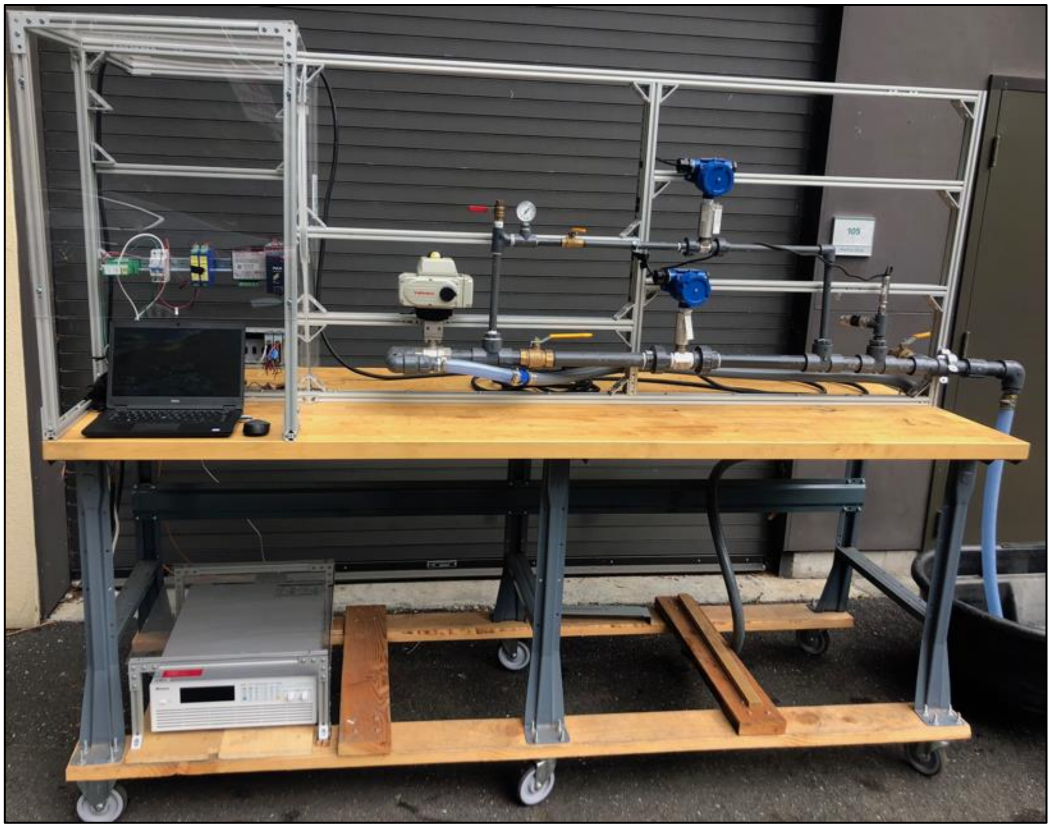

Global LEAP SWP TEST BENCH INSTRUCTION MANUAL

February 17, 2023

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1. Introduction

This instruction manual outlines the following:

- A complete equipment list inclusive of the equipment needed to test solar water pumps (SWPs) to the *Global LEAP SWP Test Methods, version 2* on a test bench similar to the one at the Schatz Energy Research Center (Schatz Center).
- Instructions on how to build the test bench and incorporate all equipment and materials needed for testing
- Additional resources that could be helpful for this work

Note: other equipment and test bench parameters and software may be used to test SWPs to the Global LEAP SWP Test Method; however, this instruction manual outlines specific detail about one configuration that has been in use since 2019 at the Schatz Energy Research Center.

2. Equipment List

This section lists all required/ recommended equipment for the SWP test bench, and it provides diagrams and photos to show more detail as to the layout and where each item fits into the whole system.

The SWP test bench may be broken down into sections when thinking through all of the included equipment and how to configure and connect it all into one system. The test bench has four, defined sections:

1. DAQ (data acquisition)
2. Piping network (and equipment integrated into this)
3. Chroma (solar array simulator/power source for testing)
4. Test bench frame

Below, each subsection will describe the equipment and materials required for each of the four sections and display where each belongs on the test bench. Outside of the test bench, there are other required and recommended items used for SWP testing along with facility requirements that are also outlined below. Note that the specific items listed in each table within this section may be replaced by equivalent items in some circumstances, which could depend upon availability and unique test lab conditions.

2.1 Test bench

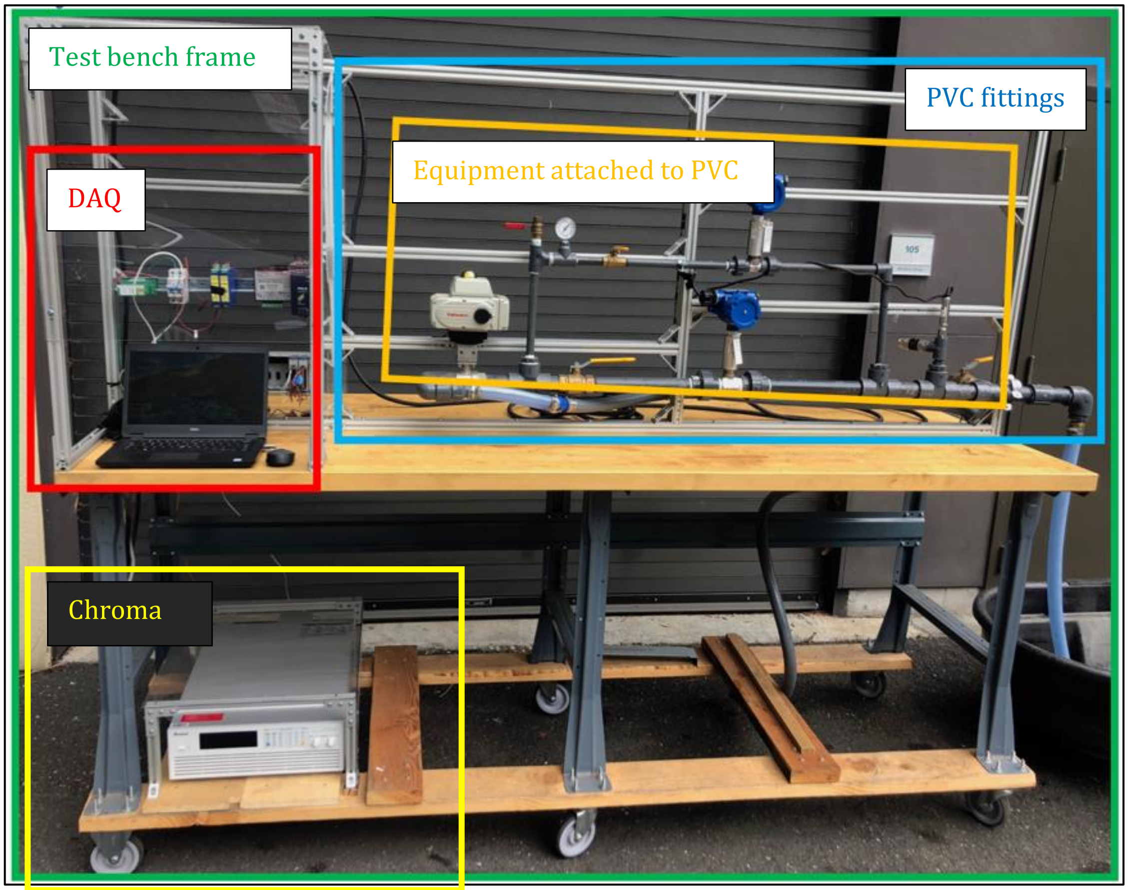


Figure 1. Test bench with the four designated sections specified

Figure 1 above outlines the organized layout of the SWP test bench with its four, defined sections.

2.1-1 DAQ

The data acquisition, or DAQ, section of the test bench includes equipment used for transferring measurement data from testing onto the computer via LabView software. In this section of the test bench, there are various electrical wiring connections required to complete these circuits. Table 1 below lists each item required for the DAQ section of the test bench, and the photo below shows where each item is incorporated, associated with the assigned item number in the table. This table also lists where each item was/ may be purchased and the estimated price per unit, if available, which may be variable depending on when and where each item is purchased. **Note that it is crucial to ensure all DAQ equipment are purchased already calibrated, when applicable, and to file their calibration reports in laboratory records.** Requesting a calibration upon purchase may incur additional costs, but this is required for acceptable test result accuracy.

Table 1. DAQ equipment used on SWP test bench

DAQ							
(D)	**item number**	**item**	**store/ website**	**description**	**price per unit***	**QTY**	**total cost**
	1D, 2D	omega drf-VDC (#1, #2)	Omega	DIN Rail DC or AC Voltage input signal condictioner (60mV to 650V), response time for DC signals, 70mS	$ 198.75	2	$ 397.50
	3D	WattNode Module for Modbus- WND-M1-MB, Opt BAUD=19200, AD=1	ctlsys.com		$ 330.32	1	$ 330.32
	4D	PULS Power supply- CS10.241; AC 100-120' 200-240V; DC 24-28V, 10A	DigiKey	AC/DC converter. Enclosed AC DC converts output 24V---10A 90~132 VAC, 180~264 VAC Input	$ 295.00	1	$ 295.00
	5D	CompactDAQ Chassis - National Instruments cDAQ-9178	National Instruments	Allows for synchronize measurements across a network and digitize data to sensors, minimize noise, simplify cable network. Has usb, ethernet, or wifi, mult slots to account for i/o for variouse applications. 8 slots, USB 2.0, onboard trigger.	$ 797.50	1	$ 797.50
	6D	Ni9265 C-series current output module	National Instruments		$ 619.00	1	$ 619.00
	7D	C series current input module - NI 9203	National Instruments		$ 887.00	1	$ 887.00
	8D	Ni9210 C-series temperature input module	National Instruments		$ 535.00	1	$ 535.00
	9D	multi-usb hub	Amazon.com		$ 65.53	1	$ 65.53
	10D	Laptop - Dell Latitude 5490	Amazon.com		$ 418.01	1	$ 418.01
	11D	DC Current transducer- CR5220-70	CR Magnetics	For reading in the current of the PV input into the controller/ daq system	$ 138.40	1	$ 138.40
	12D	IEC Supplementary Protector: 16 A Amps, 440V DC, 10kA at 440V DC, Screw Clamp, C	Grainger		$96.52	1	$ 96.52
	13D	Wire: 18 AWG wire spool- 1 spool of each color: red, black, green, white	Amazon.com		$ 8.95	4	$ 35.80
	14D	13 AWG SO cable- 4 -wire- extension cable	Amazon.com	purchase a few meters of this to act as an extension to connect the pump in the trough of water to the DAQ and controller equipment on the other side of the test bench	$ 16.90	1	$ 16.90

**note: price estimates listed above may not be currently or universally accurate; this exact equipment and model numbers may not be used in every test bench scenario.*

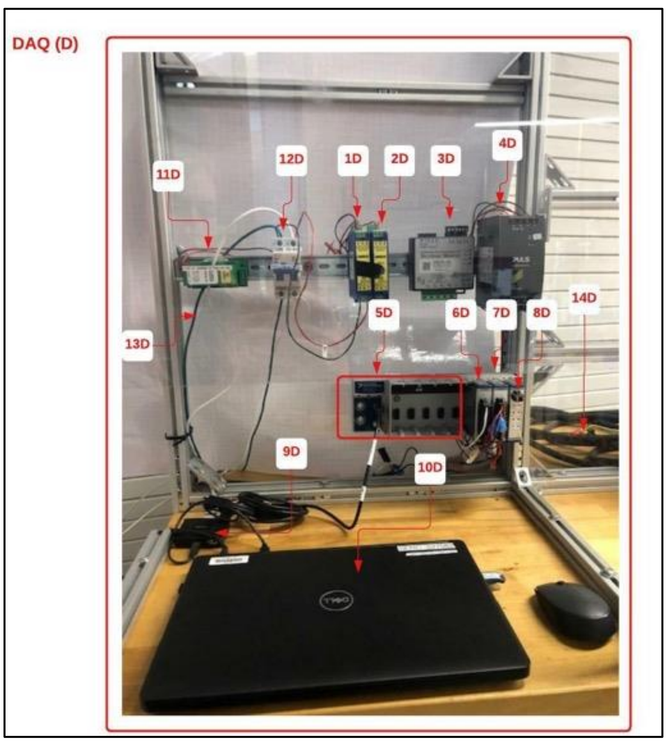


Figure 2. Labeled DAQ equipment on test bench

2.1-2 Piping network

The majority of the test bench incorporates a PVC piping network. Ensure to always use Schedule 80, plastic threaded PVC for optimal connections and pressure sustaining, when available. Each connection incorporates thread sealing PTFE plumbers' tape, further described below in this document. There are several PVC adapters that are incorporated into the network to make test bench maintenance easier and more accessible. Table 2 below itemizes all of the included PVC connectors, and Table 3 itemizes the equipment that is integrated into the piping network. These tables display a price estimate and where each item was purchased for the majority of the items, but the price will vary depending on where and when each item is purchased.

