : PE Coating
PE : Plain End BE : Bevel End
TE : Thread End TC : Thread Coupling
SE : Swaging End

※2 H: Heat(Ladle)Analysis
P: Product Analysis
W: Weld Product Analysis
TR : Trace

※3 Rt 0.5 : 0.5% underload

※4 B : Base Metal
H : Heat Affected Zone
W : Weld Metal

※5 Impact test
– Direction : Transverse

※ For each reduction of 0.01% below the specified maximum concentration for carbon an increase of 0.05% above the specified maximum concentration for Mn is permissible up to a maximum of 1.65% for grades ≥L245 or B, But ≤L360 or X52; up to a maximum of 1.75% for grades > L360 or X52, but < L485 or X70; and up to a maximum of 2.00% for grade L485 or X70.
– API SPECIFICATION 5L Table 4, Chemical Requirements Note. b –

※ NACE MR 0175 HARDNESS ONLY

HEAT TREATMENT	VISUAL & DIMENSION TEST	GUIDE BENDING TEST	NON-DESTRUCTIVE TEST (RT–DIGITAL / ASTM WIRE set B)	DROP WEIGHT TEAR TEST	RMT[mT(Gs)]	HIC TEST	SSCC TEST
-	GOOD	GOOD	GOOD	-	GOOD		-

본 제품은 관련 규격에 합격 되었음을 보증합니다.
WE HEREBY CERTIFY THAT THE MATERIAL DESCRIBED HEREIN HAS BEEN ACCEPTED IN ACCORDANCE WITH THE PRESCRIBED SPECIFICATION AND ORDER

SURVEYOR

HISTEEL CO., LTD.
YUNG WOO. LIM
INSPECTION MANAGER

HIS-D300-5
㈜하이스틸
A4(210X297)

Figure 7: Inspection Chart for SAWL steel pipe

Maximum Propulsion Loads

As above, the TM can provide up to 500,000 lb of pushing force. In the case of hard, impermeable strata, the machine would stall with 500,000 lb of resistance. For a 36" diameter pipe, with a ⅜" wall thickness, approximately 167.7 square inches of pipe wall cross sectional area, results in a maximum applied pressure of 2,981 psi applied to the bore face under hydraulic ram propulsion alone. Based on industry experts' consultation, this is approximately twice the typical compressive strength of consolidated sandstone and exceeds typical unconsolidated strata compressive strengths.

Straight Alignment

Please see TM Trajectory section for details.

Minimum Curvature

Please see TM Trajectory section for details.

Vertically

Please see TM Trajectory section for details.

Horizontally

Please see TM Trajectory section for details.

Subsystems and Full TM Functional Test Program

Functional tests are currently planned for the PEACH device. We will start with bench testing on expected strata types, which includes Caliche. Upon completion of bench testing, integration and testing with the Barbco Tribor will be conducted in cooperation with Barbco at their test facility. The first integration test will proceed under no-load conditions. The second integration test will proceed during live boring operations. If all tests are passed, we can consider deploying the Barbco Tribor with plasma head extensions to the competition.

Functional tests for the Barbco Tribor have been developed by Barbco. Quality control checklist travel with the unit as the Tribor makes its way through the complete manufacturing process to ensure each subsystem is operational as designed. Pressures are adjusted and monitored for each subsystem after first fire. The Tribor is run under static loads up to the maximum setting per subsystem for some length of time. The unit is then reviewed for wear, leaks or additional adjustments if needed. Prototypes are taken to a test yard for live in-ground testing.

TM Production Schedule

We have on-site development meetings planned with Barbco to develop and integrate the PEACH unit and redesign and modify some extant subsystems, including their steering head assembly. These meetings and engineering cycles are planned to begin over the next few weeks, with certain accommodations being made on both sides with regards to the ongoing pandemic conditions.

TM Cost Breakdown and Funding Plan

Our team anticipates a total budget of $157,200 including a 20% contingency. Due to the restrictions on bringing our own heavy equipment, we have excluded such items from our budget. However, we have had conversations with some companies for rental/purchase.

Item	Cost estimate	Sourced by team?	Cost to team	Procurement
EQUIPMENT				
Crane, rigging, peripherals	$160,000	No	$0	
Welding	$15,000	Yes	$15,000	To be rented
Pile driving	$90,000	No	$0	Have Barbco contact
Plasma drill	$15,000	Yes	$15,000	To be purchased
Air compressor	$4,500	No	$0	
Forklift	$9,500	No	$0	
MATERIALS				
Steel pipe	$24,000	Yes	$24,000	Seeking sponsorship
Command center	$16,000	Yes	$16,000	
Concrete	$25,000	Yes	$25,000	Seeking sponsorship
TRAINING				

Welding certifications	$8,000	Yes	$8,000	To be purchased
Crane and rigging certifications	$6,000	Yes	$6,000	To be purchased
MISC				
Software licenses	$2,000	Yes	$2,000	Seeking sponsorship
Shop costs	$20,000	Yes	$20,000	Seeking sponsorship
Sum without sponsorship			$131,000	
Total **(with 20% contingency)**			**$157,200**	

We will raise these funds through a combination of school grants, corporate sponsorship and in-kind sponsorship. We anticipate funding 25% of our costs through various grants from MIT, primarily from the Edgerton Center. We seek to defray 15-25% of our costs through in-kind sponsorship and the remainder through corporate partnerships with previous and new sponsors.

Electronics System Overview

Our electronics system comprises a number of two major subsystems: the turnkey Barbco boring machine and the Plasma Exfoliation And Cutting Head (PEACH). The Boring Auxiliary Control Unit (BACU), Power System, and Communication System discussed below specifically pertain to the BACU. The base station comprises a computer station running both remote control, telemetry collection software, and sensor suites to help augment the turneky Barbco control unit.

