RIGOROUS LLC

October 8, 2021

High Tunnel Gantry System

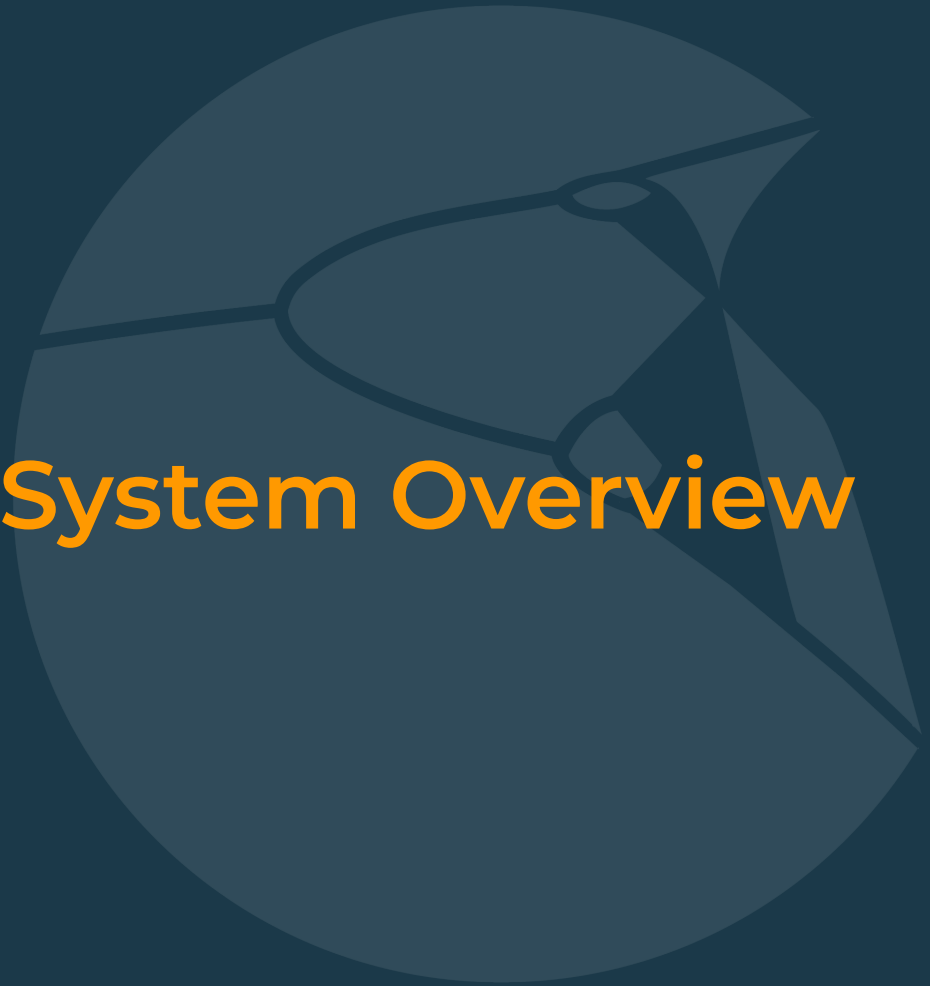
Preliminary Design Review

NORTHEAST SARE
Sustainable Agriculture Research & Education

Agenda

1. System Overview
2. Rail System
3. Transport Cart
4. Toolbar
5. Trolley Car
6. Automated Row Cover System (ARCS)
7. Concept of Operations

NORTHEAST SARE
Sustainable Agriculture Research & Education



System Overview

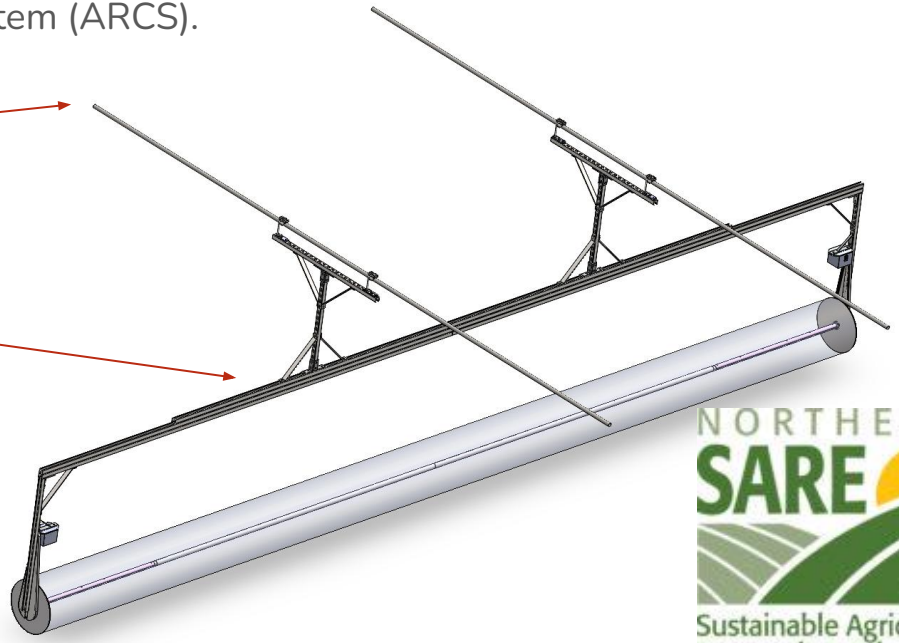
RIGOROUS LLC

System Overview

The High Tunnel Gantry System (HTGS) consists of one or more overhead rails, used as a monorail or together with a toolbar. Like a tractor, the toolbar works with interchangeable implements. A Trolley Car moves the implements along the rails to precise locations. We will develop two implements; a Transport Cart and an Automated Row Cover System (ARCS).

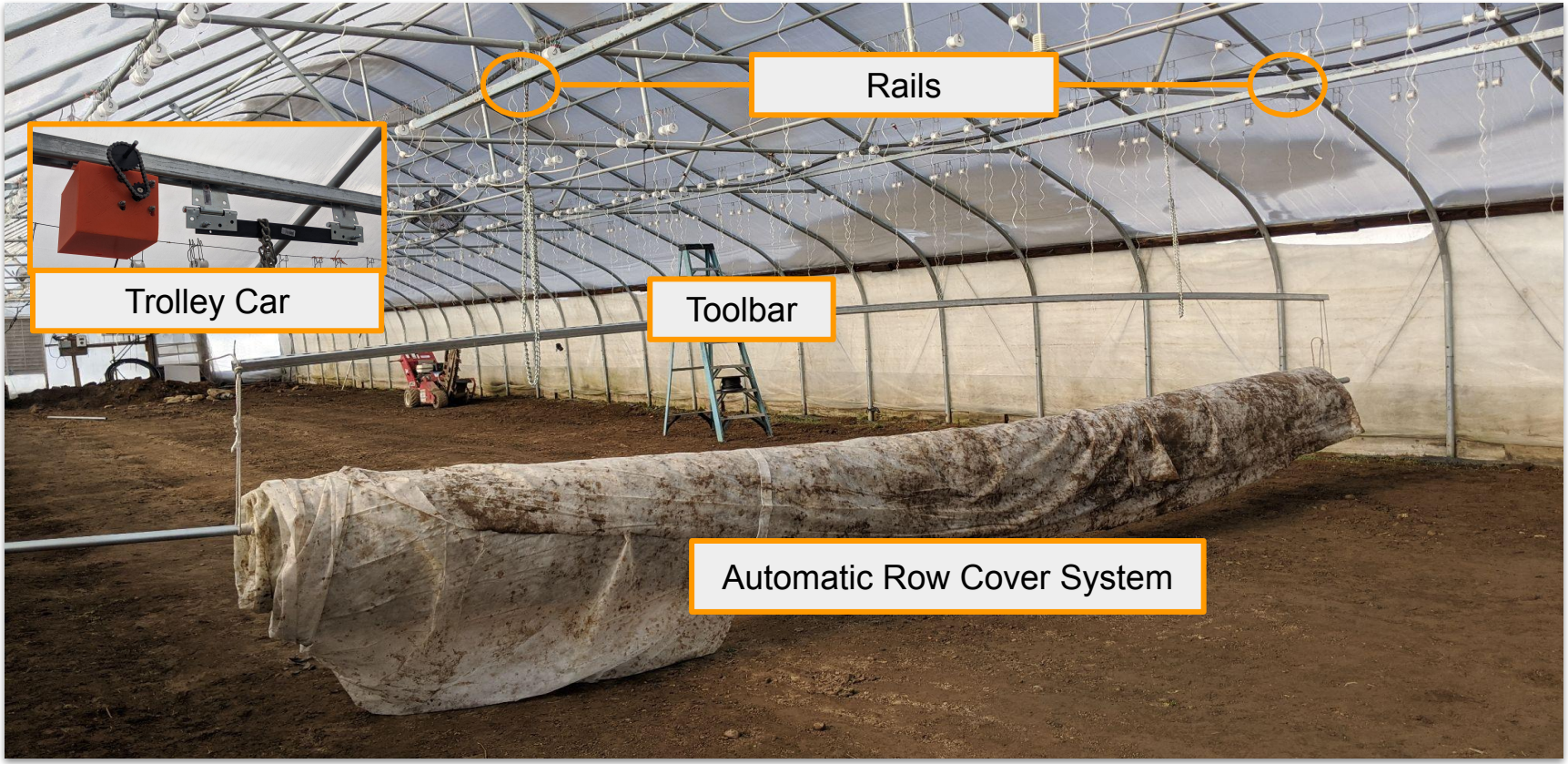
Primary Subsystems

- Rail System
- Transport Cart
- Toolbar
- Trolley Car
- Automated Row Cover System (ARCS)