Note that it is required that all measurement equipment utilized by the test bench must be purchased calibrated and be sent to the test lab with a calibration report. Ensure to save the calibration report in a designated file for each calibrated piece of equipment for the test bench. Requesting a calibration upon purchase may incur additional costs, but this is required for acceptable test result accuracy.

The required items within the piping network are displayed below in Figure 3, which shows where each PVC connector and integrated equipment is connected on the test bench.

Table 2. PVC piping network on test bench

Piping network							
(P)	**PVC fittings**						
		item number	**item**	**store/ website**	**price per unit***	**QTY**	**total cost**
		1P	Schd 80 PVC- 1 1/4" thread to hose adapter (insert)- female NPT	ACE Hardware	$ 1.59	1	$ 1.59
		2P	Schd 80-PVC- 1 1/4" 90 degree elbow adapter, female NPT	ACE Hardware	$ 1.59	1	$ 1.59
		3P	Schd 80-PVC- 1 1/4" 90 degree elbow, female NPT	PVC Pipe Supplies	$ 2.69	2	$ 5.38
		4P	Schd 80-PVC 1 1/4" x 4" (length) straight male pipe (nipple) NPT	PVC Pipe Supplies	$ 3.89	5	$ 19.45
		5P	Schd 80-PVC 1 1/4" Tee female NPT	PVC Pipe Supplies	$ 5.79	4	$ 23.16
		6P	Schd 80-PVC 1 1/4" to 3/4" reducer (male to female) NPT	PVC Pipe Supplies	$ 2.59	4	$ 10.36
		7P	Schd 80-PVC 1/2" x 10" nipple NPT	ACE Hardware	$ 1.79	4	$ 7.16
		8P	Schd 80-PVC- 1/2" tee, female NPT	PVC Pipe Supplies	$ 2.29	3	$ 6.87
		9P	Schd 80-PVC 1/2" x 1.5" nipple NPT	ACE Hardware	$ 0.79	2	$ 1.58
		10P	Sch 80-PVC- reducer 1/2" to 1/4" NPT	ACE Hardware		1	
		11P	Schd 80-PVC 1/2" x 4" nipple NPT	ACE Hardware	$ 0.99	1	$ 0.99
		12P	Schd 80-PVC- 1/2" union NPT	ACE Hardware	$ 4.79	2	$ 9.58
		13P	Schd 80-PVC 1/2" 90 degree elbow, female NPT	ACE Hardware	$ 3.99	1	$ 3.99
		14P	Schd 80-PVC- 1 1/4" x 2" nipple, male NPT	ACE Hardware	$ 1.79	2	$ 3.58
		15P	Schd 80- PVC- 1 1/4" x 12" nipple, male NPT	PVC Pipe Supplies	$ 2.59	2	$ 5.18
		16P	Schd 80-PVC- 1 1/4" union, female (replacing nipple) NPT	ACE Hardware	$ 8.49	2	$ 16.98
		17P	Schd 80-PVC- PVC 1/2" x 2" (length) straight male pipe (nipple) NPT	PVC Pipe Supplies	$ 2.59	1	$ 2.59
		18P	Sch 80- PV -reducer 1/2" to 1/4" male to female NPT				
		19P	Sch 80- PV -reducer 1.25" to 3/4" male to female NPT	PVC Pipe Supplies	$ 1.49	1	$ 1.49
		20P	Schd 80-PVC 3/4" thread to hose adapter	PVC Pipe Supplies	$ 1.59	1	$ 1.59
		21P	Schd 80-PVC - reducer bushing 3/4" to 1/2" (male to female) NPT	PVC Pipe Supplies	$ 1.49	1	$ 1.49
		22P	Schd 80- PVC 1/2" x 2" adapter socket, female NPT	PVC Pipe Supplies	$ 1.19	1	$ 1.19
		23P	Schd 80- PVC1/2" x 1/4" straight male pipe NPT				
		24P	Brass inline ball valve, 600 psi, 1.25"- 600 CWP PN40 DN32	Grainger	$ 52.20	2	$ 104.40
		25P	Brass inline ball valve, 600 psi, 1/2"- 60 CWP PN40 DN15	Grainger	$ 18.79	1	$ 18.79
		26P	Brass inline ball valve 1/4" 107-401NL, 600psi CWP	Grainger	$ 12.30	1	$ 12.30
		**note: price estimates listed above may not be currently or universally accurate; this exact equipment and model numbers may not be used in every test bench scenario.*					

Table 3. Equipment attached to PVC piping network on test bench

Equipment attached to PVC piping network							
(E)	**item number**	**item**	**store/ website**	**price per unit***	**QTY**	**total cost**	**notes/ photos**
	1E	flow meter (model number FTB-107 and 103) **cable glands**	McMaster	$ 4.00	2	$ 8.00	
	2E	flow meter (model number FTB-107 and 103) **cap**	McMaster	$ 4.00	2	$ 8.00	
	3E	GP-15-SS Pressure Snubber- NPT Pipe adapter	Okeefecontrols	$ 10.00	1	$ 10.00	
	4E	Polyester braid reinfored inch tubing 3/4"(OD), 200psi (price by the foot)	McMaster	$ 1.55	25	$ 38.75	
	5E	Pressure Relief Valve, 300 psi- Kunkle valve, stainless steel, FNPT Inlet Type, 1/2" MNPT Outlet type- EMRN CRN0C8022.5CL	Grainger	$ 595.20	1	$ 595.20	
	6E	Electric actuated ball valve - Valworx 565270A	Assured Automation	$ 1,031.20	1	$ 1,031.20	note: not deemed necessary for testing
	7E	Flowmeter with signal conditioner - Omega FTB 103	Omega	$ 2,094.60	1	$ 2,094.60	
	8E	Flowmeter with signal conditioner - Omega FTB 107	Omega	$ 2,309.00	1	$ 2,309.00	
	9E	Pressure transducer - Omega PX409-250GV	Omega	$ 644.60	1	$ 644.60	
	10E	Item # MTG-22200S-PVC, PVC Mini Tuff Guard Isolator, 1/4" Inlet Male NPT, Composite PTFE/FKM Diaphragm, w/ 0-200 PSI 2" Dia. Black Painted Steel, Brass Internals Gauge	Grainger	$ 48.50	1	$ 48.50	

**note: price estimates listed above may not be currently or universally accurate; this exact equipment and model numbers may not be used in every test bench scenario.*

Note that the electric actuated ball valve was deemed not necessary for testing (item *6E* above). This item was originally purchased with the idea of automating testing; however, manually adjusting the test bench pressure using ball valves with adjustable handles has proven more effective for testing. This item was included in the table above but may be replaced by additional PVC adapters if desired.

Figure 3. PVC piping network with equipment attached labeled items

2.1-3 Chroma

The Chroma set up on the test bench includes several items, which are listed in Table 4, below. Figure 4 displays the equipment in this section of the test bench. Note that several items needed to build this section of the test bench are included in Figure 5 below, in the Test Bench Frame section; this is because several items are used across multiple sections of the test bench. Such items included across several sections include various types of connection gussets, hex screws, t-slotted framing, and more.

Note that the Chroma unit itself, when purchased, also included connection/ communication cables, a software kit, and a mounting kit for set up and use.

Table 4. Chroma equipment list

Chroma- PV array simulator						
item number	**item**	**store/ website**	**description**	**price per unit***	**QTY**	**total cost**
1C	Chroma 62150H-600S	Chroma USA	solar array simulator, software kit, rack mount kit	$ 21,858.20	1	$ 21,858
2C	Clear Impact-resistant Polycarbonate Sheets and Bars (see items 1T-e and 1T-f in Test Bench Frame table)	McMaster Carr	--	--	--	--
3C	Solid single four slot t-slotted framing rails (1 x 1") (length needed 39")	McMaster Carr	--	$ 0.79	39	$ 30.81
4C	10 AWG electrical wire spool for DAQ output leads- red and black	Amazon	current-carrying output of Chroma	$ 36.92	2	$ 73.84

**note: price estimates listed above may not be currently or universally accurate; this exact equipment and model numbers may not be used in every test bench scenario.*

Figure 4. Chroma set up with labeled items

2.1-4 Test bench frame

The test bench frame includes the materials used to hold all of the testing equipment. Table 5 below includes an itemized list of the necessary pieces to build up the test bench frame, and Figure 5 displays where each is integrated into the test bench. Figure 6 also displays an itemized layout. Note that the exact sizes/ amounts listed in Table 5 for several items may not represent what was actually purchased. For instance, sometimes, only specified multi-packs of an item are available and must be purchased. Another example is the polycarbonate sheets: they must be purchased at standard available sizes and cut down to the appropriate dimensions specified in the table below to fit the test bench. With some items needed in bulk quantities, such as hex screws or t-nuts, it makes sense to purchase more than the number determined to be needed to allow for repair/ replacements or test bench expansion or updates.

Table 5. Test bench frame equipment list

Test bench frame							
(T)	**item number**	**item**	**store/ website**	**description**	**price per unit***	**QTY**	**total cost**
	1T	Clear Impact-resistant Polycarbonate Sheets and Bars	McMaster Carr	Safety shields for test bench	--	--	--
	1T-a	22" x 24"	McMaster Carr	Safety shield separating the PVC network from DAQ section	--	1	--
	1T-b	22" x 38"	McMaster Carr	safety shields on top of the DAQ	--	1	--
	1T-c	17.5" x 36"	McMaster Carr	safety shield half-cut in front of the computer to protect tester from electronics	--	2	--
	1T-d	10" x 24.5"	McMaster Carr	safety shields on either side of Chroma	--	2	--
	1T-e	20" x 24.5"	McMaster Carr	top of Chroma shield	--	1	--
	2T	Surface strut channel brackets elbow- 3.5 x 3.5" (each gets 5 hex screws and t-nuts)	McMaster Carr		$ 6.97	10	$ 69.70
	3T	Grainger butcher block workbench assembly: 4000 lb load capacity, 96x30x33.75, steel legs	Grainger		$ 1,059.34	1	$ 1,059.34
	4T	Corrrosion-resistance medium-duty standard plate casters and wheels- 6"	Grainger	wheel and caster assembly- 1200lb capacity	$ 200.00	6	$ 1,200.00
	5T	Mounting Track, 35mm DIN Rail (60")	McMaster Carr		--	--	--
	6T	Solid single four slot t-slotted framing rails (1 x 1") (170" needed)	McMaster Carr		$ 0.79	170	$ 134.30
	7T	T Gusset (3.5" x 3"), 2-pack (each uses 2 hex screws and t-nuts)	VersaFrame		$ 4.49	2	$ 8.98
	8T	(Short)Inside-Corner Gusset corner bracket (1.5 x 1 5/16x 1.5 x 1"), 15 series (each gets 2 hex screws and t-nuts)	80/20, Grainger		$ 8.46	13	$ 109.98
	9T	Tall Inside- corner Gusset corner bracket (2x 2 x 2") (each gets 8 hex screws and t-nuts)	80/20, Grainger		$ 8.46	24	$ 203.04
	10T	Solid double six slot t-slotted framing rails (silver anodized aluminum, 2" x 1" solid) 465"	McMaster Carr		$ 79.76	4	$ 319.04
	11T	slide-in T-nuts	McMaster Carr		--	--	--
	12T	2x4 Douglas Fir plank (36" length)			--	2	--
	13T	2x4 Dougla Fir plank (96" length)			--	2	--
	14T	hex socket cap screw- M1.4-M42, coarse (8mm nominal thread, 1.25 pitch)		pack of 500, for connecting all gussets and measurement equipment on test bench	$ 375.00	1	$ 375.00
	15T	hext bolt- m4- m16, coarse, configurable thread (steel) (10mm head)		for connecting wooden planks and wheels to test bench (100 pack)	$ 10.66	1	$ 10.66
	16T	1.5" Screw-on conduit and cable hangers	Grainger	for the PVC/ hosing on the outlet-side of the test bench; connecting to frame (2) and for the PVC/ hosing on the inlet side and in the high-flow piping network branch (2)	$ 13.77	4	$ 55.08
	17T	3/4" screw-on conduit and cable hanger	Grainger	(1) for the low-flow PVC branch to the framing	$ 7.15	1	$ 7.15
	18T	Wiring duct for t-slotted framing (1in nom wd, 0.6 slot height, 0.3 slot wd, lead-free pvc (9' total needed)	Grainger	to protect and manage daq wiring. QTY price is for 72" (need 101")	$ 45.30	2	$ 90.60
	19T	Phillips head screws for butcher block to legs			--	24	--