Sensor List and Location Map

Inertial Measurement Sensor

Figure 8: VectorNav VN-100 IMU

The IMU we will be using on the tunnel boring machine is the VectorNav VN-100 and will be interfaced with the VCU over RS232. It has a ±16G accelerometer range and attitude (angular) accuracy of up to 0.5°-rms. The IMU sensors would be placed primarily in areas of the tunnel boring machine with at least 1 degree of freedom to both confirm physical actuation of components and to give a rough estimate of their location. Furthermore, it would be used to help determine the precise location of the cutter head(plasma cutter) itself to give an accurate estimation of the tunnel boring process.

High Temperature Temperature Probes

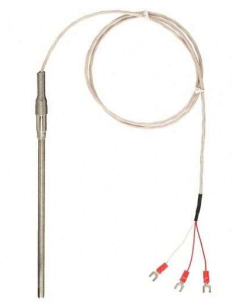


Figure 9: High Temperature sensor

High temperature areas such as the plasma cutter head require high temperature surface probes which can be mounted to take temperature readings of the housing assembly and / or the air temperature of the cooling gas circulated throughout the system. Each probe can be tailored to a suitable temperature range and adjusted based on their requirements. This sensor produces an analog reading and would be passed into the myRIO.

Airflow Sensors

Figure 10: Honeywell HAFUHT0300L4AXT airflow sensor

The Honeywell HAFUHT0300L4AXT airflow sensor is rated for 0 ~ 300 SLPM and contains female fittings of 0.375". These sensors would allow us to ensure that the plasma cutting head has proper cooling gas circulation. Multiple sensors would be placed along the length of the coolant piping / working gas plumbing to ensure that there are no leaks or blockages in the system throughout the telescoping process of the boring machine. This sensor uses I2C to interface with the myRIO.

<u>Electronics Control Unit</u>

The main electronics system of the boring machine centers around the combined Boring Auxiliary Control Unit (BACU) and the Barbco control panel, which in combination, is responsible for managing all task executions and data collections pertaining to the operations of the boring machine. Since the Barbco control panel is a turnkey solution that allows for robust operation of the drilling operations, we will not focus on it within this discussion. Rather, we instead focus on the custom solutions that we will need to build out. At the heart of the BACU is myRIO, an embedded platform sponsored by National Instruments that has a Xilinx Zynq-7010 as its core processor, which is an SoC that combines an FPGA and a Dual-core ARM Cortex-A9 that runs on 667 MHz clock frequency. Additionally, the myRIO also has 512 MB of nonvolatile memory and 256 MB of DDR3 memory All mission critical electrical components, sensors on the plasma head, and associated equipment are connected to the myRIO over various common interfaces particularly I2C, RS232, digital, and analog I/O. For these components, we will only be using wired connections to the myRIO to ensure maximum connectivity given the challenges of running wireless systems in a subterranean environment.

Figure 11: myRio 1900

To monitor safety and progress on the tunneling process, the LabVIEW system will allow the team to conduct both health check functionality and device values from sensors. At this moment, we envision displaying the power levels of both HV and LV systems as well as whether they are actively on or off. A number of temperature measurements will also be displayed ranging from sensors monitoring the cutting head to those monitoring current and voltage. The GUI will also help the team to visualize the tunnel's 2D and 3D path throughout the competition, triangulating positional information. Likewise, GUI will allow the team to trip components ranging from high voltage and low voltage fuses while also allowing for variable control for systems that require active changes such as the rate / pressure of cooling gas.

Communication Overview

Due to the turnkey nature of the Barbco machine itself, most of the complexity involved in the drilling process has already been addressed in Barbco operational manuals and instructional material. We recognize that while the Barbco device itself is a self-contained unit, it requires synergistic compatibility with custom produced electronics to ensure smooth decision making. All sensors pertaining to custom electronics will be connected to our central myRIO device and then concurrently displayed onto our computer/fed directly into our base station terminal. In terms of software architecture of our data acquisition platform, we plan on using LabVIEW for our base station. Previous iterations of the MIT Hyperloop team have extensively used LabVIEW for their pod control systems and we are able to attain enough IO for our use case. With LabVIEW's Graphical User Interface (GUI) for each electronic component, we are able to better report / monitor sensor readings visually while also using LabVIEW's automated control structures to implement state machine kill switches if certain thresholds are breached. This unique combination of both automatic and manual fine-tuned control allows us to react in real time to the unique challenges of bridging the gap between the Barbco boring machine and our custom electronic packages. Both display panels would be viewed in the command module to allow for side-by-side analysis of sensor values and boring progress.

Power Consumption and Electrical Layout

Plasma Exfoliation Head Specifications

The plasma head consists of concentric tubes providing compressed air to cool the head, and working gas to generate plasma, with a centrally located pair of electrodes providing both the ionization potential and the current source for the plasma channel.

Compressed air will be supplied from the on site compressor at approximately 10 cubic feet per minute to provide cooling and working gas for the plasma tip. To ensure the plasma bit operates within acceptable temperature bounds, the cutting head will also contain a remotely monitored temperature sensor. Current methods to reduce heat fatigue of the head include increasing the rate of cooling gas or reducing the electrical current fed to the plasma bit. If temperatures exit safe operational boundaries, the plasma head can be shut down to prevent damage.