NORTHEAST SARE Sustainable Agriculture Research & Education

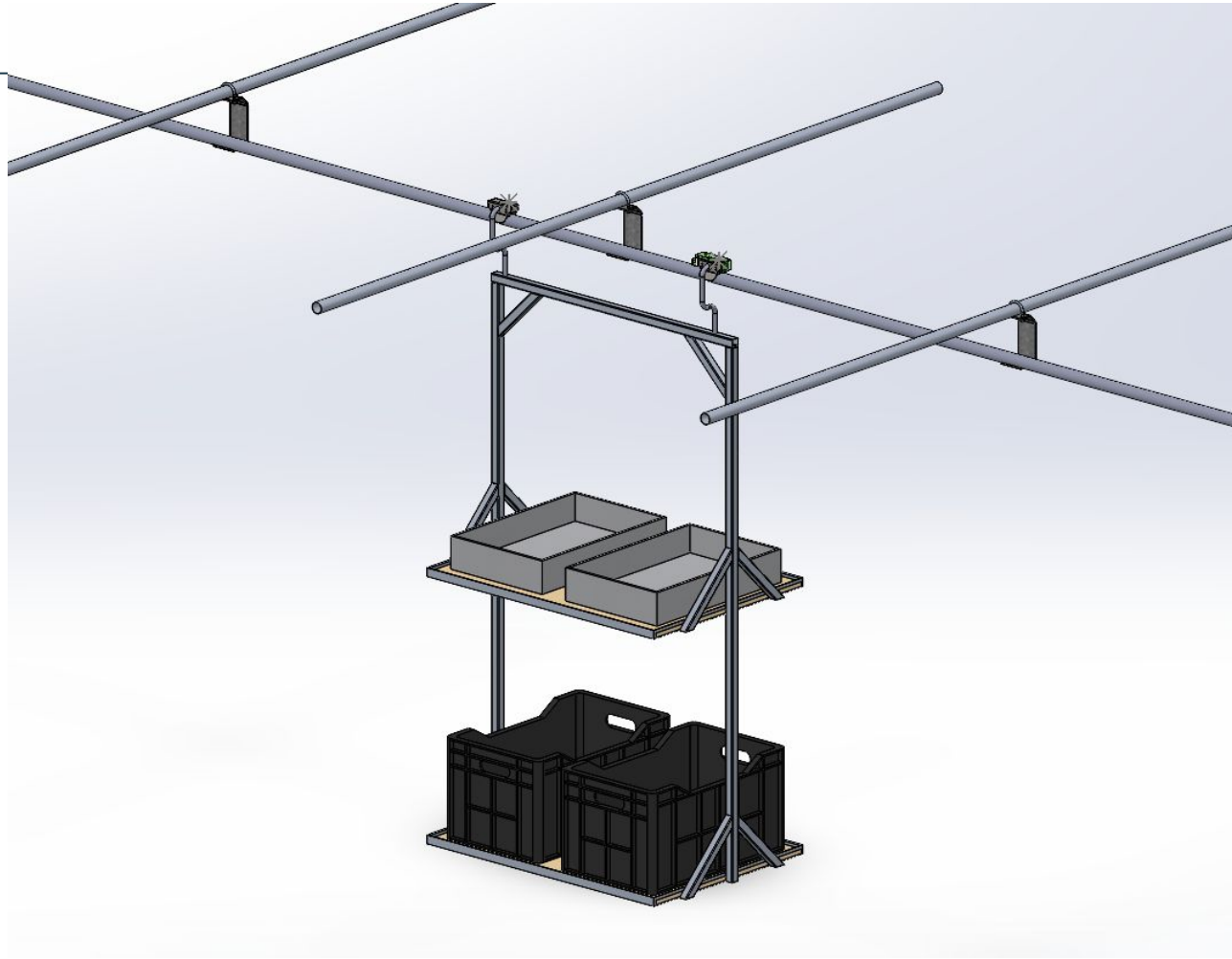
System Overview - Components



RIGOROUS LLC

Transport Cart

- Keep cart weight < 55 lbs
- Easy on/off of rail without accidental dismounting
- Fits standard bins
- Cannot be significantly overloaded



Farm Partners: Jericho Settlers Farm

- Former employers, long time friends and collaborators
- 19 High Tunnels
- Four season production, specialists in winter greens and season extension
- Early adopters of appropriate technologies
- Identified the need for the ARCS, created the first prototype
- Great people open to trying something new!

Rimol Gothic Style High Tunnel 30’ x 104”

- Truss style supports are necessary to support estimated loads (300lbs per rail)
- Space between outside bed and sidewall - 18”
- Width of beds, outside edge to outside edge - 25’ 22”
- Height of sidewall cross braces -
  - L - 79” to dirt, 77” to base board
  - R - 80” to dirt, 77” to base board
- Crossbar height
  - L - 10’8”
  - R - 10’5”
- Distance between crossbars - 16’4”

Rail System

RIGOROUS LLC

Rail System - Overview

The Rail System is the track for the gantry system. The rails are placed above the rows in the high tunnel, allowing the passage of tooling throughout the season. Gantry tools use the rails for transportation throughout the high tunnel. The rails are made from round pipe used for fence top rails and hung with U-bolt hangers. Rails are connected by swaged fittings and screws.

Subsystems

- Rail - Round tube that creates a track for the gantry system.
- Hangers - U shaped hanger to support the rail and allow trolley passage.
- Rail Connections - Swaged ends plus screws.

Hanger

Rail Connector

Rail

RIGOROUS LLC

Rail System - Rail

The rail is a 1 3/8” SS20 fence top rail that is hung from the high tunnel cross bars to act as a track for the gantry system. Fence top rail is readily available and can typically be purchased locally to mitigate shipping costs.

Functions

- Gantry Track - All HTGS implements utilize the rail as a track for trolley passage.

Key Requirements

- Load: 300 lbf
- Easy passage of hanging trolleys

RIGOROUS LLC

Rail System - Rail Connectors

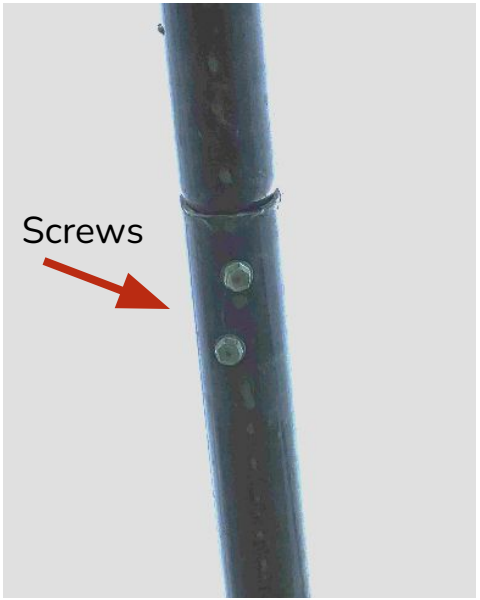
The rails have a swaged end and an open end. The rails are connected by inserting the swaged end into the next rails open end. The connection is secured with screws.

Functions

- Swaged Fitting - Swage fittings allow easy for easy installation.
- Screw Fastener - Two screws prevent the rails for seperating.

Key Requirements

- Trolley Passage - Connections need to be smooth on the upper portion of the rail to allow smooth trolley passage.



RIGOROUS LLC

Rail System - Hangers

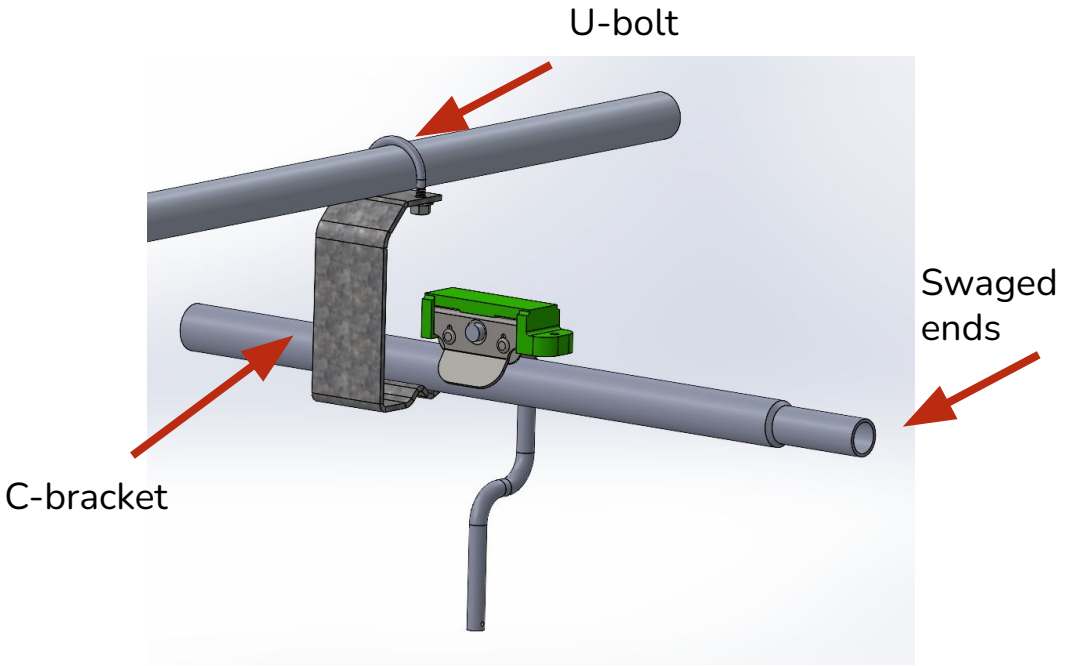
The hangers attach to the high tunnel cross bars with a U-bolt. A C-bracket hangs below with a mounting location for the rail. The rail is bolted to the bottom of the C-bracket.