**note: price estimates listed above may not be currently or universally accurate; this exact equipment and model numbers may not be used in every test bench scenario.*

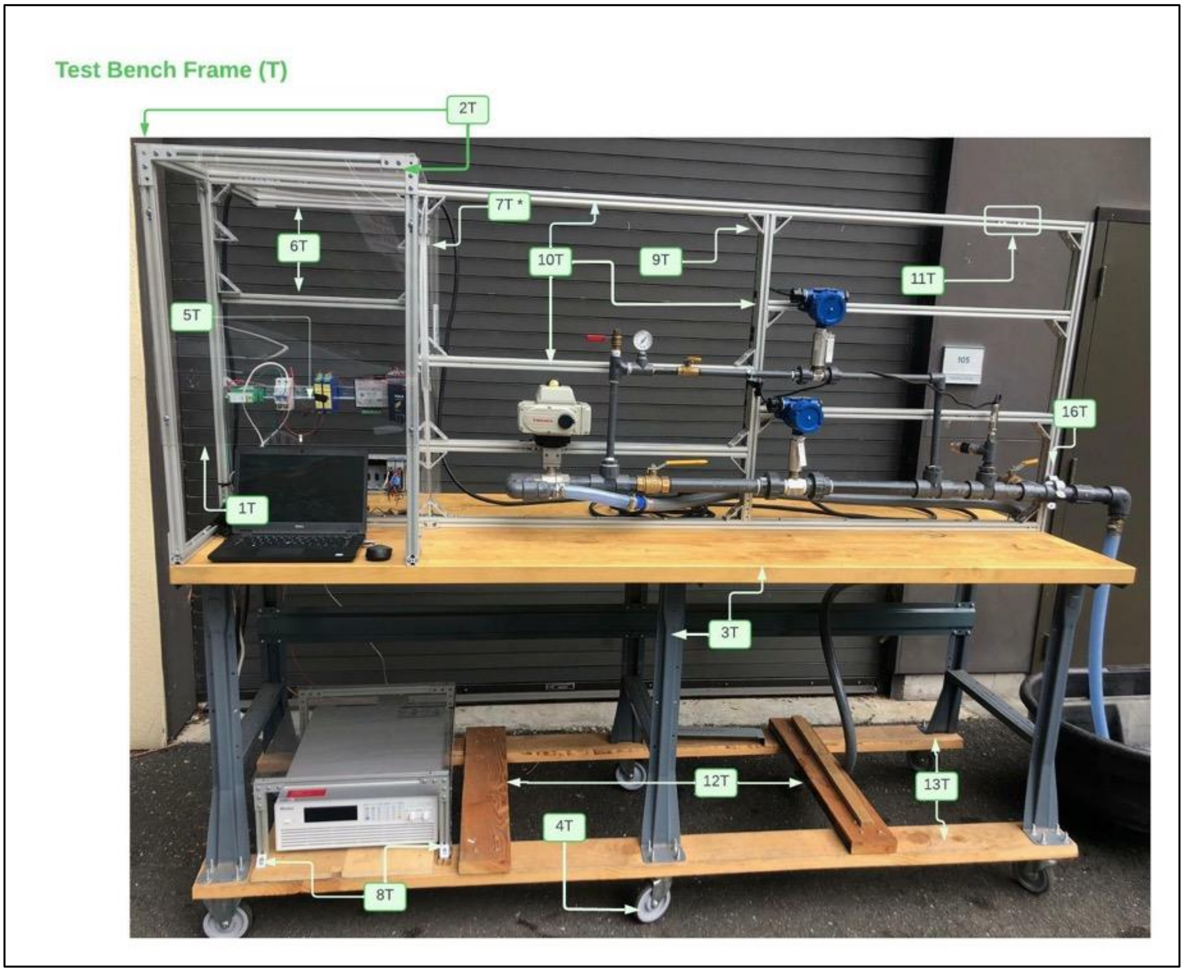


Figure 5. Test bench photo displayed with integrated equipment to frame.

**Item 7T cannot be seen in the photo above; however, one of these items is located near where it is indicated in the figure above.*

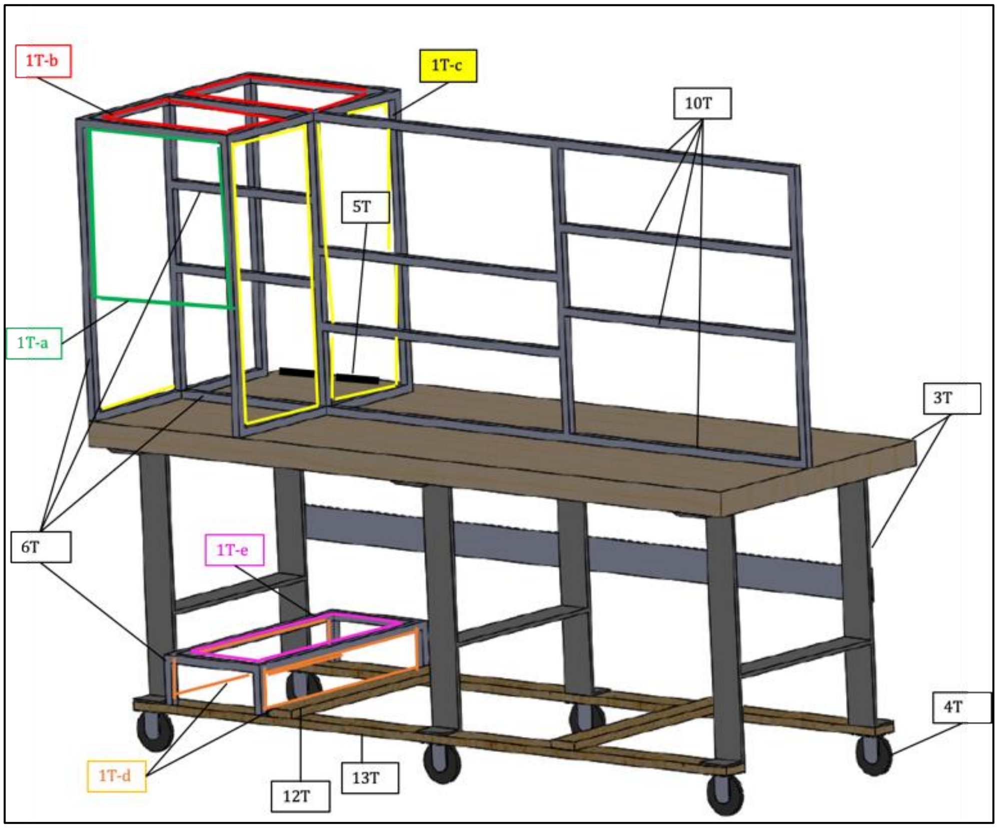


Figure 6. Simplified diagram of test bench framing

Note that Figure 5 and Figure 6 do not include all listed items in Table 5.

If specific items need to be replaced with alternative models/ parts, then make sure any weight-bearing materials have enough capacity to hold the testing equipment. Note that for this specific test bench outlined in this instruction manual, the following items have the rated weight restrictions:

Table 6. Major SWP test bench items that are weight-bearing and their ratings

Item	Item code in Table 5	Rating (lb.)
Grainger butcherblock workbench assembly	3T	4000
Corrosion-resistant caster-wheel assembly	4T	1200

Note the weight ratings provided when purchasing new equipment, and record this information somewhere so that the test bench limitations are known. Table 9, below, outlines the general test bench limitations of this test bench, which includes weight limitations.

2.2 Additional testing equipment and facility requirements

Besides from the test bench permanent equipment/ items needed, there are additional materials needed for SWP testing. Table 7 lists several required and recommended tools and other materials, some of which will need to be used for certain tests. Note that not all of these tools and materials are specifically required for general testing; however, they are highly recommended as they serve different, useful purposes. If similar tools/ materials are available or more accessible that serve equally as useful as the list below, then they are encouraged to be used for different aspects of testing. Please refer to SWP testing SOPs for more insight into what materials are needed for each specific test or procedure involved in this work.

Table 7. Other equipment/ materials required and recommended for test

Other equipment and materials used for testing and suggested equipment						
item	**suggested store/ website**	**description**	**price per unit***	**QTY**	**total cost**	**Recommendation/ Requirement**
50-gallon livestock tank	Ace	water trough to fill with water for testing	--	1	--	required.
Plumber's Tape	--	will need to continue buying this	--	--	--	required.
furniture dolly area needed (17.5" x 29.5")	--		--	1	--	recommended
flexible tubing 3/4"		buy at least 10m of this; will use it	--	--	--	required.
Ear hose clamps 3/4"	McMaster Carr	buy an entire pack	$ 5.89	1	$ 5.89	required.
Pinch Clamp Plier	McMaster Carr	--	$ 39.25	1	$ 39.25	required.
adjustable hose clamps	--	--	--	--	--	required.
allen wrench	--	--	--	--	--	recommended
13 AWG SO cable- 4 -wire- extension cable	Amazon.com	purchase a few meters of this to act as an extension to connect the pump in the trough of water to the DAQ and controller equipment on the other side of the test bench	$ 16.90	1	$ 16.90	required.
stopwatch	--	for dry run protection test and strain relief test	--	1	--	required.
digital camera or phone camera	--	for visual screening, take photos during testing, and internal inspection	--	--	--	required.
meter measuring stick	--	for the drop test and measuring the dimensions of the components	--	--	--	required.
clamp meter with ability to measure inrush current	--	for inrush current measurement- can use EX830 clamp meter	--	--	--	required.
customized multi-angle set up for strain relief	--	--	--	1	--	required.
general tools: screwdrivers, vice, pipe wrench, vice, torque wrench; power tools: drill with different bits	--	--	--	--	--	recommended
Several 250W PV modules	--	this is in cases of Alternative Test Method; in these cases, could request PV array from SWP manufacturer. Good to have these on hand.	--	6	--	recommended- required if need to do the Alternative Method testing on any pumps received.
Semi-transparent material	--	in cases where the alternative test method is needed	--	--	--	recommended- required if need to do the Alternative Method testing on any pumps received.
safety glasses	--	for the drop test and can be used in some cases during internal inspection	--	--	--	recommended
scale	--	to weigh all components	--	1	--	required.
2kg weight	--	for strain relief	--	1	--	required.
clamp to connect 2kg weight to cable for strain relief	--	for strain relief	--	1	--	required.
5 gallon bucket with lid for oil disposal	McMaster Carr	internal inspection	--	1	--	required.
akro bins	--	for organizing tools and materials	--	4	--	recommended
calibrated multimeter- Fluke 287 recommended	--	for calibrations	--	--	--	required.
mineral oil	--	for test bench maintenance	--	--	--	required.
Oil filter to separate oil from water if there's a leakage	New Pig	--	$ 389.00	1	--	recommended
multiple sizes/ types of schedule 80 PVC adapters	--	--	--	--	--	required.
banana plug adapters	--	used during some in-house calibration procedures	--	--	--	required.
Spill tray	--	Used during internal inspection to catch any leaked oil when taking the pump apart.	--	--	--	recommended
Fire extinguisher	--	For electrical safety	--	--	--	recommended
machine oil	--	maintenence	--	--	--	required.
extra WAGO connectors	--	for in-house calibrations, test bench updates, etc.	--	--	--	recommended
extra planks of wood/ strong base the size of the solar array simulator	--	to build strong base for the solar array simulator to permanently sit across the bottom base of the test bench.	--	--	--	recommended.
Label maker	--	For organization	--	--	--	recommended.
wipe for oils and solvents (bag of 66)	McMaster	--	$ 16.82	1	$ 16.82	recommended
**note: price estimates listed above may not be currently or universally accurate; this exact equipment and model numbers may not be used in every test bench scenario.*						

The items listed in the table above have different purposes for testing work. Some of the items are recommended or required for safety purposes, some for calibration and maintenance procedures, some to enable flexibility of the test bench, and some are used for specific tests outlined in the test methods. In the table, there are 250W PV modules and semi-transparent material listed, which are specifically for testing using the Alternative

Test Method, which is outlined in the published SWP Test Method and described in *12 SWP Alternative Test Method SOP*.

Several common tools are listed in the above table as recommended items to have on-hand for testing, as with each SWP that arrives for testing, there are adjustments that need to be made since SWPs come in different shapes and sizes (and the test bench is not as easily adjustable). It is important to have various tools in order to make necessary adjustments for a wide-range of products. Similarly, it is also recommended that the test lab acquire various PVC adapters to accommodate for various sizes of pump outlet pipes as the test bench has one size of hose and PVC that will need to connect to the pump's outlet.

See **Appendix A- Additional Recommended/Required Materials** for more detail on several of these required/ recommended items.

In addition, there are also several facility requirements in order to perform this testing, as listed in Table 8 below.