Operationally, the plasma head will consume up to 25kW (250A) at ~100V nominal supply, but the laser cavity requires approximately 20W (.002A) for 2 seconds at an electrode potential of approximately 10kV to initiate the plasma channel. To accommodate the variable nature of the plasma head, we envision two separate electrical systems; one which would be dedicated to ignition and the other which would be used for primary operation. The electrical subsystem assigned for ignition would primarily consist of step-up transformers to ensure that ignition voltage can be stored and discharged. This arc starting circuitry would produce an AC voltage of the target 10K VAC at 2 MHz which produces the spark inside of the plasma torch to create the plasma arc. For primary operation, the plasma power supply would convert single or three phase AC line voltage into a smooth, constant DC voltage. This DC voltage is responsible for maintaining the plasma arc throughout the cut and its variable nature would allow for control over cutting speed/depth.

Figure 12: Lincoln Electric Spirit II plasma series

For our purposes, the Lincoln Electric Spirit II Series plasma systems would provide a commercial solution that would align with our primary power requirements. The Spirit II 400 allows for both fully automated or manual process control which would allow us to fine-tune all stages of the power-up/down procedures. The Spirit II 400 also includes a custom pilot arc solution with a single unipolar high voltage impulse. This specific arc initiation helps eliminate RF noise and EMI, minimizing interference with nearby sensitive electronic equipment. With this Lincoln Electric unit, we are able to provide enough power for both systems. It is important to note that all power adjustments and the Lincoln Electric unit will be housed at surface level with all circuitry components pertaining to the step-up / step-down of voltage / current above ground. For input power, we will be using 8 AWG wiring to feed the Lincoln Electric unit and for routing power below ground, would be using shield 6 AWG. Note that all power and compressed air lines would be fed below to the plasma bit through the augur central shaft cavity of the boring machine .

In terms of startup and shutdown procedures of the plasma bit, we note that establishing the plasma channel may require multiple attempts and plan to address the complexities involved with remote ignition with refined testing. Likewise, with shutdown of the plasma head, we plan to conduct testing to find the correct power reduction curve to reduce thermal shock. This will help us ensure that the plasma head is able to preserve its structural integrity and prevent fracturing of the electrode or its neighboring components. Before use of the cutting head in the field, we will both conduct visual and acoustic emission testing of housing and jacket assembly to ensure that all components are within operational limits to prevent failure during operation. During operation of the plasma bit, the constant flow of clean cooling gas will also help to keep the cutter head free from debris, allowing for a continuous arc.

We estimate that a single plasma cutting head should be able to cut a 20mm deep and 15mm wide kerf in the bore face in under 2 minutes at nominal power levels. Further testing with an operational device will allow us to refine our target cutting speed.

Loading and Unloading Plan

Our team will perform 6 different types of critical lifts. The plans are detailed below and are in compliance with the National Commission for the Certification of Crane Operators (NCCCO) standards. Our qualified “site operations" team will perform each lift with the Terex RT-1045 crane and GWS Talon80 Chain Sling. Lift No. 1-3 are executed to unload the shipping container. The container is rigged and lifted with the Top Lift Sling Method, according to the Freight Container lifting standards of the Office of Scientific and Technical Information (OSTI). Lift No. 4 will unload the Barbco Tribor system into the pit. Lift No. 5 and Lift No. 6 will be performed 5 times each to unload the 36” pipe from the truck and then load 36” pipe onto the Barbco system. Lifts No. 1 and No. 3 will use the 4 leg, 10 mm, 8.5 m Grade 80 Container lifting chains for the two 40’ containers, with a capacity of 6.7 tonnes. Lift No. 2 will be lifted with the 4 leg, 10 mm, 4.5m Grade 80 Container lifting chains for the one 20’ container.