Functions

- Rail Hanger - U-Bolt hanger with C-Bracket and mounting location for rail

Key Requirements

- Vertical Clearance - 5.5 inches
- Horizontal Clearance - 2 inches



Transport Cart

RIGOROUS LLC

Transport Cart - Overview

The Transport Cart is a hanging cart used to move objects throughout the high tunnel. The cart includes built shelves and trolleys to attach to the rail. The cart hangs from a single rail and is pushed down a row. The cart can be lifted from the rail and moved between rows.

Subsystems

- Frame - Support structure for the transport cart.
- Trolleys - Two hanging trolleys to hang the frame from the rail.
- Shelves - Two shelves to place objects for transport.

RIGOROUS LLC

Transport Cart - Frame

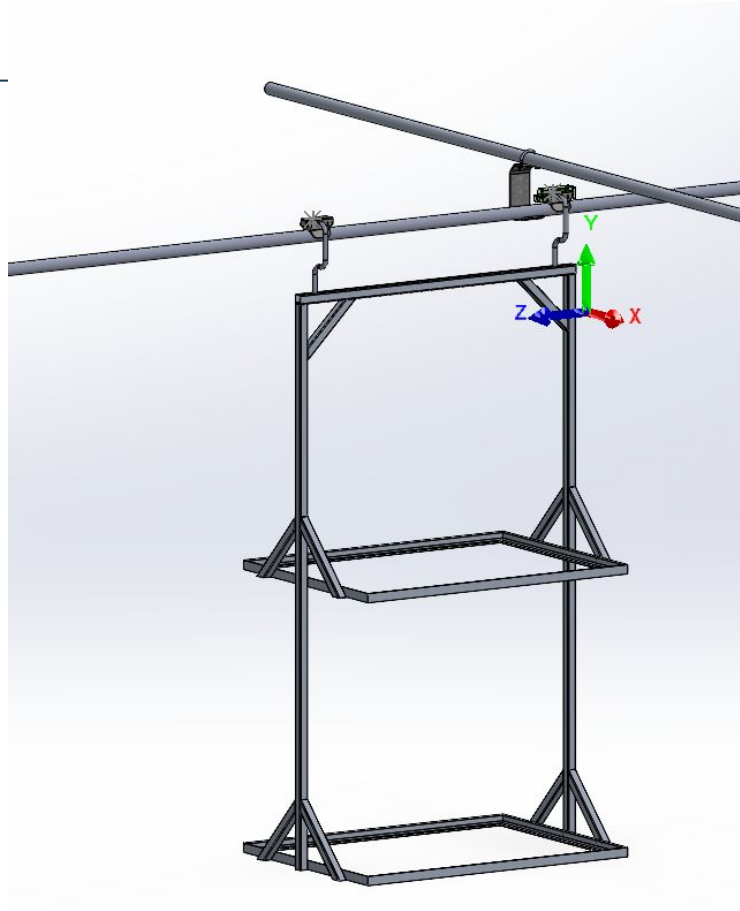
The Transport Cart has a welded 1” aluminum square tube frame. The top of the frame has a Trolley Attachment bar with key slots and locking pin to secure Trolleys. A single pair of side bars extend vertically down the center of the cart to support shelves. Shelf supports are placed at the bottom and middle of the cart.

Functions

- Trolley Attachment Bar - Top bar parallel to the rail with key slots and locking pin to attach trolleys.
- Side Bars - Vertical 1” square tube to attach shelves.
- Shelf Supports - Steel angle with gussets to support the bottom and middle shelves.

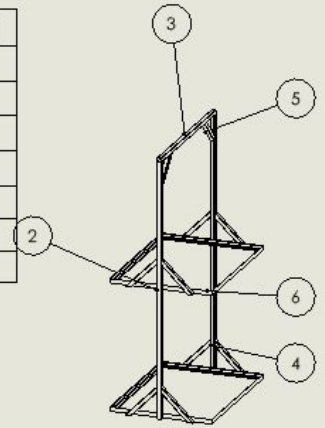
Key Requirements

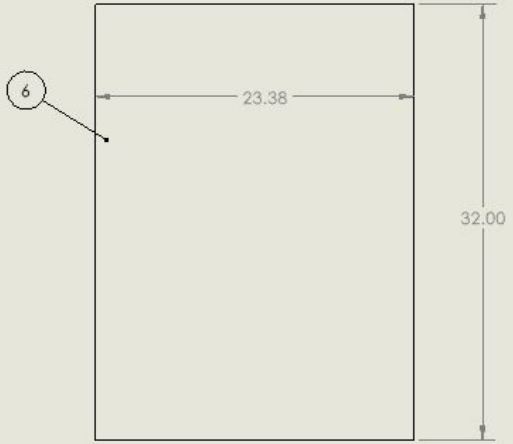
- Load Requirement - 300 lbf.
- Total Weight < 55 lbs
- Maximum Width - 26”
- Maximum Height - 96”



Frame weight: 18.65 lbs

ITEM NO.	QTY.	DESCRIPTION	LENGTH	ANGLE1
1	4	L 1.00 X 1.00 X .125	32.25	45°
2	2	1.00 X 1.00 Square Tubing	60	0°
3	1	1.00 X 1.00 Square Tubing	34.25	0°
4	8	1.00 X 1.00 Square Tubing	10.61	45°
5	2	1.00 X 1.00 Square Tubing	8.49	45°
6	2	1/2 Ply or Metal Mesh	23 3/8"	0
6	4	L 1.00 X 1.00 X .125	24	45°





	NAME	DATE
DRAWN	Bryan	8.20.21
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

Materials can be made from aluminum or steel square and L profile tubing.

SIZE	DWG. NO.	REV
A	Trolley Cart	
SCALE: 1:24	WEIGHT:	SHEET 1 OF 2

RIGOROUS LLC

Transport Cart - Trolleys

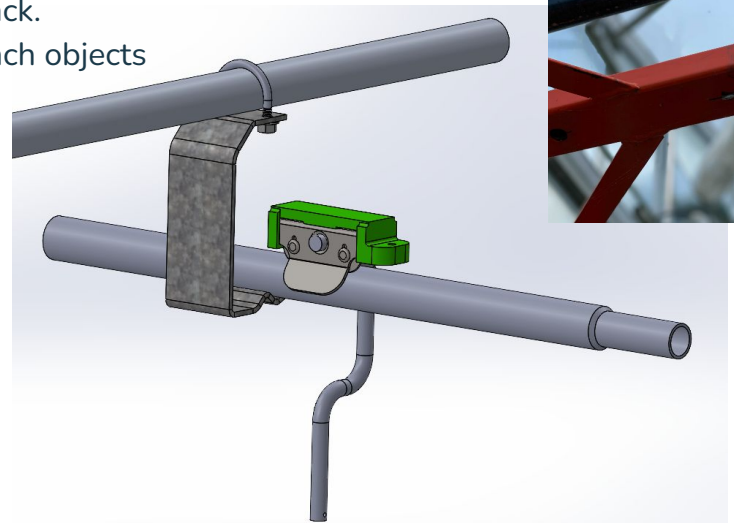
Trolleys are passive rollers that hang and move travel along the Rail System. The trolleys consist of a steel spools and hanging bar. The Trolleys attach using through a key and slot opening the in the frame with a pin and fastener to secure the trolley. The trolley is a standard part from Railex.

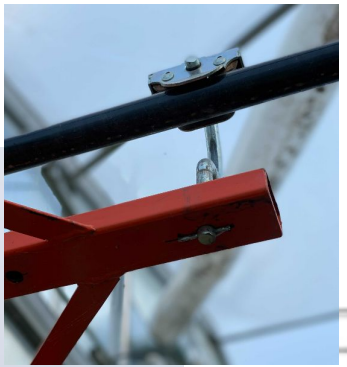
Functions

- Steel Spools - Rolling wheels that sit on the rail and allow easy motion down the track.
- Hanging Bar - Horizontal bar to attach objects to the trolley.