Table 8. Facilities requirements for testing SWPs

Facilities and Tester requirements for testing	
Condition/ item	**notes**
Breaker box/ AC power	The Chroma requires an AC input. The minimum AC input recommended can be provided by a 208Vac, 20A breaker box; this is to ensure there is enough power to test (up to ~4kW can be simulated by the Chroma). Additionally, if power tools are needed, they will need electricity, along with the computer used to collect data.
Flat, exposed space to conduct Alternative Test Method when needed	Adjacent to the normal testing location, there needs to be a large, flat space (at least 250sq.ft) to perform the Alternative test method when needed. This space must be close enough to the normal testing space so that the test bench DAQ equipment can be powered from the grid and exposed to full sun.
Indoor shelter to protect testing equipment from outdoor elements.	The electrical equipment cannot get wet; there must be a designated space indoors to protect testing equipment from the outdoor elements.
Running, clean water and nearby drainage	Clean water is required for testing, and a nearby drainage is needed to discard of the water after testing has been completed for each pump. The equipment used for testing cannot handle dirty water, so it is not recommended letting water sit in between testing if it will be longer than one day, unless there is a cover for it.
Hazardous waste disposal	During the internal inspection, some motor enclosures are filled with hydraulic oil, which is considered toxic waste and must be disposed of properly. There must be access to hazardous waste disposal onsite or nearby the testing facility.
Oil/water filter ability	During testing, some of the SWPs leak oil into the source water used for testing. There must be a way to filter the oil out of the source water so that it may be safely and properly disposed of. A filter may be purchased or made, and the collected oil may be disposed of via safe biological processes or via acceptable toxic waste disposal.
Metal recycling and e-waste recycling	There must be recycling and e-waste disposal accessibility onsite or nearby the testing facility for tested, nonfunctional SWPs.
Other recycling availability	The pumps arrive generally in cardboard or wooden boxes; there must be a facility that can take these other materials for recycling.
Testing space- test bench	The test bench set up requires about 50 square-feet of space for storage and use; additionally, it is recommended that some additional space be used for shelving and storing tools and materials. Additionally storage space for pumps that haven't been disassembled after testing is recommended.
Internet	Internet must be available/ accessible at the facility in order to perform some of the SWP tests and maintain communication to clients during and after testing.
LabView experience	Must have someone on team that is familiar with LabView to set up the DAQ with this software.
Electronic experience	Must have testers on team that has experience with electronics and safety protocol related to this type of hands-on work.

In addition to the requirements listed above, there are also software requirements for the test laptop or computer. The following programs or equivalent must be able to be used:

- Microsoft Office: Excel, Word
    - Excel add-ins required: Visual Basic, solver
- Adobe (to save and read PDFs)
- LabView

- Software required for the solar array simulator

2.3 Test limitations

Note the test limitations of the test bench, which rely on the limiting equipment integrated. Limitations include: electrical power input, system pressure, flow rate, and possibly other identifiable factors. The electrical power input limitations relate to the available AC power outlets and hookups, the solar array simulator model chosen and its ratings, DAQ equipment input limitations, and any safety equipment put in-line with the DAQ equipment (such as any fuse switches utilized). System pressure limitations mostly relate to the PVC network and the items and connections integrated; for instance, one common limiting piece of this network may be the threaded hosing and its connections. Additionally, pressure limitations may change overtime with use, so it is important to replace parts and connections when needed and practice routine maintenance on the test bench, which is detailed in the *SWP Calibration and Maintenance SOP*. The following table lists several of the testing limitations of the test bench outlined in this manual.

Table 9. SWP test bench testing limitations of test bench in this manual

Testing Limitations				
PV POWER INPUT				**TEST LIMIT**
Equipment	limit	units	Notes	
Chroma	4.16	kW	MAX input TO chroma is 208V, 20A. Need to calculate if get close to limit whether or not voltage and amperage will remain under this.	***2.4 kW***
PV array- Alternative test method	2.4	kW	And we are limited by the season. This limitation is based on configuration and space mainly. There may be some flexibility in certain circumstances.	
HEAD/TEST BENCH PRESSURE				
	limit	units	Notes	**200 psi/ 140 meters of head** (to ensure we don't trigger safety valve)
manual ball valve	600	psi	--	
automatic ball valve	1000	psi	This piece is deemed unnecessary for testing; however, it is still integrated into the test bench.	
Large flow meter	250	psi	--	
Small flow meter	250	psi	--	
PVC network	300-600	psi	hose clamps do not have psi ratings from what was researched.	
maximum pressure safety valve	250	psi	--	
PHYSICAL PUMP SIZE				
	limit	units	Notes	--
testing tanks	1000	gal		
FLOW RATE				
	limit range	units	Notes	***5-350 lpm***
Large flow meter	6-93/22-353	GPM/lpm	--	
Low flow meter	1.25-9.5/4.7-35	GPM/lpm	--	

3. Test bench diagram and building instructions

This section provides instructions and tips on how to build the test bench for testing SWPs.

Before starting to build a SWP test bench, ensure to follow all safety precautions related to the use of power tools and possible shop machinery, wiring electrical circuits and making electrical connections, and lifting heavy weight. Please refer to the *1. SWP Testing Safety* Standard Operating Procedure (SOP) for more information about testing safety, which can be translated to this test bench building work as well.

The figure below outlines general measurements of each section of the test bench that may be used as guidance when building a new one.

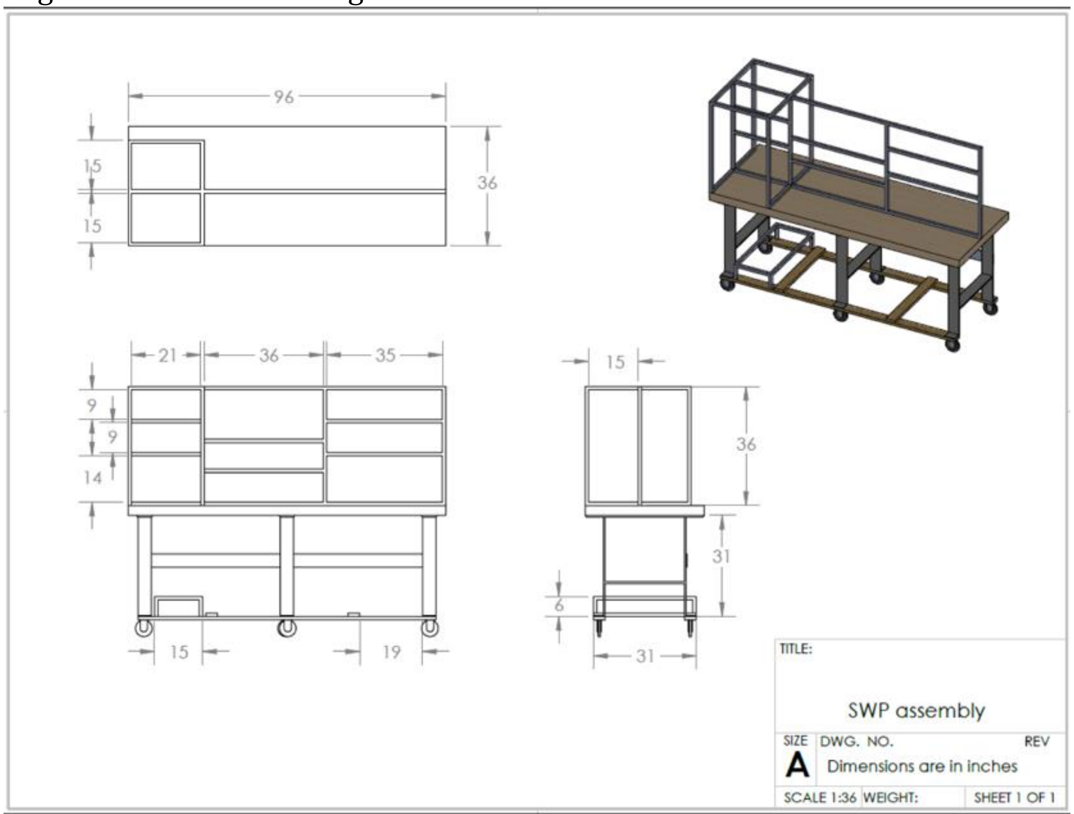


Figure 7. Rendering of the test bench in this manual, including dimensional measurements of all sections

3.1 Building the test bench frame

The following steps shall be followed as guidelines to building a new SWP test bench:

1. Reference the Tables 1-8 above to ensure all materials and equipment are available, and all general requirements are met. In addition to these materials, you will also need basic tools needed for building, such as several sizes of screwdrivers, drill (and different sizes/ shapes of drill bits), circular saw or hack saw (for cutting metal and polycarbonate sheeting), screws/ bolts, etc.
2. Start building the SWP test bench by first building out a strong, wooden base with wheels for the bench to sit upon (six wheels, distributed evenly on either side of the test bench) (reference Table 5 for guidance and Figure 7 to measure out even placement of wheels).
    a. This base is built to enable the full test bench to become mobile and to provide more durability. A strong wood (Douglas Fir or something equivalent

in durability: weight-bearing, rot resistant, strong) or an equivalent material may be used to build out the base.

b. Cut the required number of wooden base pieces to the specified lengths specified in Table 5. There should be two longer pieces and two shorter pieces.

c. To affix these items, large bolts may be used, as specified in the Table 5, above. The figures below show the wooden base of the test bench and where the bolts are utilized for each permanent connection.

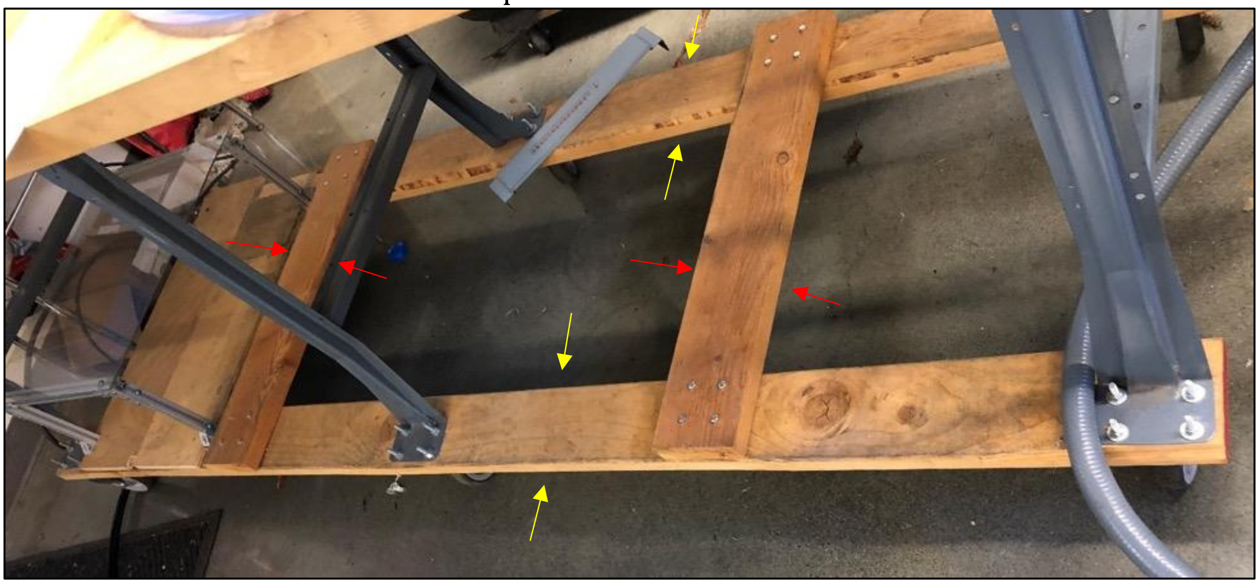


Figure 8. Wooden base with wheels that the test bench sits upon to enable mobility (red arrows pointing to short wooden planks, yellow to the longer wooden planks used for the base)

Figure 9. Wooden base bolted together to ensure durability

Figure 10. Metal legs bolted to the wooden frame directly over the wheels (underneath the wooden frame)

Figure 11. Wheels installed on casters that are bolted to the underside of the wooden base- there are six wheels total.

3. Note that the shorter planks of wood should be spaced across the longer planks in between where the steel test bench legs and wheels are going to be installed, so space out accordingly (Figure 8 and Figure 10).
4. Secure the casters and wheels on the underside of the long wooden planks of the base (Figure 11).
    a. Space them out evenly so that there are three wheels per long-side of the test bench at equal distances from one another.
    b. Use hex bolts and washers to permanently connect the casters to the wooden plank, as shown in Figure 11 above.
5. Next, secure the steel test bench legs (listed as item *3T* in Table 5) of the SWP test bench to the wooden base (see Figure 10 and Figure 12).
    a. The steel legs should be bolted to the center of the wooden base and spaced equal distances apart to ensure proper balance and strength (see Figure 12 below).