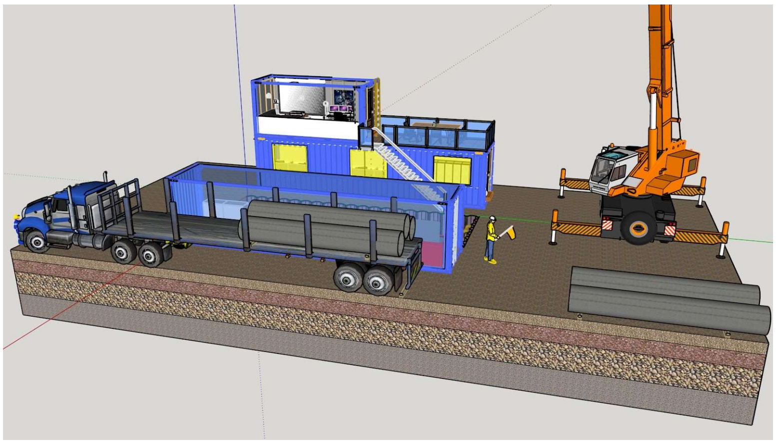


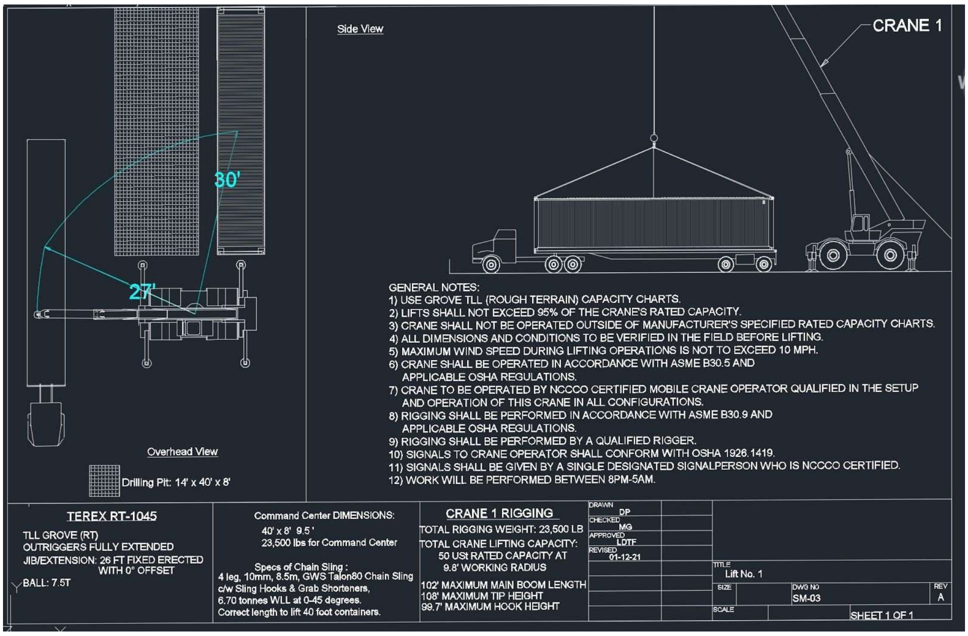
Figure 13: Drill Site Overview—Loading

When the truck from Kelly Pipe arrives at our team's drilling site, we must already have our site prepped with our system in place (Figure 13). In this case, the priority will be to have our loading zone established right next to the fabrication container. This loading zone will also serve as a metal prep and fabrication area, before it is loaded into the systems and welded to the pipe already pushed into the tunnel.

The five 36” x .375” x 20’ pipes will be laid on some dunnage, which will be set up after the truck pulls off. The contained dunnage area is necessary due to the size and weight of the pipes. Without a contained area for the heavy pipe, the pipe may unexpectedly roll out, potentially hurting site engineers.