Key Requirements

- Tube Size - 1 3/8”
- Load: 125 lbf each





RIGOROUS LLC

Transport Cart - Shelves

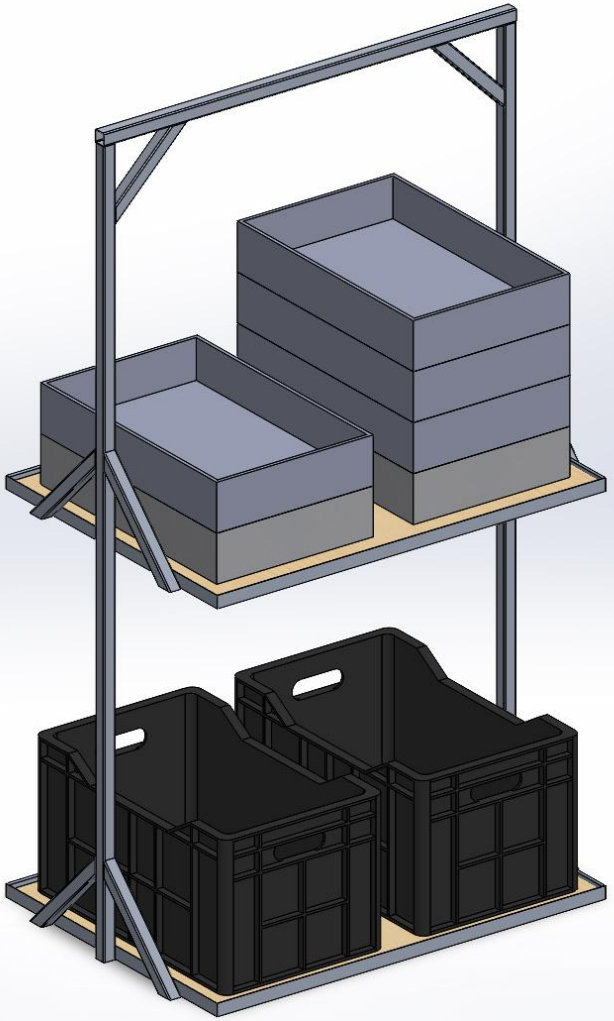
The shelves are designed to support a variety of popular tray, crate, and carton sizes. The shelves are a single plywood insert that rests on the frame.

Functions

- Shelf Base - Plywood insert for the shelf base.
- Supported Containers:
  - 10# Tomato Cartons (13”W x 20”L x 3.75”D) (2-wide)
  - 15# Tomato Cartons (16”W x 23.5”L x 4.5”D) (2-wide)
  - Plastic 10# Tomato Tray (13.25”W x 19”L x 5”D)
  - 1020 Plant Trays (10.94”W x 21.44” L x 2.44”D)
  - Stackable Crate (23.75”W X 18”L X 11.5” D)
  - Bread Tray (25” W x 21.5” L x 4.5” D)
  - Fish Tote (18”W x 31.5”L x 11.5”D)

Key Requirements

- Number of Shelves - 2
- Shelf Size - 24” x 36”
- Strong enough to hold 300 lbs



Transport Cart - Load Capacity

Tray Name	Tray Size	Cart Capacity	Stack Size	Weight
10# Tomato Cartons	13”x20”x3.75”	24	6	240 lbs
15# Tomato Cartons	16”x23.5”x4.5”	16	4	240 lbs
1020 Trays	11”x21.5”x2.5”	40	10	200 lbs (but likely stacking empty trays)
Bread Tray	25”x21.5”x4.5”	8	4	200 lbs
Stackable Crate	23.75”x18”x11.5”	6	1, 2	210 lbs

Toolbar

RIGOROUS LLC

Toolbar - Overview

The Toolbar serves as a generic attachment to connect implements and tooling. The toolbar is designed to span multiple rails and be driven by multiple Trolley Cars. The toolbar includes passive Trolleys to hang from the Rail System.

Subsystems

- Frame - Support Structure for the Toolbar.
- Adjustable Height - System to adjust the height of the tool bar.
- Attachment Point - System to attach tooling to the toolbar.
- Trolleys - Four hanging trolleys to hang the frame from the rail. This is the same trolley used for the Transport Cart.

RIGOROUS LLC

Toolbar - Frame

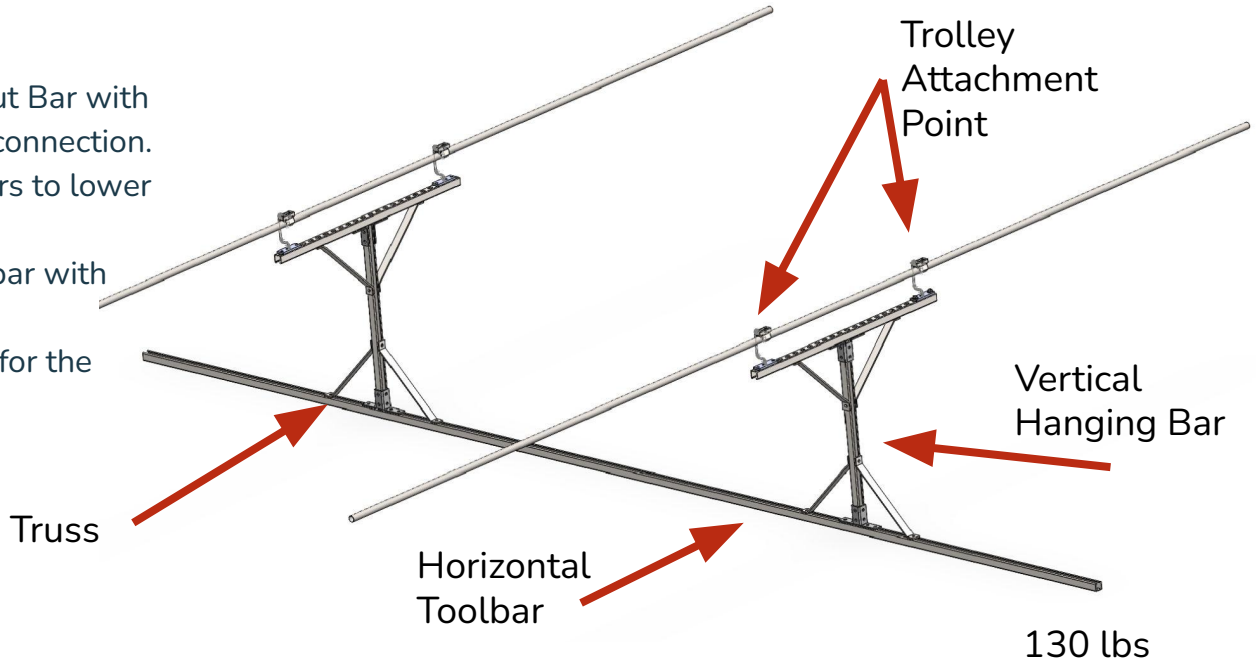
The Toolbar Frame is designed to hang from Trolleys on the Rail System. The Frame will include rigid bars from the Trolleys to a spanning bar for Tooling Attachments. The Frame must support the ARCS load weight and torque applied during spooling operations.

Functions

- Trolley Attachment Point - Unistrut Bar with holes for trolley pin and fastener connection.
- Vertical Hanging Bar - Vertical bars to lower toolbar from Rail System.
- Horizontal Toolbar - Primary toolbar with Unistrut for Tooling Attachments.
- Truss System - Support structure for the Horizontal Toolbar.

Key Requirements

- Load: 300 lbf



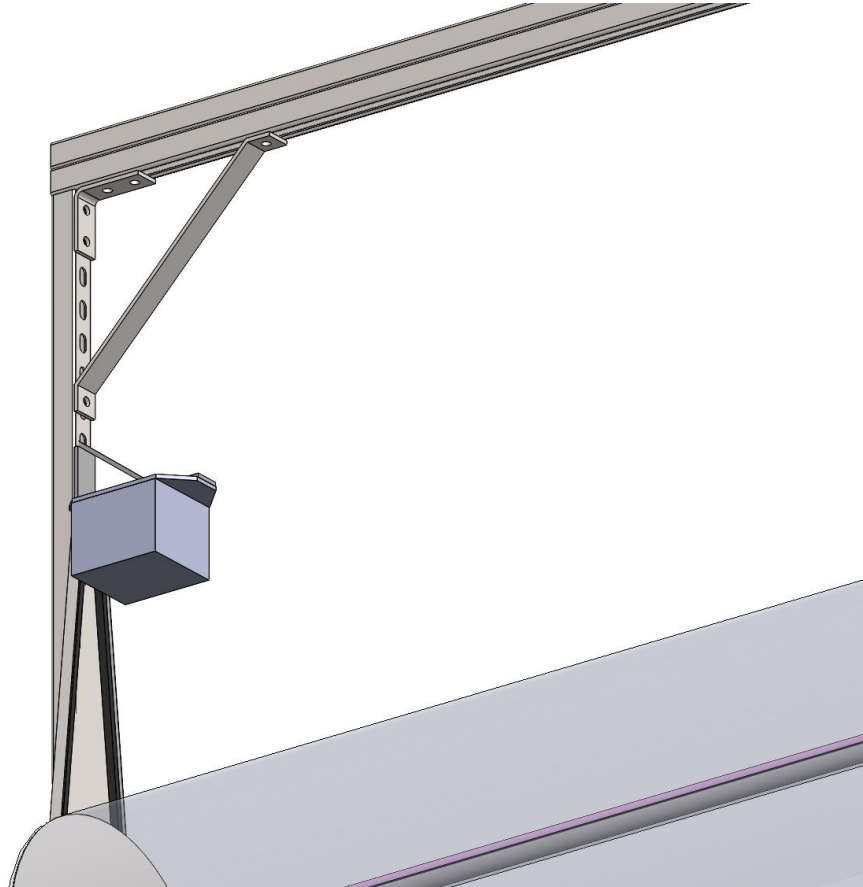
RIGOROUS LLC

Toolbar - Attachment Point

The Unistrut allows for various attachment points to provide a mechanism to attach tools and implements to the Toolbar.

Functions

- Off-the-shelf attachment system.
- Non-permanent attachment for implements.
- Supports 30’ span, anticipates bend in metal.