Figure 12. Metal legs bolted with hex bolts securely to the wooden base piece and approximately centered for balance and strength

   b. Each metal leg should be secured above each wheel, as shown in the figure above.
6. Before connecting the butcher block table to the metal legs, ensure its surface has been applied with mineral oil (this helps to make the table water-resistant). To do this, see this procedure outlined in the *SWP Calibration and Maintenance* SOP.
7. The butcher block should be secured to the metal legs of the test bench as per the manufacturer's instructions. See the figures below to see how the legs placement should look after affixing to the butcher block.

Figure 13. SWP test bench metal legs screwed to the underside of the butcher block table

Figure 14. SWP test bench metal legs and support across screwed to the underside of the butcher block table

Figure 15. Metal legs attached to the butcher block

Figure 16. Underside of the butcher block with legs attached

8. Next, cut the correct lengths of the *double* T-slotted aluminum framing rails (item *10T* in Table 5) for the of the base of the framing network that will be attached to the butcher block's surface. Refer to Figure 7 and Figure 17 for the approximate measurements needed and guidance for placement. Note that the *double* T-slotted framing that makes up the base of the framing network should be cut as long as the test bench.
9. Connect the *double* T-slotted framing acting as the base to the butcher block by driving hex bolts with washers spaced approximately 8" apart directly into both materials.
    a. See the figures below, which show that the base of the framing should be attached to the butcher block close to the center, length-wise along with the hex bolt connection. Ensure that the measurements are approximately met in placement as specified by the diagram in Figure 17, below.

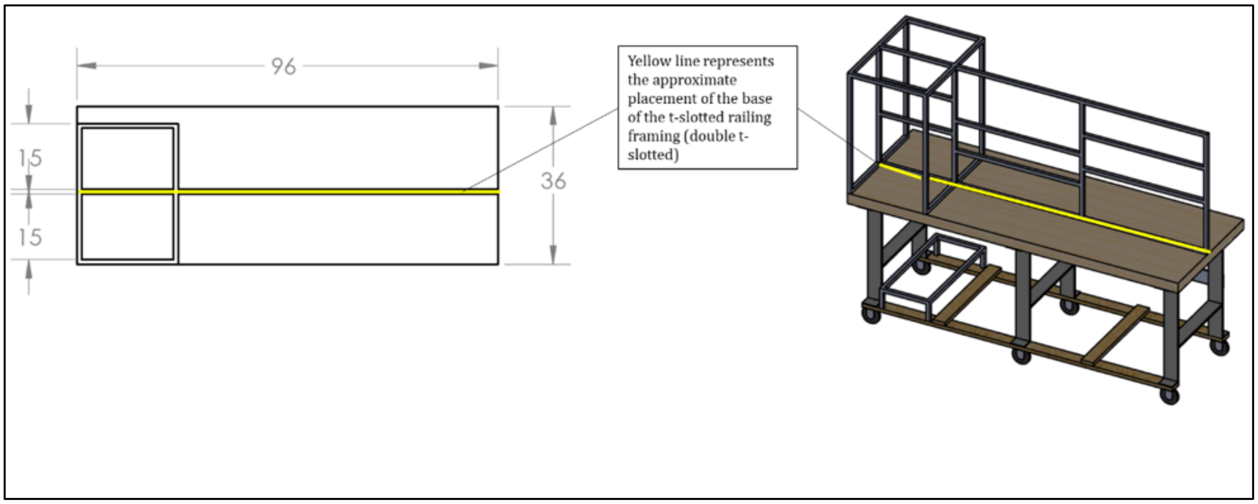


Figure 17. Yellow outlines approximately where the double T-slotted framing base should be affixed to the butcher block

Figure 18. Base of the t-slotted framing bolted directly to the butcher block down the center of the surface to build the rest of the metal frame upon

Figure 19. Hex bolt and washer driven through the t-slotted framing and into the butcher block for solid connection

10. Cut the other pieces for the framing rail network rest to build up on top of the base as per the segmented measurements specified in Figure 7.
    a. Note that *double* T-slotted framing (item *10T* in Table 5) is utilized for most of the framing network; however, there are several segments of the framing that utilizes *single* T-slotted framing (item *6T* in Table 5). See the figure below to see where the *double* T-slotted framing is applied, and where the *single* T-slotted framing is utilized.
        i. Note that if *double* T-slotted framing is preferred to be used, it may be used for the entire test bench framing; however, more eight-screw gussets may be required than listed currently in Table 5 to attach all framing segments if this is decided.
        ii. Note: *single* T-slotted framing should not be used to replace areas of test bench frame specified for the *double* T-slotted framing; this is mainly due to weight capacity of the *double* versus the *single.*

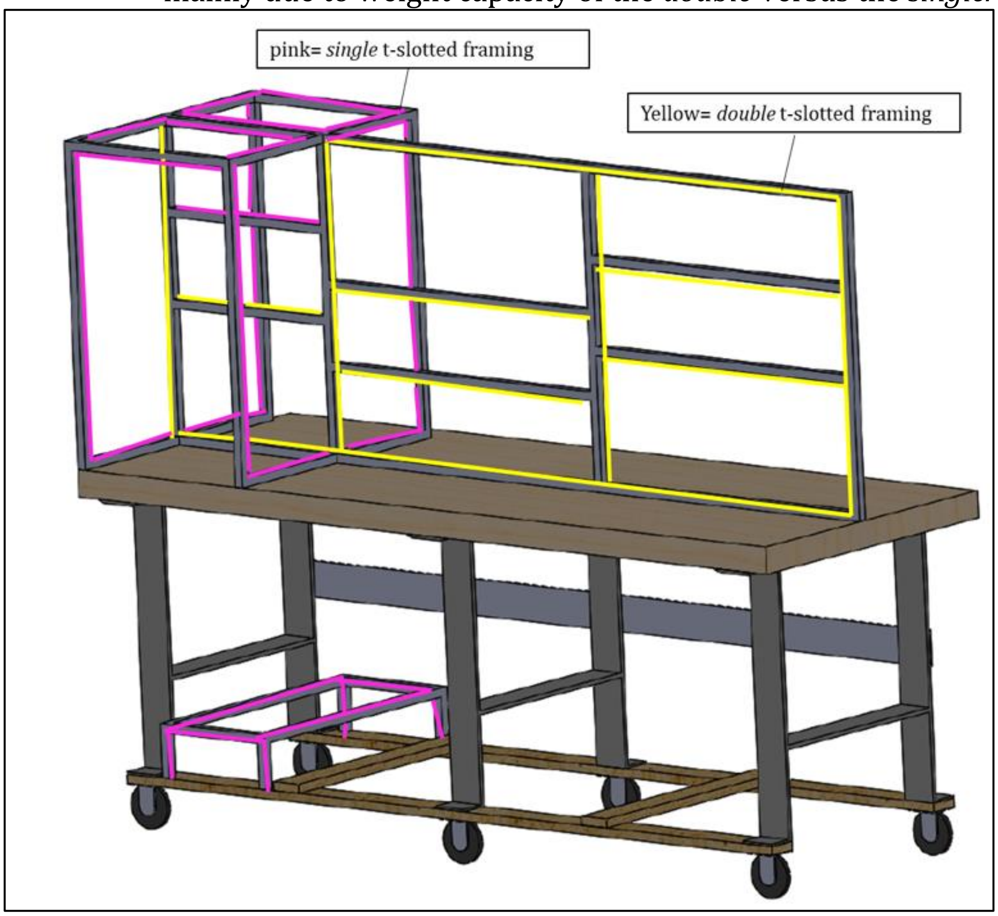


*Figure 20. Test bench framing: yellow represents **double** t-slotted framing section(s), and pink represents **single** t-slotted framing section(s)*

11. To make framing connections, gussets and hex screws will be utilized to make corner connections. Additionally, L gussets will be connected to outer corners to secure framing sections to one another in the DAQ and Chroma sections of the network (not needed in the PVC network section of the test bench).

12. Before each framing segment is connected, install slide-in t-nuts (t-nuts) to the T-slots in the rails. These will be used to make almost all of the connections to the framing: connecting the gussets, integrated equipment, screw conduits for PVC network, DAQ equipment, polycarbonate sheets, and possibly more depending on the segment being installed.
    a. Reference Table 5 to see the number of t-nuts and hex screws needed per gusset type (included in items *2T*, *7T*, *8T*, and *9T*), and see Figure 2, Figure 3, and Figure 5 to see how many components there are attached to each section of framing to help plan.
        i. In general, the measurement and DAQ equipment attached to the framing usually use two t-nuts and hex screws each for attachment.
        ii. Almost every rail-to-rail connection for the *double* T-slotted framing will utilize an eight-screw gusset (meaning eight t-nuts), and every rail-to-rail connection for the *single* T-slotted framing will utilize a two-screw gusset (meaning two t-nuts).
        iii. All outer corners of the DAQ and Chroma sections of the test bench will utilize L gussets, and there will be four T gussets used to connect the polycarbonate sheeting to the double t-slotted framing separating the DAQ and PVC network sections of the network.
            1. See Table 5 for the number of t-nuts and hex screws are required for these gusset types.
        iv. See the figure below for a general layout (note that the figure is not inclusive of every single gusset needed; however, it helps to describe the concept).

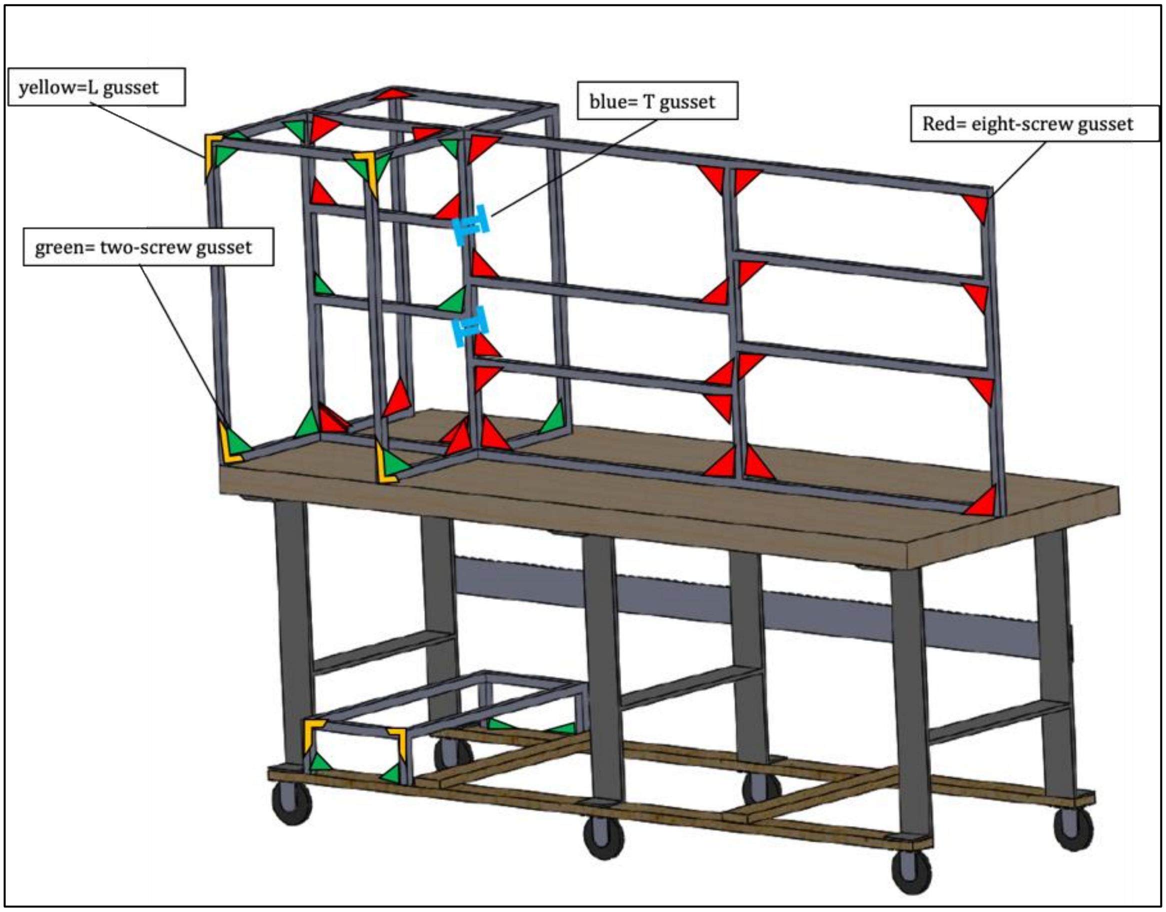


Figure 21. Approximate layout of all gussets on the test bench framing.

v. Note that the PVC screw conduits utilized to hold the weight of the PVC/ hosing components also connect to the framing via one t-nut and hex screw each. In general, there should be 2-3 of these items needed for the railing segments within the PVC network section of the test bench, and 1-2 PVC screw conduits closer to the segments closest to the test bench inlet hosing.

b. Note: it is advised to count how many items per SWP test bench section that will need to utilize t-nuts (other than considering gussets, also consider which rail will hold which equipment and determine the number of t-nuts).

c. Before completing the railing network in each section (generally by installing the connection gusset), ensure the required number of t-nuts have been slid into place within the groove of the t-slotted framing. It is recommended to include more t-nuts than the number estimated for each section to allow for more additions, if needed.