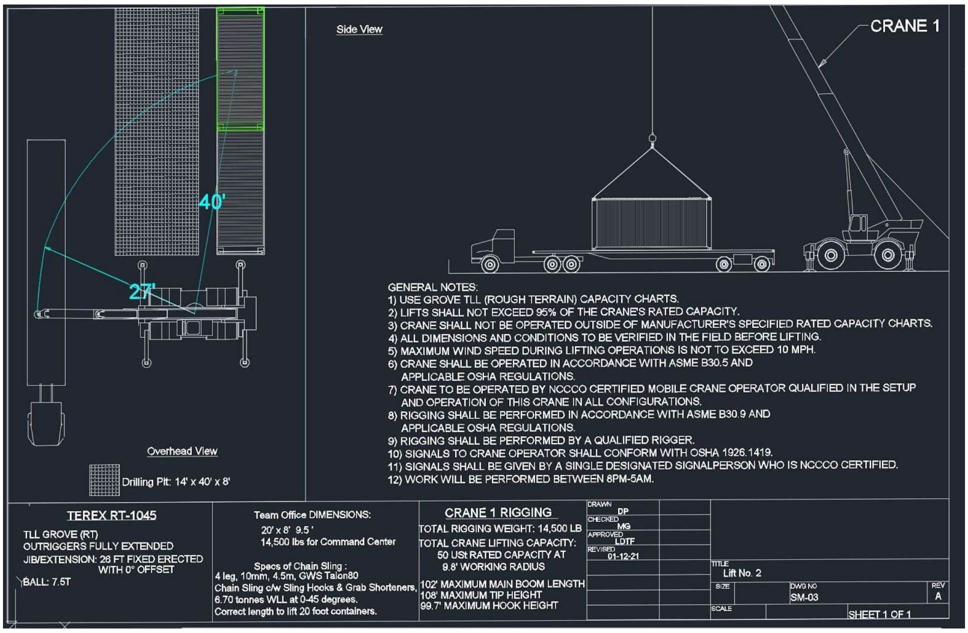
Lift No.1

40’ High Cube Shipping Container Command Center and PPE Storage



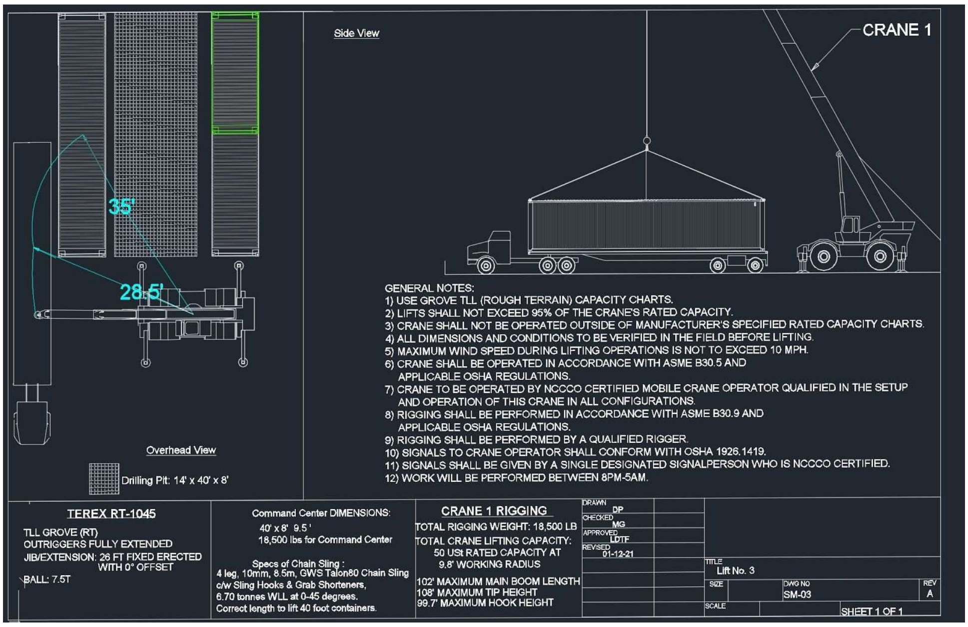
Lift No. 2

20’ High Cube Shipping Container Office



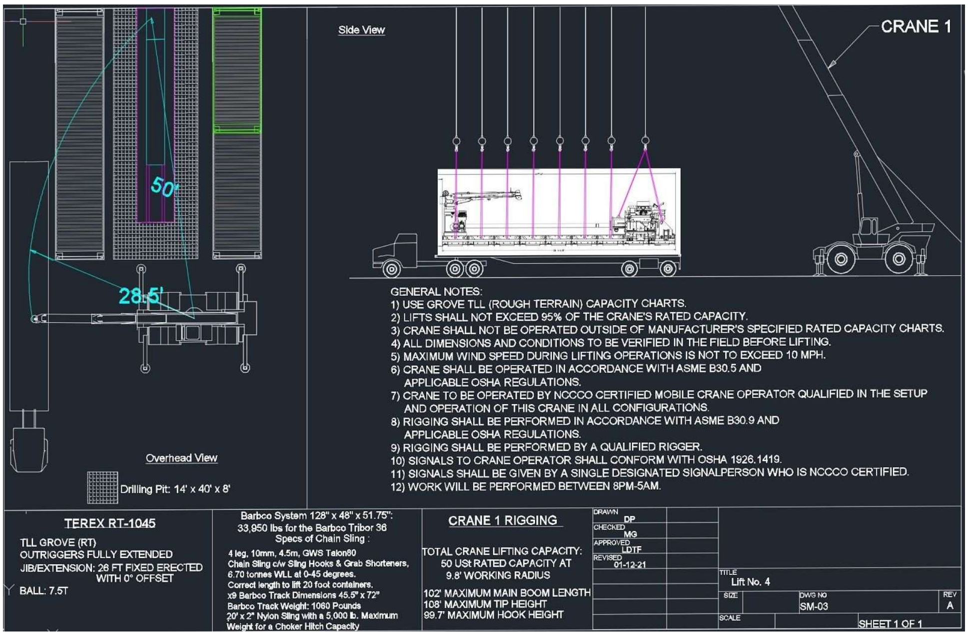
Lift No. 3

40’ High Cubed Fabrication High Cubed Shipping Container



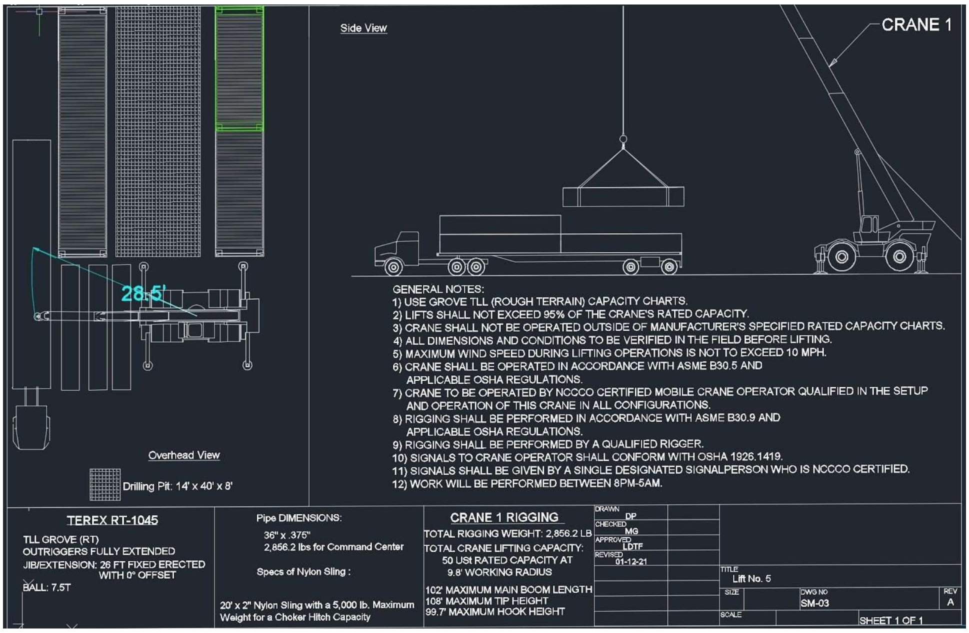
Lift No. 4

Unload Barbco Tribor System into pit



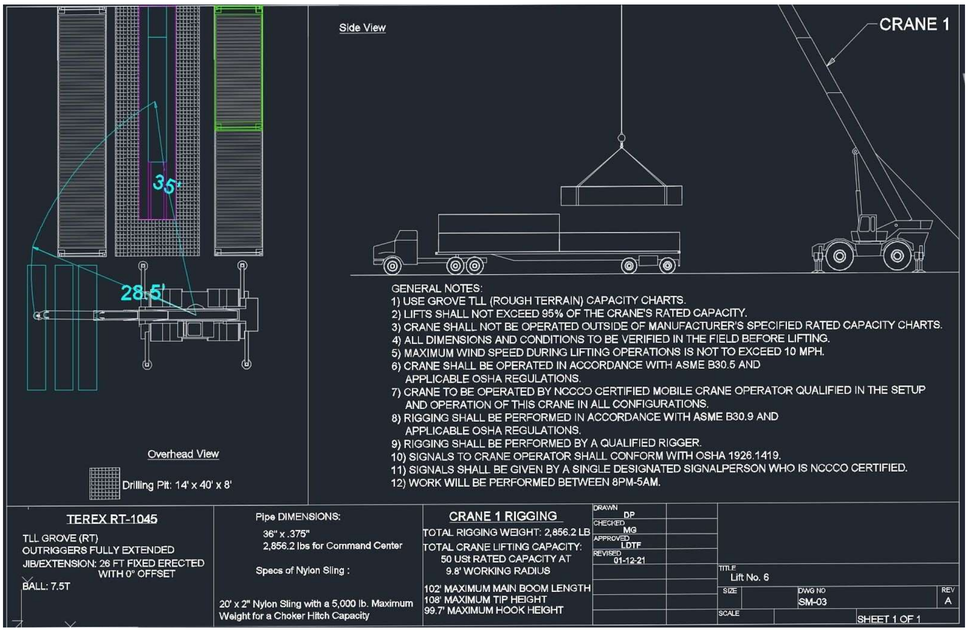
Lift No. 5

Unload x5 36" Kelly Pipe from the Truck, to the metal prep area



Lift No. 6

Load each 36" Pipe into the Barbco Tribor System



Stored Energy

We are using compressed air both as the ionizing gas for the plasma exfoliator and the cooling gas for the Plasma Exfoliator and the Cutting Head (PEACH). For our purposes, we will be using the Sunbelt 375 CFM 125 PSI diesel air compressor.

Figure 14: Sunbelt 375 CFM 125 PSI air compressor

The Sunbelt compressor has an automatic shutdown protection and built-in pressure regulator with the maximum pressure rating of 125 PSI. Based on the readings from the airflow sensors, the air compressor operator would adjust the pressure regulator to ensure a steady 10 cubic feet per minute of compressed air into the plasma cutter's cooling lines. We will not be using any external pressure vessels for the storage of the compressed air used for cooling.

We also note that depending on the competition requirements and whether our vendors will be able to help prep our tunnel piping, our welding system may require onsite usage of compressed oxygen/acetylene to bevel the piping. To reduce our risk profile, these tanks do not have to be stored on site and would be removed after the task is complete so that we do not have combustible gas near active spark sources after our initial pipe prepping process.

Hazardous Materials

Two hazards exist with loading and unloading pipe. The first hazard is that large metal pipes will be densely positioned by the fabrication container. The second hazard has to do with the lifting and loading the pipe properly onto the Barbco Tribor system directly. With each pipe weighing 2,856.2 lbs per 20' piece, all personnel on the site must recognize the hazard and follow lift plans accordingly. All personnel must wear proper PPE and have proper qualifications. Qualifications include rigging and crane signals certification courses. The site foreman must also approve any personnel allowed on site. Before every load, the slings to the pipe must be checked for any damage. If there is any damage to sling, the sling must be cut and decommissioned immediately. Extra slings will be in the fabrication shipping container. Before any lift there must be an inspection of the chains or slings, for any damage or abrasions, that could present a hazard to the site and personnel. All personnel are prohibited from walking under a live load. A team member who walks under a live load may lose their qualifications to remain on site. Fortunately, our team has members experienced with large equipment and heavy lifts. These team members hold certifications for rigging, crane signaling, Class 7 All Terrain Forklifts, and Crane Operation.