NORTHEAST SARE
Sustainable Agriculture Research & Education

Trolley Car

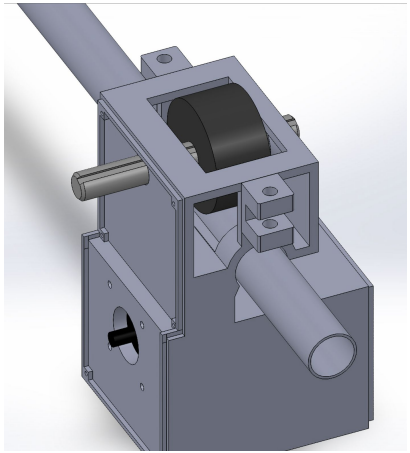
RIGOROUS LLC

Trolley Car - Overview

The Trolley Car is a motorized trolley that connects and moves implements on the Rail System. The Trolley Car has drive wheels connected to a drive motor to move the trolley down the rail. The system will calculate the position of the Trolley car along the track using motor position feedback. An internal control system will manage the movement and process external motion commands. Trolley Cars can operate independently or together in coordinated motions. A bottom facing camera will record crow imagery and provide situational awareness for operators.

Subsystems

- Enclosure
- Traction System
- Drive System
- Trolley Control System
- Vision System



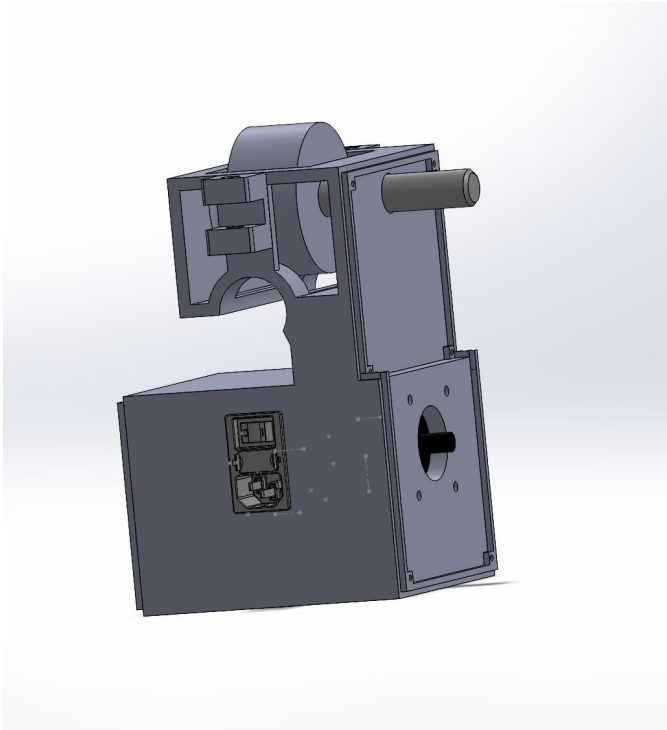
RIGOROUS LLC

Trolley Car - Enclosure

The enclosure houses the electrical system, drive system, and computing system for the Trolley Car. The enclosure can be quickly moved between rails and attached to implements using the integrated hitch.

Functions

- Integrated Mounting Features - Built in standoffs to mount the following system components:
  - **Traction System:** Bearings, Shaft, Drive Wheels
  - **Drive System:** Motor, Motor Controller
  - **Power Electronics:** AC Receptacle w/ Fuse & Power Switch, 48VDC Converter, 5 VDC Converter
  - **Computing System:** Computer, Camera
- Trolley Hitch - Hitch to attach trolley to implements including the toolbar.



Key Requirements

- Water and Dust Resistant - All system components will be fully enclosed without gaps in the lids.

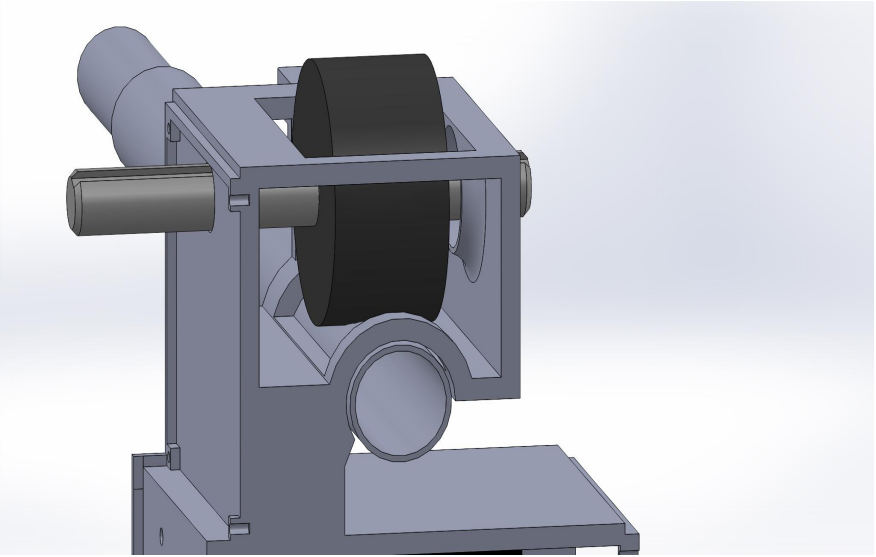
RIGOROUS LLC

Trolley Car - Traction System

The Traction System converts the motors rotational motion into linear motion along the rail. The enclosure is designed to suspend the Trolley Car from the drive wheel. The weight of the Trolley Car is the normal force alliped to the wheel for traction along the rail. The drive wheel is attached by a drive shaft and chain & sprocket to the motor.

Functions

- Drive Wheel - 3” Rubber keyed drive wheel with ¾” shaft.
- Bearings - Ball bearings for the shaft.
- Drive Shaft - Keyed ¾” aluminum shaft.
- Chain - #25 Chain
- Sprockets
    - Motor - 12 Teeth
    - Drive Shaft - 24 Teeth



Key Requirements

- Tractive Force: 30 lbf

RIGOROUS LLC

Trolley Car - Drive system

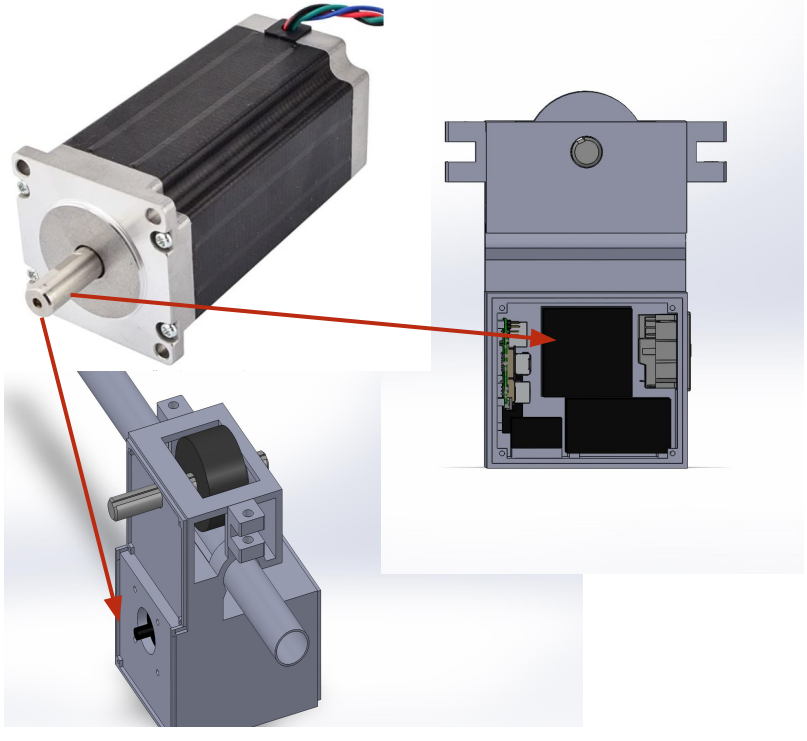
The Drive System provides the power for the Traction System. A stepper motor drives a sprocket connected to the Traction System. A motor controller provide powers and control for the Trolley Car.

Functions

- NMEA 23 Stepper Motor - Motor for driving traction system. Motor position output used for relative positioning.
- Motor Controller - Power and controller for the stepper motor. Digital interface for status and control.

Key Requirements

- Motor Torque: 425 oz. in.
- Motor Voltage: 48 VDC
- Motor Current: 4 Amps



RIGOROUS LLC

Trolley Car - Vision System

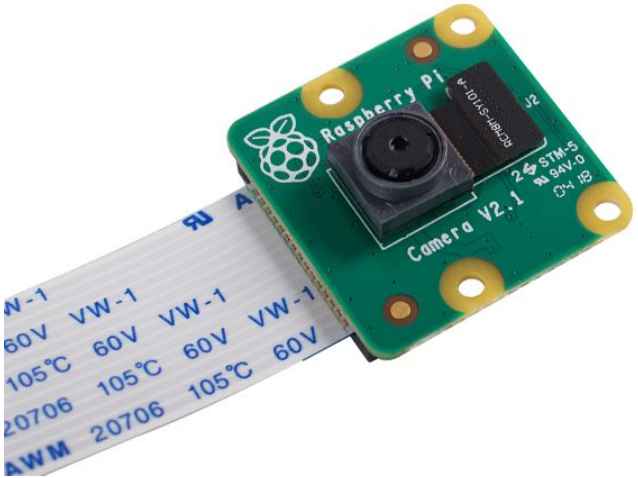
The Vision System is a downward facing camera to image the rows. The images will be used to verify the Trolley Car is operating correctly. Images will be uploaded periodically for operators to verify the system is working.