Figure 22. t-slot nut that is used to secure equipment onto the framing with a hex screw

Figure 23. Some of the outer perimeter railing utilizes L-shaped gussets, which are affixed using an Allen wrench, hex screws, and t-nuts that are slid into the railing's slot.

13. After sliding in the required number of t-nuts to a t-slotted framing rail segment, you may begin to make each railing connection to build the network.
    a. Some helpful resources are listed in **Appendix B-Resources for Making Connections** on how to affix these types of railings into a network using hex screws, t-nuts, and gussets.
    b. Also, see the figures below to see some examples of the gussets and elbows utilized to attach corners of the framing together.

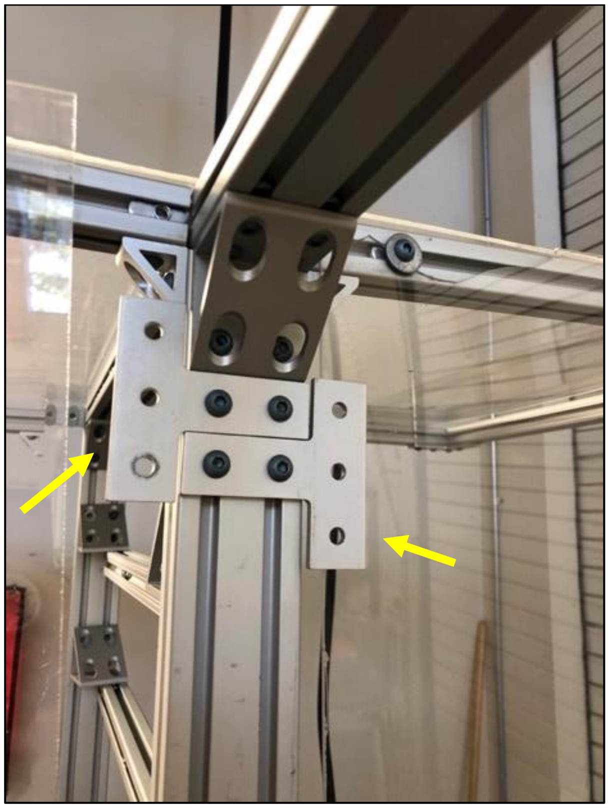


Figure 24. Double t-slotted framing railing connected to the polycarbonate sheets by 2 t-gussets, 4 hex screws, and 4 t-nuts

Figure 25. T-slotted framing base is bolted directly to the surface of the butcher block bench and t-nuts are slide into the framing grooves prior to connecting both ends of each segment in the test bench

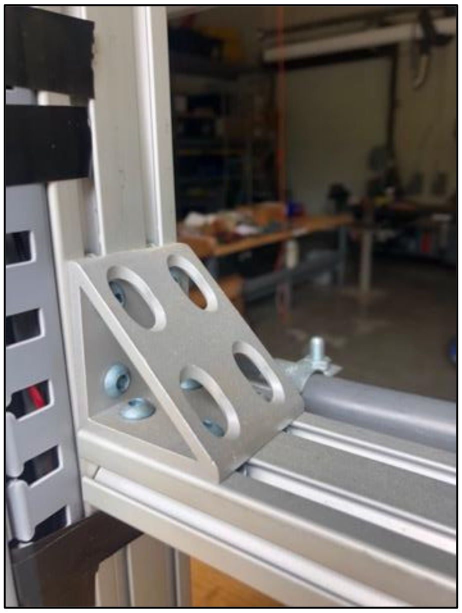


Figure 26. Double T-slotted framing held together in the corners with a gusset, 8 hex screws, and 8 t-nuts

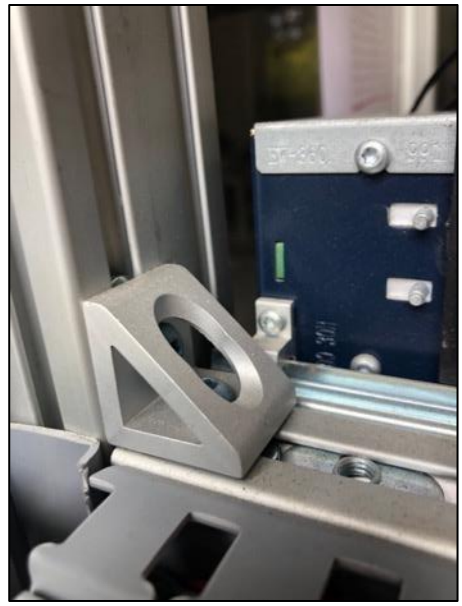


Figure 27. Single T-slotted framing held together in the corners with a gusset, 2 hex screws, and 2 t-slot nuts

Figure 28. T-slotted framing held together in the corners with an elbow support, 3 hex screws, and 3 t-nuts- the screws are also going through a polycarbonate sheet here (more could be used here)

Figure 29. T-slotted framing held together in the bottom corner with 1 elbow support, and 5 hex screws, and 5 t-nuts. The base framing is bolted into the surface of the butcher block

14. Once the t-slotted segments are built in the DAQ section of the test bench, install 35mm mounting track (item *5T* from *Table 5*) to both the *single* t-slotted framing segment(s) (item *6T* from *Table 5)* and butcher block as specified in Figure 30

below. This mounting track is used to better attach the DAQ equipment to the railing network and to hold terminal blocks to help connect the Chroma to the DAQ equipment.

Figure 30. Blue indicating where the 23mm mounting track should be affixed to the t-slotted railing segment and butcher block utilizing t-nuts and hex screws, or washers and hex bolts, respectively.

15. After the railing network has been built and mounting track affixed, cut polycarbonate sheets in the measurements specified in Table 5 (subitems listed under item *1T*). Affix the sheets to the railing in the locations specified in Figure 6 by drilling holes along each edge that will be directly connected to a t-slotted frame and connecting the two materials using hex screws, washers, and t-nuts affixed approximately every 8".
    a. To do this, some of the gussets (elbows, t-gussets) might need to be temporarily removed to re-install over a polycarbonate sheet to "pinch" it in between the hex screw head and the t-slotted framing. In general, the sheets need to be attached so that they are affixed around the electrical DAQ equipment, testing computer, and the solar array simulator.

Figure 31. polycarbonate sheet affixed between t-slotted framing using hex screws, t-nuts, and elbow gusset

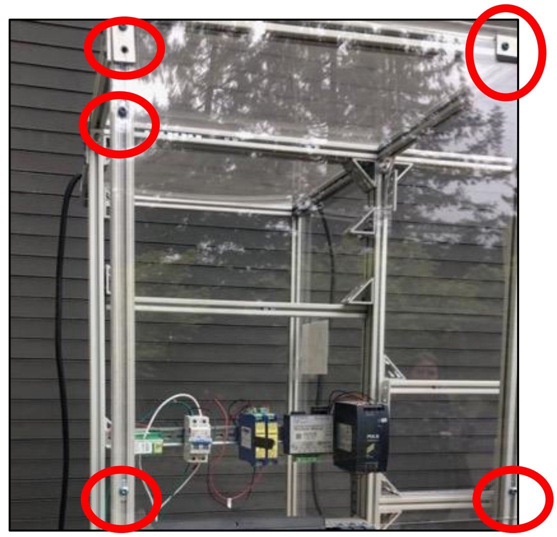


Figure 32. Polycarbonate sheet affixed to the t-slotted framing with hex screws and t-nuts and some gussets on the corners

Figure 33. Polycarbonate shield installed on the t-slotted framing by drilling a hole and attaching with a hex screw twisted tight to a t-nut with a washer in-between the screw and the sheet

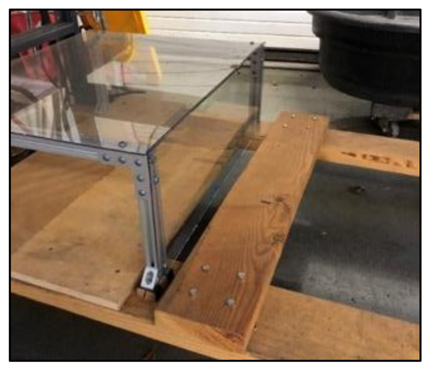


Figure 34. Polycarbonate shield box built to protect the Chroma from water exposure (note: Chroma not pictured here). To secure this "box", gussets, elbow supports, hex screws, and t-nuts are utilized along the t-slotted framing. The base of the framing is bolted to the wooden base

16. The figures above show some examples of how to affix the polycarbonate sheeting.
17. Note that the main purpose of the polycarbonate sheets is for safety. The sheets are installed in specified locations to both help protect electrical equipment from potential water exposure as well as protect the tester from electrical equipment should there be an electrical safety hazard during testing.

3.2 Installing the piping network

1. Reference Table 2 to ensure all materials and equipment are available. In addition to these materials, you will also need plumber's tape, ear hose clamps, PVC screw conduits to attach to the framing, hex screws, an Allen wrench, and possibly some additional tools to help with installing all parts.

2. Following guidance in Figure 3, attach the PVC connectors in-line as shown. Each PVC connection should include an application of plumbers' tape on the male-end to reduce the chance of water leakage throughout the system. The PVC should connect to the integrated equipment in the indicated places in the diagram as well.
    a. To properly apply plumbers' tape to the end of a PVC connector, first ensure that the direction it is wrapped is in-flow with how the connector will be tightened when connected.
    b. Additionally, ensure the tape is wrapped in several layers, enough so that you cannot see the PVC through it/ underneath.

Figure 35. Plumber's tape wrapped clockwise around male-end of PVC adapter; the arrows show the direction the other piece will push against it, which should be in-line with the tape.

Figure 36. Layered and wrapped plumber's tape on male-end of a PVC adapter

3. Attach permanent hosing using ear clamps on the outlet of the PVC network and, if needed, within the network, as these can withstand higher pressures than the adjustable clamps. You must use pinch clamp pliers for this installation.

Figure 37. Hose clamp affixes threaded hose to PVC adapter on the outlet of the PVC network

Figure 38. Pinch clamp pliers used for making permanent connections with ear hose clamps

Figure 39. Adjustable non-permanent hose clamps fitting the threaded hosing to PVC adapter number 20 at the piping network's inlet- this is okay to use at the inlet to allow for any needed adjustment

4. For connecting non-permanent threaded hosing at the inlet of PVC piping network, use basic hose clamps that can be easily loosened/ tightened using a flathead screwdriver is acceptable. Non-permanent connectors should *never* be used for any connection that is not on the inlet or outlet of the PVC network. See the threaded inlet hosing connected with two basic, adjustable hose clamps to the PVC adapter item *20P* in Table 2.
5. Equipment integrated in the PVC network (outlined in *Table 3*) shall be connected in-line with the PVC adapters via threaded inputs/outputs, following Figure 3 as a

guideline for the layout and Table 2 as a reference to ensure all of the equipment has been acquired.

   a. Note that all male-ended threading of the in-line equipment shall also have Plumber's tape applied as well before connecting to the PVC network.
   b. Note that the flow meters have two electrical output openings on either side: the opening that the electrical leads will run through should have a gland installed, and the other opening should have a cap installed to protect the internal electrical connections from water exposure.
      i. Also note the direction in which all measurement equipment is installed in-line with the PVC network; direction of installation may be very important.
   c. All electrical leads connecting the measurement equipment to the DAQ should be secured within the ducting along the t-slotted framing, as described in the next section.

6. To secure the PVC network and integrated equipment to the vertical test bench framing, PVC screw conduits with hex screws and t-slot nuts will be utilized in different parts of the network.
   a. Shown in the figure below, affix parts of the PVC network to the frame using PVC screw conduits that can be connected using hex screws and t- nuts wedged into the framing slot. Ensure that the equipment connected in-line with the PVC network, such as the flow meters, are also secured to the framing.
   b. In places of the network where there is an inline flow meter or actuated ball valve, use the hex screws and t-nuts to secure them to the framing. See the figures below or examples.