Welding, Cutting and Preparation of the Pipe

The preparation of the pipe in the loading and fabrication area will require an angle grinder to clean up the 45 degree bevel joint, required by the WPS Welding Procedure Specification of that joint. We intend to order the pipe pre-beveled, where our team's welder would only need to use an angle grinder to remove the scale and any other materials from the beveled joint—anyone nearby must wear proper PPE and Safety Glasses to avoid injury due to flying sparks.

In the case that pre-beveled pipe is unavailable, our welder will need to bevel the pipe with a mobile Oxy-Acetylene torch. Compressed air and especially compressed acetylene is a serious hazard, and our team would be willing to bevel this pipe off-site, if requested. If allowed, two of our experienced team members will hook up the oxygen and acetylene to the sunbelt rental 36" pipe beveler and begin to bevel the pipe with one operating the machine and the other holding a fire extinguisher and making sure the sparks don't get anywhere close to the acetylene tank or catch anything on fire. Once done, the tanks will be decommissioned and taken to separate shaded areas of the site, and the metal worker will then clean off the 45 degree bevel before welding. These tanks do not have to be stored on site, and may be removed after the task is complete.

The welding of the pipes in the pit can cause a hazard for everyone on the boring site. It will be made clear to the entire team that a weld is taking place. A certified welder, assistant, or firewatch will be present. The welding process may expose personnel to bright, intense arcing and metallic sparks. The arc intensity can result in short-term eye damage. The metallic sparks could result in more long-term damage. For this reason, we emphasize that appropriate PPE must be worn.

All welding will take place in the pit and with qualified personnel. However, we are exploring automated welding options. One option includes Path Robotics. As a contingency, we will rely upon certified welders.

The Barbco Tribor itself presents a hazard. Loading, operation, and unloading of the Barbco Tribor involves rigging the 33,950 pound machine up properly. The weight of this machine can crush or seriously injure nearby personnel should loading, operation, or unloading go awry. These potential hazards are mitigated by minimizing the amount of personnel on site and ensuring only certified personnel are allowed access. No baggy or hanging items are allowed as these may get caught in the machine and result in injury.

Injection Materials

The system does not use any drilling fluid/mud; hence we will not be injecting any fluids other than compressed air as mentioned in the section above.

Safety Features & Operations

For the safety of the drilling site and a more accurate drilling process, most of the team will be looking into the pit via the control center depicted in Figures 15 and 16.