Functions

- Position Verification - The images will be used to verify the system has moved to the correct position.

Key Requirements

- Camera: RBG



RIGOROUS LLC

Trolley Car - Trolley Control System

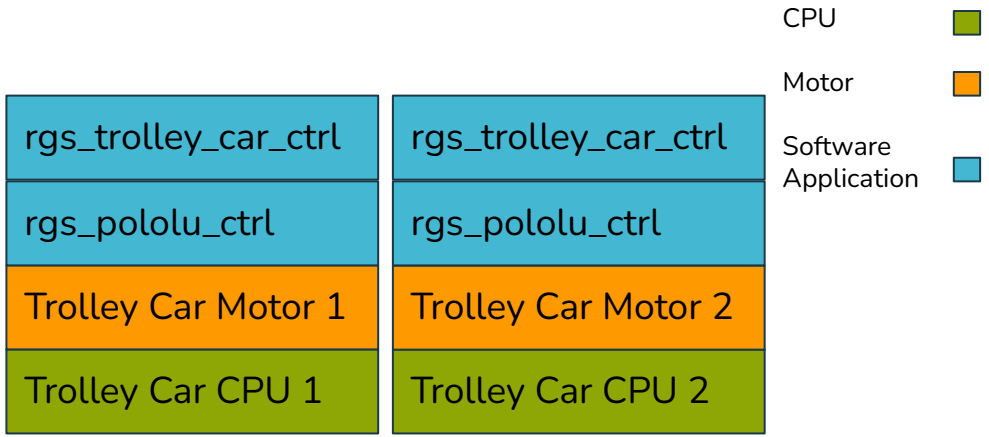
The Trolley Control System is a software subsystem to manage trolley motion, system status, and provide an external trolley control interface. Motor status is monitored for faults conditions. Command and status messages are transmitted over a dedicated HTGS wireless network.

Functions

- Embedded Computer - Processing for the system.
- Trolley Control Software - Primary controls software for the trolley and subsystems.
  - Motion Control
    - Control Modes: Drive, Stop
    - Enable Motor
    - Go to Position
    - Go to Velocity
  - Status Monitoring
    - Motor Controller Enable State
    - Input Voltage
    - Motor Current
    - Stepper Position
- Open Source Networked ROS2 Publish/Subscribe Communication Protocol

Key Requirements

- Processor: Raspberry Pi



Automated Row Cover System (ARCS)

RIGOROUS LLC

ARCS - Overview

The Automatic Row Cover System (ARCS) is designed to automatically spool row cover. The system will span the width of the high tunnel and will attach to the toolbar. The Trolley Car will automatically move the system down the high tunnel during spooling operations. The ARCS will include spooling motors and control system to automatically manage row covering.

Subsystems

- Frame
- Spool Drive System
- Motor Module
- ARCS Controller
- ARCS User Interface

NORTHEAST SARE
Sustainable Agriculture Research & Education

RIGOROUS LLC

ARCS - Frame

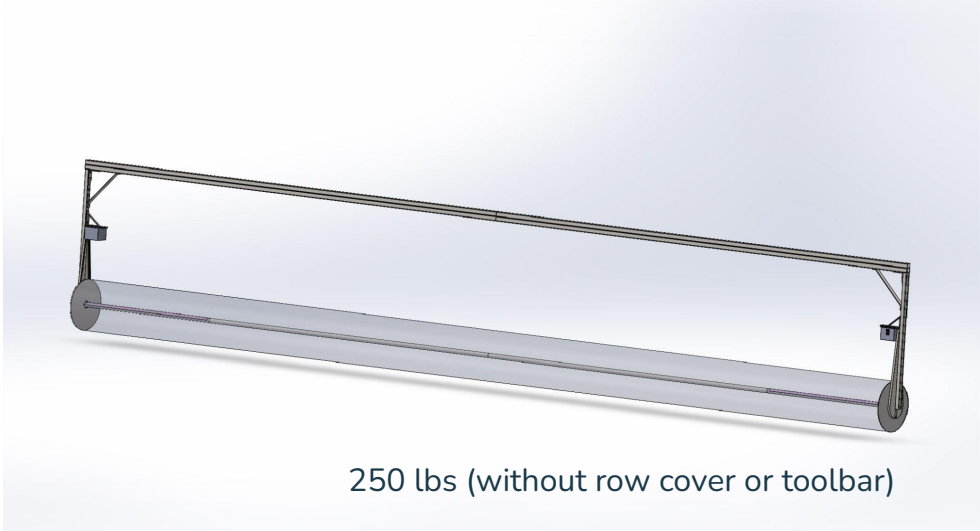
The ARCS frame will attach to the Toolbar. The frame will provide support and mounting for the main spool and Row Cover Spooling System. The spool must span the distance of the high tunnel, maximizing wall to wall coverage.

Functions

- Toolbar Attachment - Attachment from the ARCS Frame to the Toolbar.
- Main Spool Mounting - Structure and bearing to support a fully loaded spool.
- Drive System Mounting - Mounting for the motors and drive system.
- Spool - Shaft to load row cover.

Key Requirements

- Load: 80 lbf Cover
- Row Cover Width: 30’
- Row Cover Length: 100’

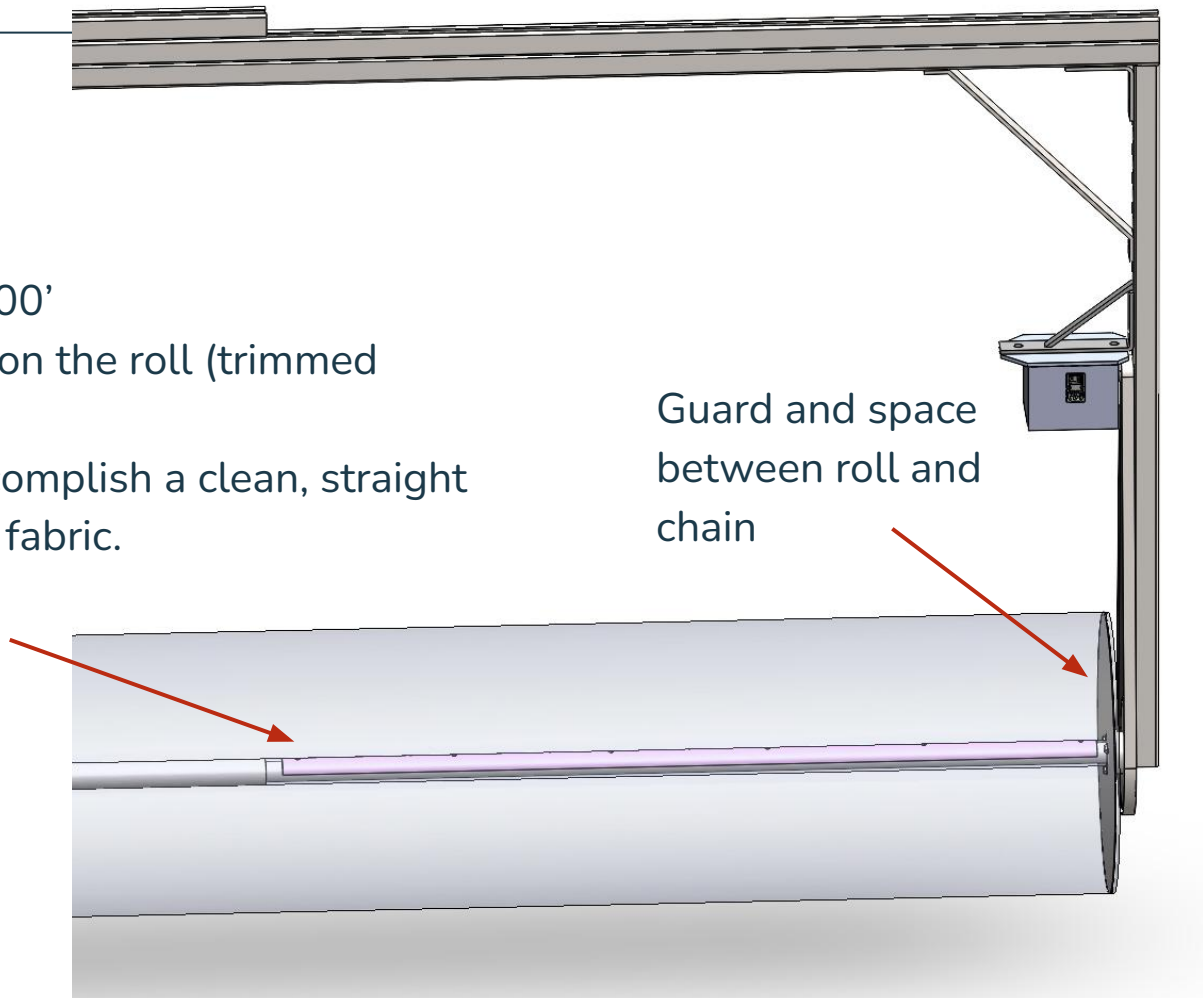


250 lbs (without row cover or toolbar)

RIGOROUS LLC

Row Cover Roll

- Standard remay size 30’ x 100’
- Targeting 28.5’ wide remay on the roll (trimmed from a standard 30’ roll
- Looking for a strategy to accomplish a clean, straight edge without ripping up the fabric.
- PVC clip to attach to bar



NORTHEAST SARE
Sustainable Agriculture Research & Education

RIGOROUS LLC

ARCS - Spool Drive System

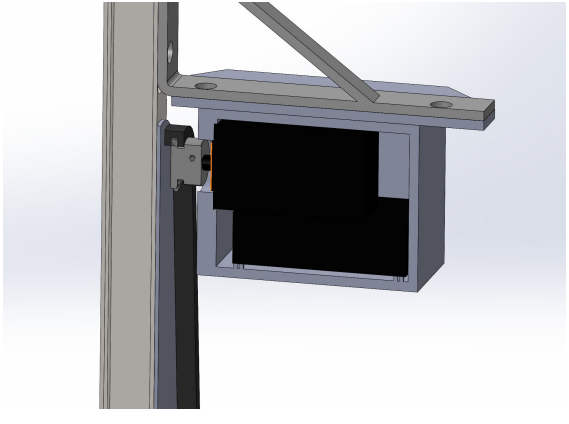
The Row Cover Spooling System is the main drive mechanism for spooling row cover. The spooling system includes drive motors to rotate the spool in both directions. The drive mechanism transfers rotational power from the motors to the main spool.