Figure 40. Flow meter attached to the t-slot framing via a t-slot nut and hex screw affixed through the racking hole on both sides of the meter

Figure 41. Pressure gauge connected in-line with PVC network. Because it is small and light in weight, it does not need to be secured to PVC network via t-slot nut and hex screw

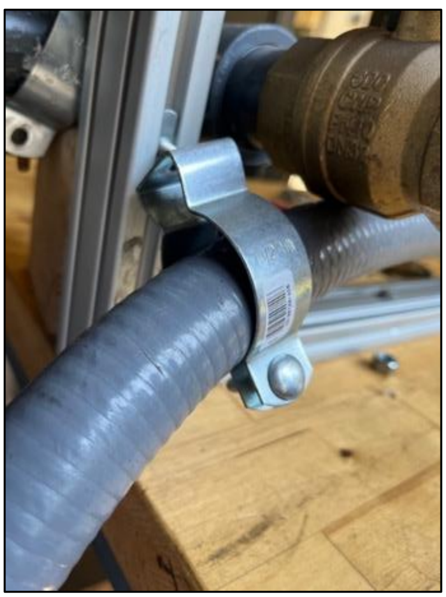


Figure 42. Screw conduit PVC screw conduit securing the outlet hosing from the PVC network to the t-slotted framing

Figure 43. Low-flow PVC branch secured to t-slotted framing with 3/4" screw conduit PVC clamp

3.3 Wiring the DAQ

After the PVC network has been built, the equipment shall be wired to the DAQ. Refer to Figure 2 on the placement of the DAQ equipment. The DAQ equipment shall be installed to the t-slotted framing using hex screws and t-nuts in the section of the test bench that has protective polycarbonate shields, as shown below in Figure 44. Electrical wiring will travel through the DAQ equipment and run through framing ducts out to the measurement equipment integrated into the PVC network.

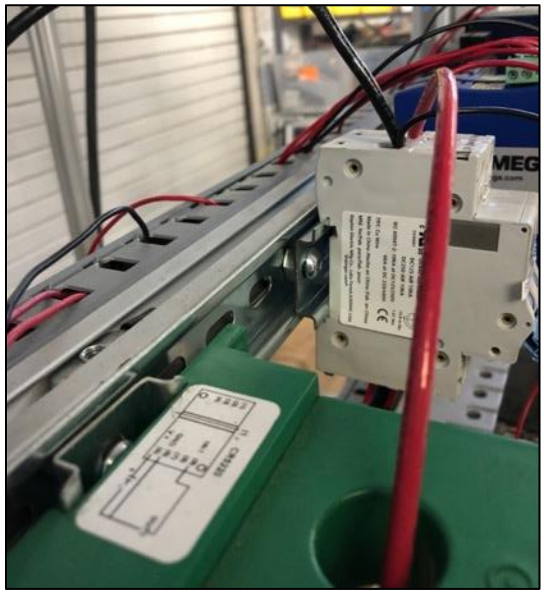


*Figure 44. DAQ equipment installed using hex screws and t-nuts to the 35mm mounting track affixed to **single** t-slotted framing within the shielded area of the test bench*

For the DAQ wiring, Figure 45 below may be referenced, which shows the wiring diagram for the SWP test bench DAQ and measurement equipment. 18 AWG color-coded wire is used for the test set up outlined in this manual for the DAQ equipment; however, ensure this will be acceptable for the specific equipment used when setting up a new test bench that may include updated or different equipment models than shown in Table 1 in this manual. Note that it is recommended the wiring be labeled at each connection point using a label maker to make any necessary troubleshooting easier and more efficient.

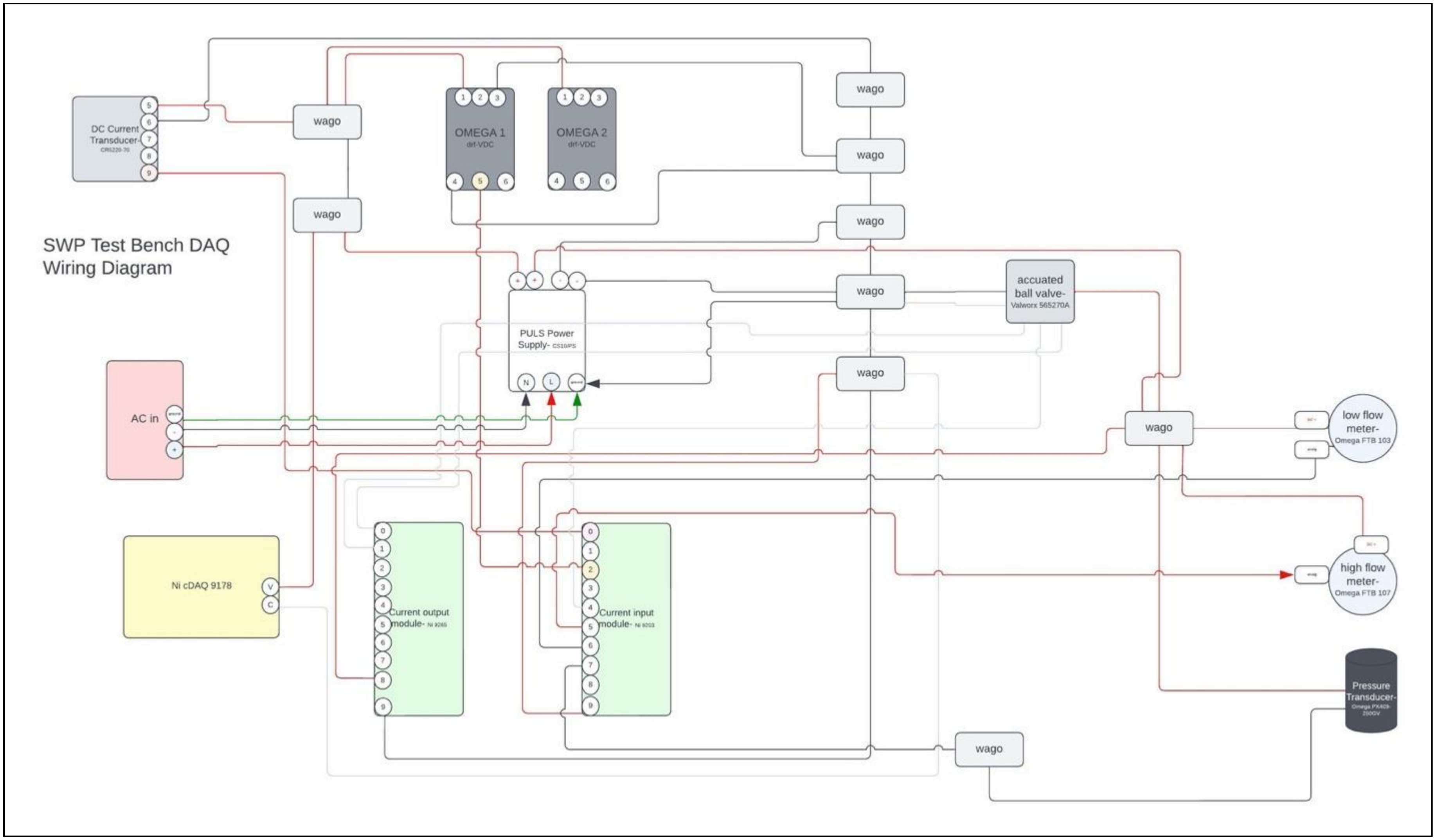


Figure *45*. DAQ wiring diagram for SWP test bench- all wire shown in image above is 18 AWG in size.

Most of the DAQ equipment have permanent electrical connection options integrated for their output and input. Some of the equipment have screw terminals or clamps that can be controlled and adjusted with a screwdriver (figures below show some examples). However, for connecting intermediate wires and connecting various electrical loops, connectors such as WAGOs or other multi-lead terminal blocks may be used. Below, there are several figures displaying various connector options that can be utilized for testing; however, there may be other options that are more convenient / available. In general, it's recommended to incorporate adjustable, small terminal blocks that can fit within the wire ducting. Note that connections should be secured in conduit in sections of the test bench that could potentially expose them to water should there be a leak. It is best practice to secure wires connecting the DAQ equipment within plastic ducting attached to the t-slotted framing with a removeable cap (see Figure 51 and Figure 52 below).

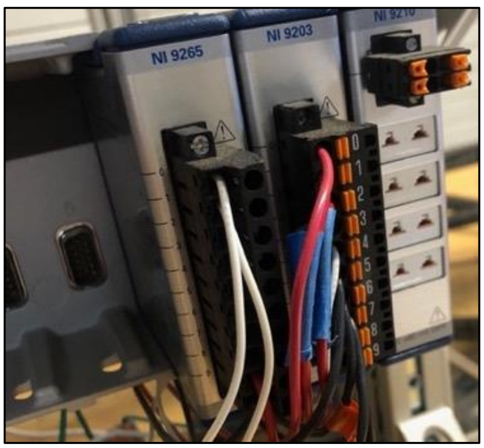


Figure 46. Clamp connections for wiring the NI DAQ

Figure 47. 16A fuse switch screw terminals

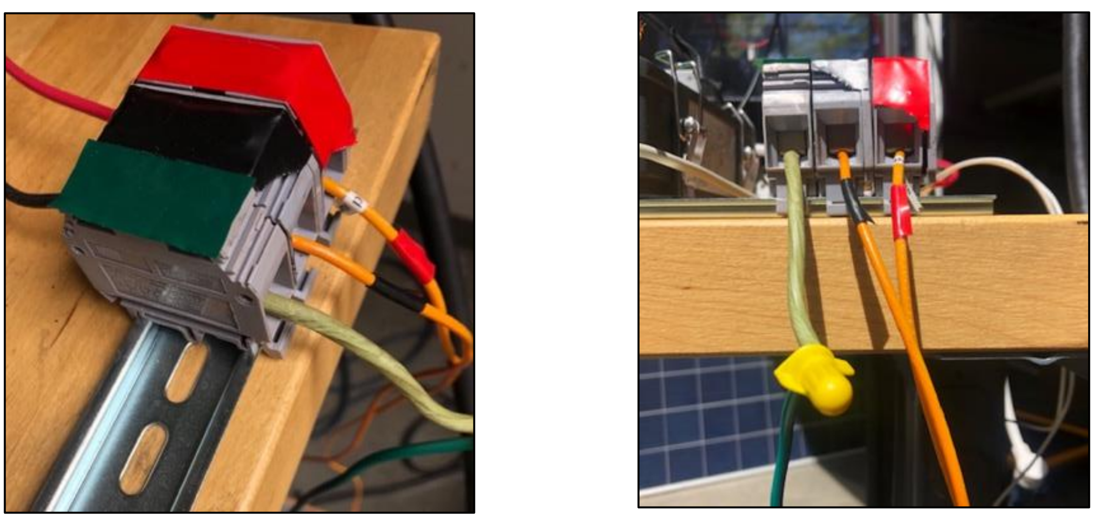


Figure 48. Screw terminal blocks attached to 35mm mounting track and used to connect input power leads from Chroma to the DAQ equipment and SWP- color-coded and enclosed in insulative material

Figure 49. Clamp connections terminal block that may be fully-enclosed and contains multiple connection capacity

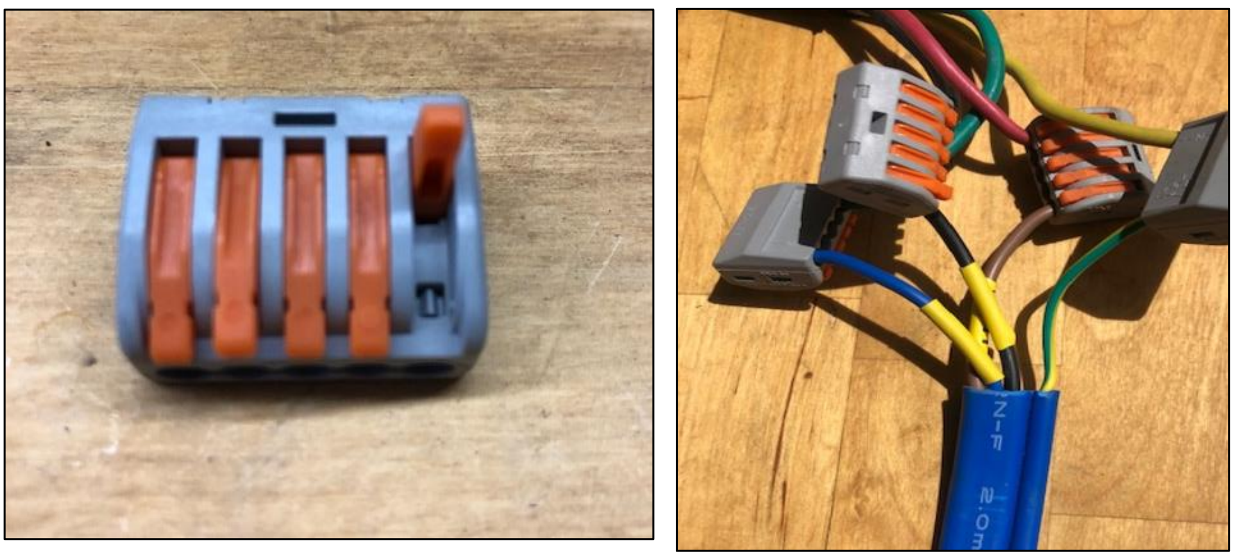


Figure 50. WAGO clamp connector- used throughout DAQ network as permanent connections, but also used in various non-permanent connection applications