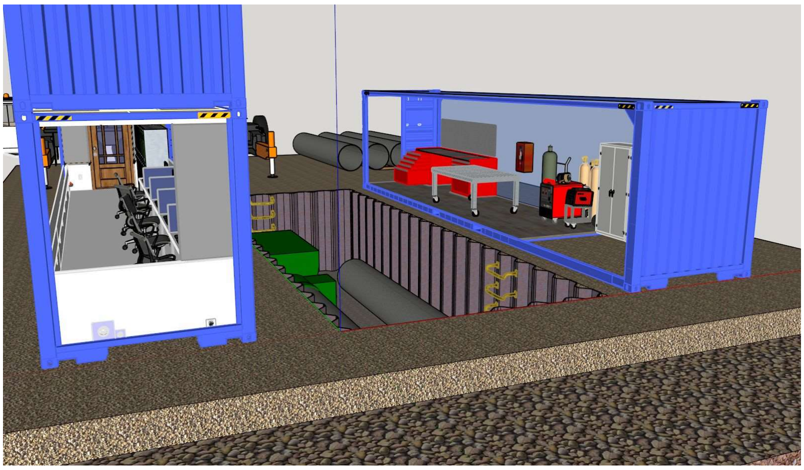


Figure 15: Command and Fabrication Container Internals (Isometric View)

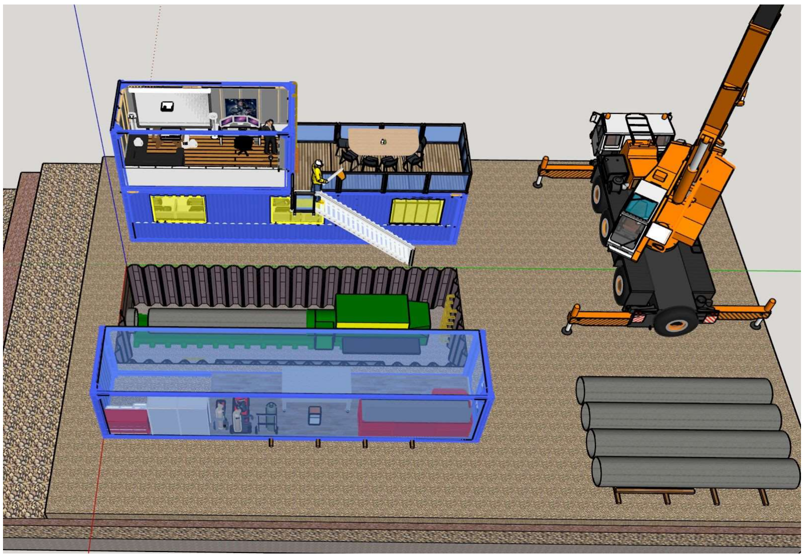


Figure 16: Command and Fabrication Container Internals (Top View)

Our control center's interior has been designed by a team member and will be prefabricated at our team partner Jupe, at their Los Angeles based factory, before the competition (www.jupe.com). This unit's Chassis will be modified, by shaving 4" of the width, so that it may act as a sleeve and slide into a shipping container. This Chassis will include a Jupe battery system, have solar panels to charge the facility throughout the day, and have an RV Standard heavy-duty 30 Amp, 120-volt plug to charge the Chassis.The prefab sleeves inside the shipping containers will be a modified Jupe chassis and fabricated out in their factory in Los Angeles, to eventually be assembled and stored in Altasea's(https://altasea.org/) warehouses in San Pedro.

The 40’ control center and the 20’ upstairs lounge and designated break area will be where the majority of the team will reside throughout the operating hours of the competition. It has been clearly stated by The Boring Company Competition, that no 3rd party contractors, who aren’t a member of the team, are not allowed to be hired and show up on site. We have decided that any person present on the drilling site must be qualified and trained to operate heavy industrial equipment during operations.

Also, any person can not enter the horizontal drilling/boring site without their PPE Personal Protective Equipment being up to the OSHA standards of:

- Eye protection
- Hard hats
- Hearing protection
- Safety shoes (steel-toe or composite-toe boots)
- Safety vests when working around roadways
- Leather gloves when changing out tooling or handling heavy materials

Crew members should NOT wear the following items because they can catch on rotating equipment and cause an injury.

- Loose clothing
- Rings
- Wristwatches
- Necklaces
- Bracelets
- Long hair (should be tied back)

The team's Boring Foreman and personnel present in the drilling pit must have electrically insulated boots. In typical boring operations, an accidental utility line strike could result in a large current running throughout the drill site, specifically the pit. However, such a fault is unlikely for the competition site in the Mojave Desert. Present personnel must also wear electrically insulated gloves to prevent electrocution due to machinery. Personnel within the command center are encouraged to wear electrically insulated gear. In short, we will follow the site inspection procedures and guidelines detailed by CALTRAIN Guidelines and

Specifications for Trenchless Technology Projects. https://dot.ca.gov/-/media/dot-media/programs/traffic-operations/documents/trenchless-booklet-a11y.pdf

Operating the Barbco System Remotely

The Barbco Tribor system will allow us to limit the amount of team members in the pit, since it has a wireless remote that will enable us to operate the system from the command center. The below discussion is borrowed from the Tribor Operation Manual.