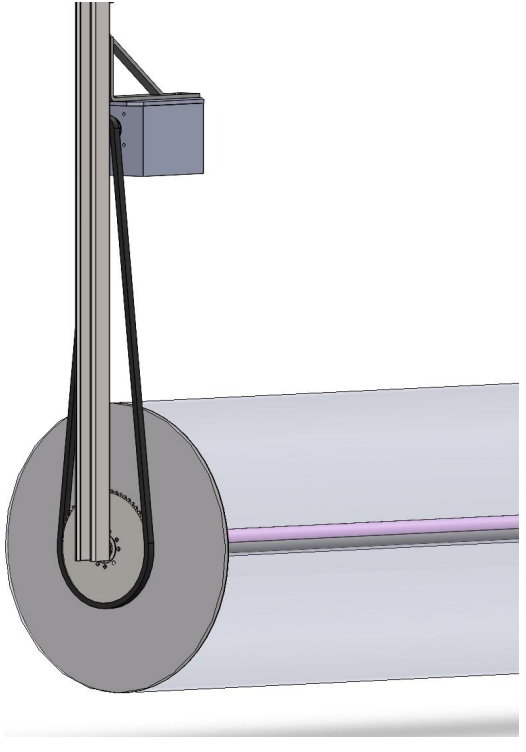
Functions

- Spooling Motors - Two motor modules to drive both sides of the spool.
- Drive Mechanism - Sprocket and chains to drive the spool.

Key Requirements

- NEMA 23 Motor Module - Utilize the components from Trolley Car.





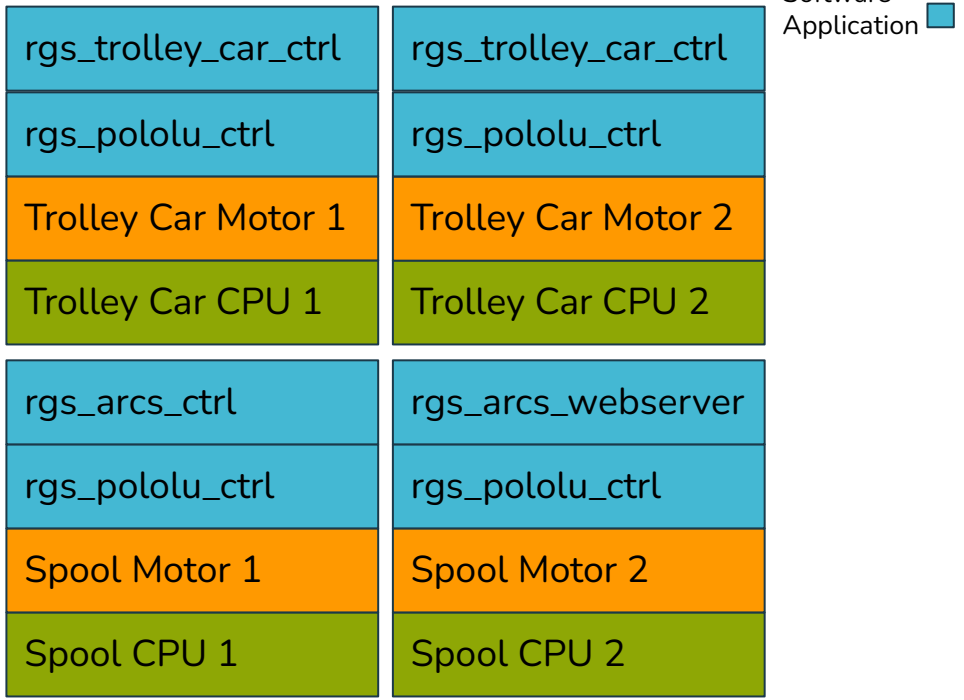
RIGOROUS LLC

ARCS - ARCS Controller

The ARCS Controller manages the process of automatically spooling row cover. The controller will coordinate the motion of two Trolley Cars and two Spooling Motors to traverse the length of the high tunnel while pulling in or letting out row cover.

Functions

- Embedded Computer - Processing for the system, same as the Trolley Car.
- ARCS Control Software - Primary controls software for the ARCS.
  - Motion Control
    - Control Modes: Automatic, Manual, Stop
    - Trolley Motion Synchronization System
    - Spooling Synchronization System
    - Automatic Cover Time Settings
  - Status Monitoring
    - Excessive Power Fault
    - Subsystem Communications
- Communications - Open Source Networked ROS2 Publish/Subscribe Communication Protocol



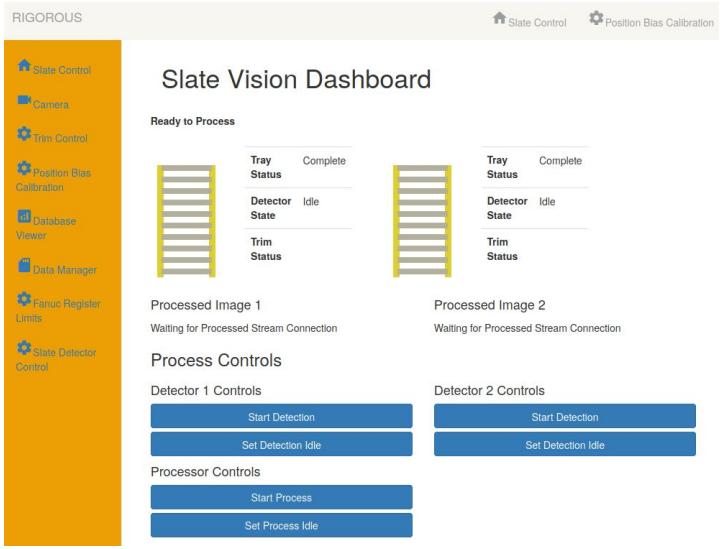
RIGOROUS LLC

ARCS - ARCS User Interface

The ARCS User Interface provides an interface for commanding the system, configuring the system, and viewing system status. The user interface will be a webpage hosted from one of the ARCS control computers. The interface will be accessible from a phone when you are connected to the HTGS network. We will connect the HTGS network to the internet for external viewing, data collection, and authorized remote control.

Functions

- Browser Based UI - Browser based user interface, viewable from a phone. Built into the ARCS control computer for offline or online use.
- System Controls
  - Mode Selection
  - Cover Time Configurations
  - Temporary Automatic Cover Override
  - Manual System Controls
- System Status
  - System Mode
  - State of Row Cover (Covered/Uncovered)
  - Temperature & Humidity
  - Picture Every 10 Minutes



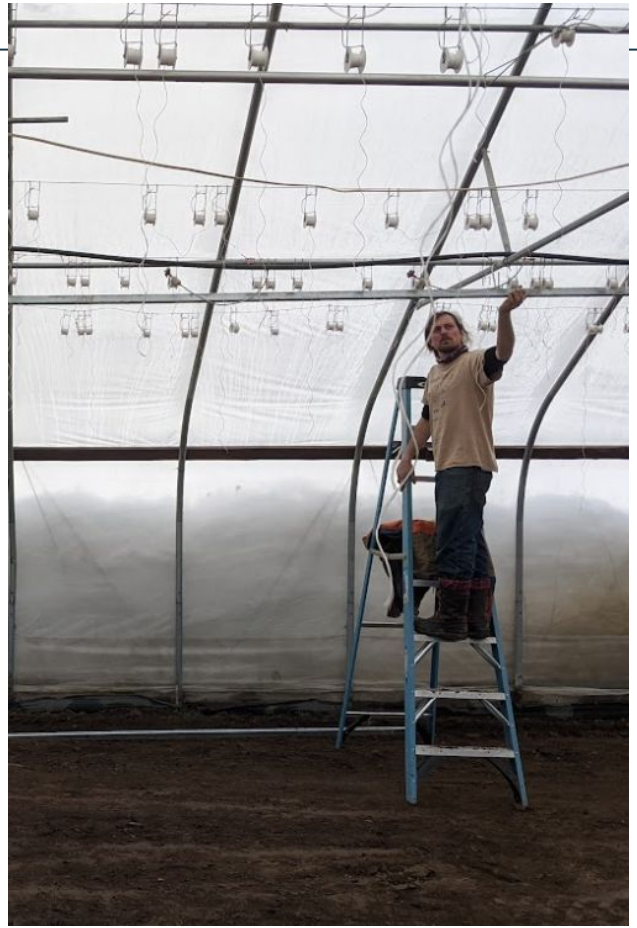
*Previous Rigorous UI just for example

Concept of Operations

CONOPS - Overview

The concept of operations defines all major processes for system operations. The CONOPS is composed of the following processes.