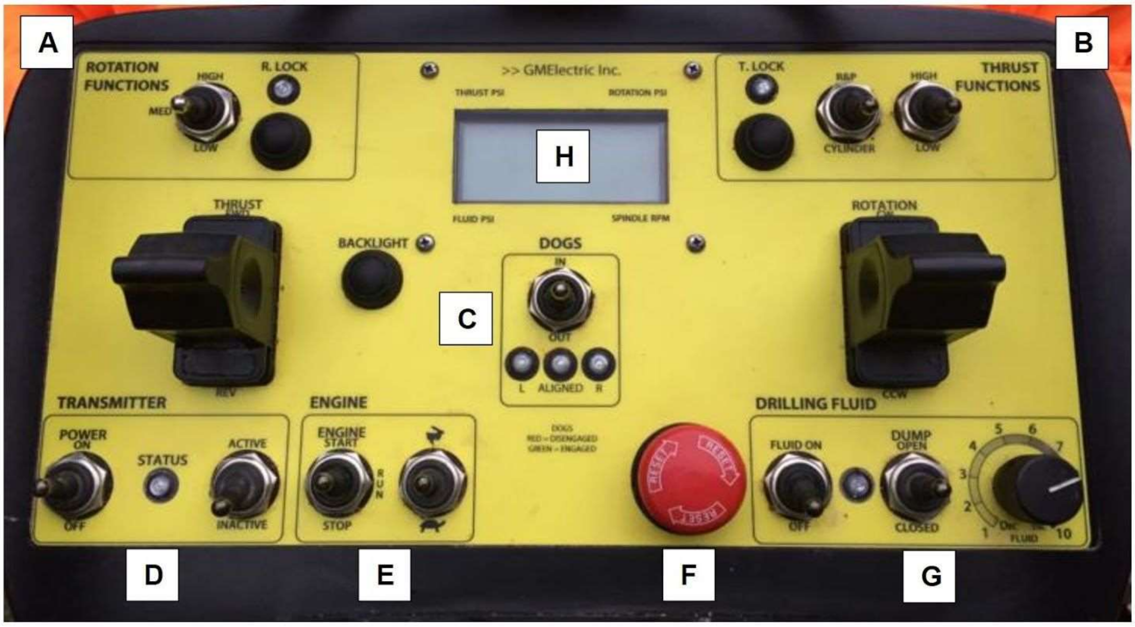


Figure 17: Barbco Tribor Control Panel

Below are descriptions of each aspect of the control panel

A - Rotation Function

- **Speed Toggle-** high, medium and low spindle speed setting adjusts the maximum torque per speed range.
- **R Lock Light & Button-** push the button to lock in the rotation speed. See auto drill mode.
- **Rotation Paddle-** proportional speed control of the rotary spindle.

B -Thrust Function

- **Cylinder / R&P Toggle-** choose between cylinder or rack and pinion thrust.
- **Speed Toggle -** high/ low rack and pinion speed setting adjusts the maximum force per speed range.

- **T Lock Light & Button -** push the button to lock in the thrust speed. See auto drill mode.
- **Thrust Paddle -** proportional speed control for thrust.

C - DOGS

- **In/Out Toggle -** steel blocks engage into the track to propel the machine forward or retracted from the track to operate the rack and pinion function.
- **L&R LED -** lights illuminate when the steel block is completely engaged into the track.
- **Aligned LED -** light illuminates when the push bar is aligned with the dog holes in the track.

D - Transmitter

- **Power Toggle -** turn power to the transmitter on/ off.
- **Status LED -** displays the status of the transmitter.
- **Active/ Inactive Toggle -** active allows all functions to work on the transmitter.

E - Engine

- **Start / Stop Toggle -** start and stop the engine from the remote.
- **Throttle -** When pushed the throttle will adjust in the corresponding direction.

F - E

- **Stop:** inactivates the transmitter and puts the machine in a controlled state.

G - DRILLING FLUID

- **On/Off -** turn the fluid pump on or off from the transmitter. Fluid master must be on.
- **Dump -** releases the fluid pressure off the drill string thru the spindle connection.
- **GPM Rheostat -** increase or decrease the output gallons from the onboard fluid pump.

H – DISPLAY

- **Thrust PSI -** digital display of thrust pressure.
- **Rotation PSI -** digital display of rotation pressure.
- **Fluid PSI**- digital display of the drilling fluid pressure.
- **Spindle RPM** - display of spindle rotations per minute.BACKLIGHT-lights up the digital display

Inspecting the Welds Remotely

Our team will have certified welders and welding inspectors that are qualified to weld the two pieces of 36” pipe on the Barbco Tribor track in the fixed 5G position. Our team will also pursue partnerships with industry innovators, nearby the Barbco Headquarters, to potentially implement automated and remote welding services with Lincoln Electric and Path Robotics.

In either case the welding process will be monitored and inspected remotely from the command center container. First, welds in progress will be actively monitored with an InGaAs camera. The high dynamic range and IR sensitivity of these cameras allows them to effectively observe bright areas and see through smoke common in welding environments. Second, a conventional camera monitors the outgoing bead. Both camera feeds are constantly monitored by a machine learning system that flags welds for manual operator review when they go out of known acceptable profiles. Parameters monitored include bead size, bead shape, and porosity.

Future Directions

Our multidisciplinary team began our collaboration with SpaceX and Boring Co. with the inaugural Hyperloop Design Competition. Over the years, we have forged partnerships through which we are developing commercial applications of our diverse technology portfolio.

We hope that the Boring Competition will provide a venue to evaluate the scalability and efficiency of our Barbco Tribor extended with plasma exfoliation. We also hope to investigate extensions of our proposed boring technology. One extension includes the application of Machine Learning algorithms for guidance and navigation.The intelligent system may innovate closed-loop digital controls for boring machine systems, which can serve to limit human-induced errors and increase operational performance. The plasma exfoliation technology can be scaled by for larger bores and other applications like geothermal.

We look forward to continuing to innovate in the Hyperloop space together with the Boring Company.