- Transport Cart Operations
- ARCS Setup
- ARCS Manual Mode
- ARCS Automatic Mode



NORTHEAST SARE
Sustainable Agriculture Research & Education

RIGOROUS LLC

CONOPS - Transport Cart Operations

The Transport Cart Operational process utilizes the Transport Cart tool to move objects throughout the high tunnel. The cart hangs from a single rail over the walking row to allow operations with trellised plants.

Procedure

- Hang Cart - The Transport Cart is hung from the rail by lifting the cart and trolleys onto the rail. The cart can be lifted of/off the rail anywhere on the rail.
- Move Cart - Cart is moved by hand along the rail.
- Load Cart - Objects are loaded and unloaded from the shelves on the Transport Cart.

NORTHEAST SARE Sustainable Agriculture Research & Education

RIGOROUS LLC

CONOPS - ARCS Setup

The ARCS Setup process mounts and prepares the ARCS for automatic or manual row cover operations. The ARCS uses two rails to span the width of the high tunnel to allow row cover spooling.

Procedure

- Hang Toolbar - Hang the Toolbar on the two rails.
- Attach ARCS - Attach the ARCS to the Toolbar.
- Connect Row Cover - Unroll the end of the row cover and roll it around the ARCS bar. Then use the PVC clips around the bar, securing it in place.
- Prepare Row Cover - Pin down the end of the row cover at one end of the high tunnel.
- Power Cable - Run power cable using cable trolleys to the ARCS.
- ARCS Settings - Open ARCS webpage set timing parameters for when to cover/uncover crops.

Hang toolbar before attaching ARCS

NORTHEAST SARE
Sustainable Agriculture Research & Education

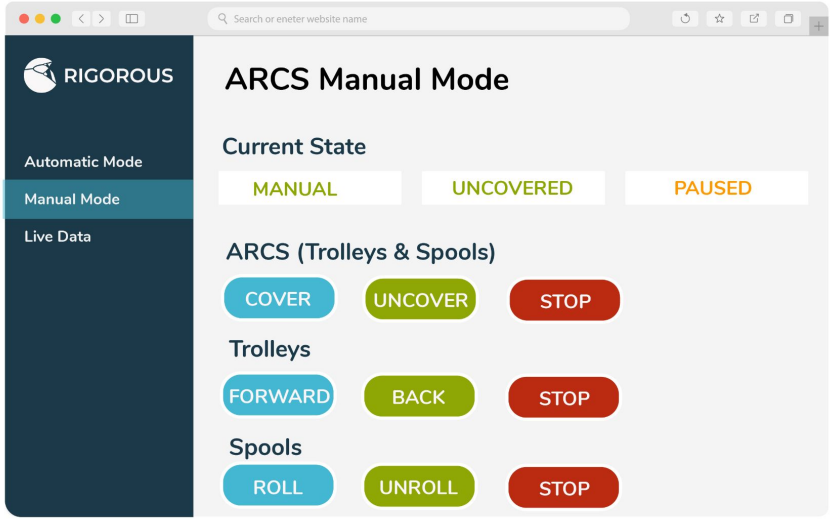
RIGOROUS LLC

CONOPS - ARCS Manual Mode

Manual Mode allows operators to directly control the ARCS. The system can be commanded to cover/uncover the high tunnel and actuate all individual components. Manual Mode is used to override Automatic settings or diagnose issues with the ARCS.

Procedure

- Enter Manual Mode - Use the ARCS webpage to Manual Mode.
- Cover/Uncover Command - Cover/Uncover allows the operator to command the system to automatically cover or uncover the rows.
- Move Command - Move command allows the operator to move the ARCS without rolling or unrolling the row cover.
- Roll/Unroll Command - Roll/Unroll command allows operators to roll or unroll the row cover without moving the ARCS.



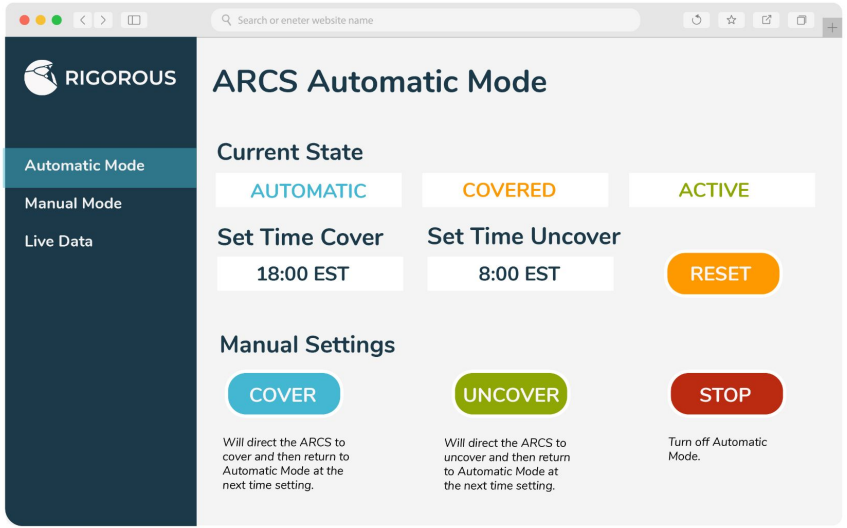
RIGOROUS LLC

CONOPS - ARCS Automatic Mode

Automatic Mode automatically manages the covering and uncovering of row cover. The system will use preset times to cover and uncover the rows. Additionally operators will have two functions to command a cover or uncover while keeping the system in Automatic Mode. The system will take back automatic operations at the next time interval.

Procedure

- Automatic Mode - Use the ARCS webpage to place the system in Automatic Mode. System will begin automatic covering.
- Cover/Uncover Command - Override cover state until the next cover event.



Thank You

NORTHEAST SARE
Sustainable Agriculture Research & Education

Timeline

- PDR, Early October 2022
- CDR, Late October / Early November 2022
- Build / Test, November, January 2022-2023
- Site Acceptance Test, Late January 2023
- Labor Savings Study (ARCS), February or March 2023
- Winter Workshop, March or April 2023
- Labor Savings Study (Transport Cart), July - August 2023
- Summer Workshop, TBD, Summer 2023 (Open Farm Week?)
- Conference Presentations, Winter 2023-2024

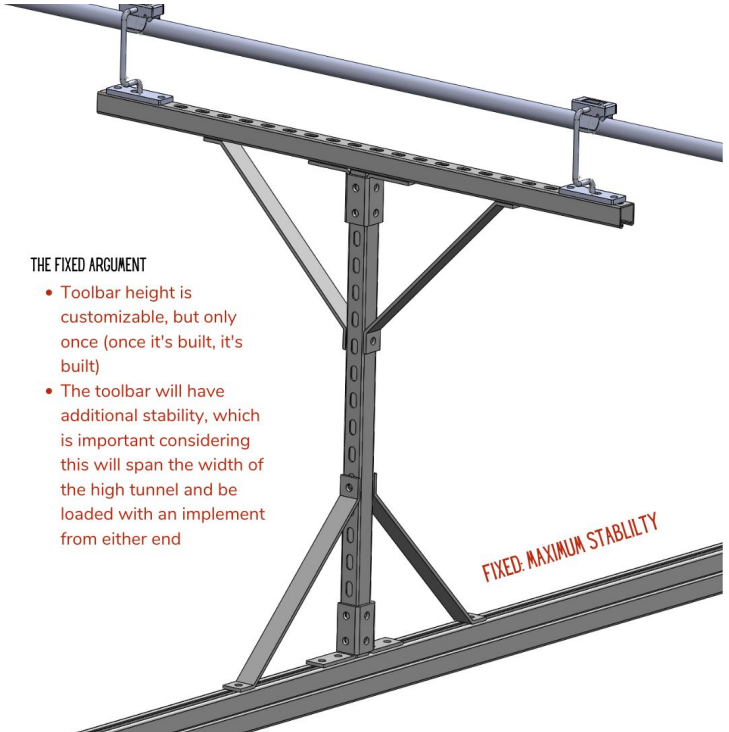
RIGOROUS LLC

Toolbar - Adjustable or Fixed Height

The height between the rails and the ground is not necessarily level or consistent between high tunnels. To accommodate the variable height, the toolbar will include a mechanism to adjust the height of the toolbar above the ground. Each side will be independently adjustable to account for slope.

THE ADJUSTABLE ARGUEMENT

- Toolbar height is adjustable, which means you could swap which high tunnel you choose to operate the system in once per season



THE FIXED ARGUMENT

- Toolbar height is customizable, but only once (once it's built, it's built)
- The toolbar will have additional stability, which is important considering this will span the width of the high tunnel and be loaded with an implement from either end

Discussion Questions

1. What issues or concerns do you have with the design of the system?
2. What do you appreciate most about the design?
3. What issues or concerns do you have with utilization of the system?
4. What do you anticipate appreciating about the way you would operate the system?
5. What is unclear to you?
6. What resonates with you?
7. If you were to construct this system, would you want to build it yourself, purchase the pre-constructed materials, or some combination of the two?