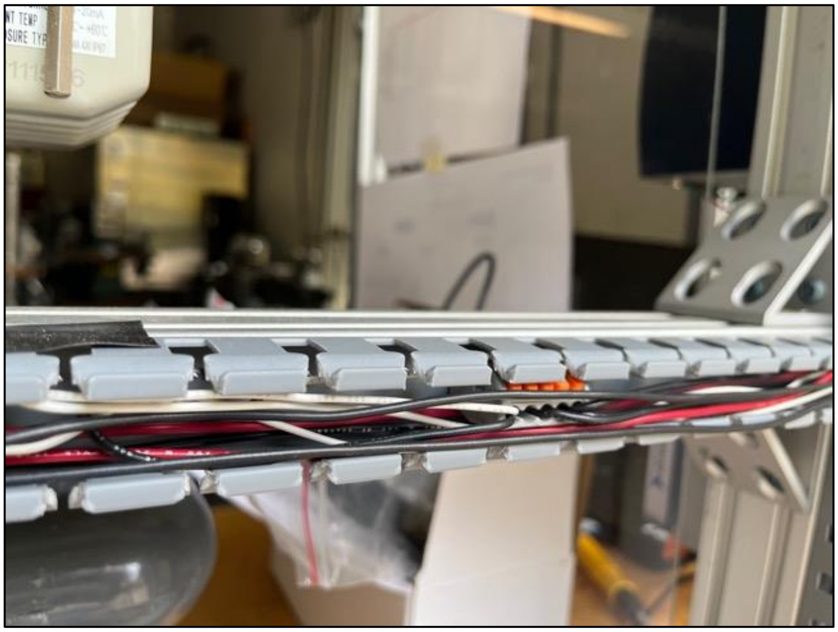


Figure 51. DAQ wires and electrical connections via WAGO are packed neatly into ducting affixed to the t-slotted framing (note these should be labeled for good practice- not pictured here).

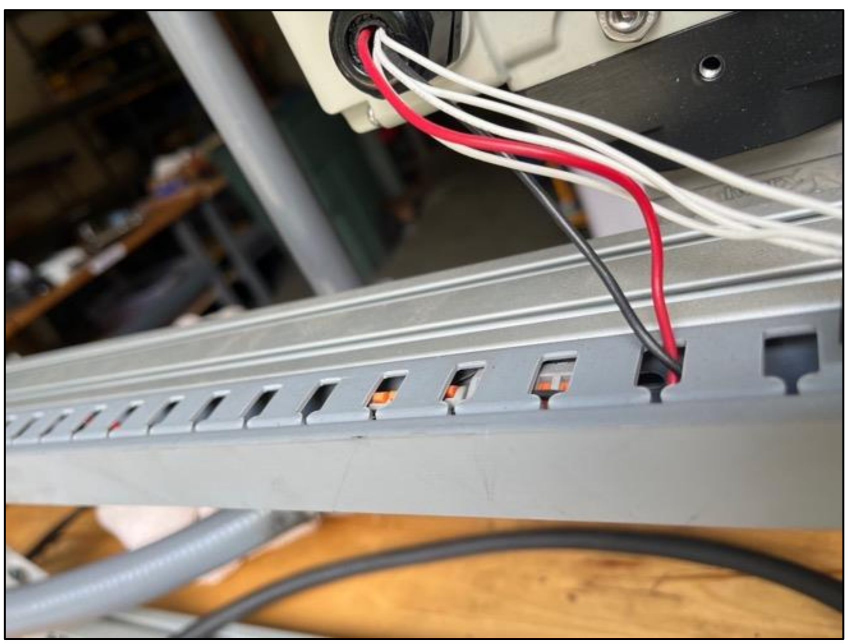


Figure 52. Plastic DAQ wire ducting affixed to the t-slotted framing with its removable cap connected

Setting up Chroma and Software

For setting up the solar array simulator and connecting it to the testing laptop, follow the instructions provided in the product instruction manual. If information is missing in the instruction manual, then reach out directly to the manufacturer's technical support team to request additional information. The set up will vary depending on the model and manufacturer of the solar array simulator, and the software used may vary. If purchasing the same Chroma model as specified in this manual, the software is included with its purchase, and the instruction manual was provided. The Chroma is connected to the test laptop via USB, and the cables were included with the purchase as well. Before setting up a solar array simulator, ensure that the testing facility has acceptable and safe electrical hookups that can support powering this piece of equipment.

3.4 Setting up LabView program

LabView, or an equivalent program that is compatible with the rest of the DAQ equipment, must be developed that can log the following measurements in real time in at least ten-second increments, preferably quicker: flow of water through PVC network (lpm), pipe system pressure (psi), PV input current (A), PV input voltage (V). Note that "PV" input current and voltage are the input power measurements from the Chroma (or the PV modules used if conducting the Alternative Test Method). These logged measurements must be able to be saved in a data file that can be accessed and compatible for copy/ pasting values into Microsoft Excel. To connect the DAQ equipment to the computer, follow the wiring instructions for each measurement device, which should include its own user manual, and the wiring diagram in Figure 45 above. The National Instruments Chassis (Ni cDAQ-9178) will plug directly into the testing laptop via USB. The computer shall read in and record all relevant measurements from the DAQ equipment during testing in LabView (or other acceptable program), and then the recorded data will be further analyzed using Microsoft Excel to generate the test results. See Figure 53 below to see the layout of the LabView program used for the testing set up in this manual for SWP testing.

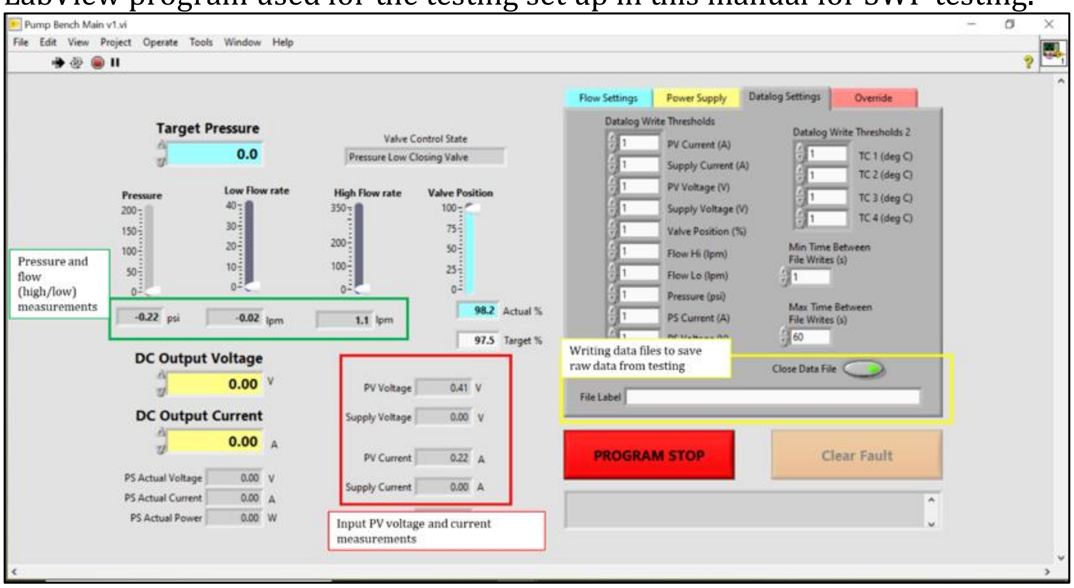


Figure 53. LabView display for testing SWP testing.

3.5 Setting up a SWP to the test bench

SWP Testing Set Up SOP shall be followed when connecting a SWP to the test bench as there are multiple procedures possible depending on the pumping kit and whether or not an external controller is included. As mentioned previously, it is helpful to have a collection of various sizes of PVC adapters so that- no matter what the pump's outlet diameter is- the pump's outlet can be connected to the static ¾" threaded inlet house to the PVC network of the SWP test bench. The figure below shows an adapter on-hand at the test lab and how it's used to connect to the outlet of a SWP to further attach to the threaded hosing inlet of the test bench.

Figure 54. PVC adapter affixed to a SWP outlet so that it may be connected to the 3/4" threaded hosing inlet of the test bench piping network (notice the tub of various-sized PVC adapters sitting in the background that is kept on-hand for testing)

Figure 55. Various sized PVC adapters on-hand at the test lab


Figure 56. Adapters that can be used for connecting various sizes of pump outlets to the static diameter of the test bench inlet

4. Appendix A- Additional Recommended/Required Materials

The table below shows photos of several of the items listed in Table 7 and provides additional detail. Note that the photos depict the specific items with the test set up described in this manual; however, these are not the only options when setting up a SWP test lab, and in some cases, may be replaced by other models/ items of equal ability.

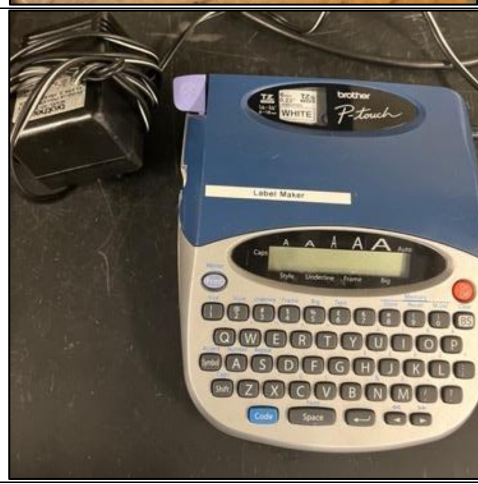
Table 10. Recommended/required materials additional detail

Item	Photo	Additional Detail
50-gallon livestock tank		This tank holds the source water for testing SWPs. Submersible pumps are placed within the water in this trough while testing; whereas, surface pumps' inlet hosing will be placed in the water within the trough during testing.

Furniture dolly		For mobilizing tank of water for testing.
Clamp meter (Extech EX830)		This clamp is used to take inrush current measurements during testing. See the *SWP Coldstart and Inrush Current* SOP for more detail on how this device is used.
Customized multi-angle		For strain relief test These are propped up on a flat surface to hold the component under test so that its cable may be configured in various target angles to be tested with a 2kg clamped weight. See the *SWP Mechanical Durability* SOP for more detail on how these are used.

Semi-transparent material		These semi-transparent squares are used to partially cover PV modules while performing the Alternative SWP Test Method in order to adjust the power input to achieve the target voltage/current inputs during testing. See the *SWP Alternative Method* SOP for more detail on how these are used.
Akro bins		Akro bins are used to help organize all of the pieces used for testing and maintaining the test bench/ testing equipment. Akro bins can hold user manuals, cables, screws, screw drivers, etc.
Calibrated digital multimeter (Fluke 287)		Having a calibrated multimeter allows for in-house equipment calibrations, troubleshooting of the equipment and wiring, and more. A calibrated multimeter is required to perform several of the in-house calibrations, as outlined in the *SWP Calibration and Maintenance* SOP.

Banana plug adapters		These adapters will be used to insert in series into the test bench electrical circuitry during calibration of the DAQ to the calibrated pressure transducer. See *SWP Calibration and Maintenance* SOP for more details.
Extra wooden planks		Extra wooden planks are recommended to place the Chroma on underneath the butcher block and on top of the test bench's wooden base.
Shop towels / solvent wipes		Shop towels are used mainly to absorb oil that is spilled or leaked from a tested pump.

Spill tray		Having a spill tray for the internal inspection procedure is extremely useful to prevent oil spilling in the testing lab, and to contain all of the small parts of a pump that are disassembled. See the *SWP Internal Inspection* SOP for more information.
Label maker		A label maker allows for better organization. It can be used to label akro bins, pumps being tested, testing equipment, DAQ electrical leads, and more. This is highly recommended for this testing work.

5. Appendix B-Resources for Making Connections

B.1. Connecting T-slotted framing rails to each other

The following resources walk through how to affix the framing rails into a network. There are different methods that can be done as well.

1. https://blog.parker.com/site/usa/en-US/details-home-page/putting-it-all-together-choosing-a-fastening-method-us
2. https://www.youtube.com/watch?v=Al3ZEqJrzVY

Figures 24-29 above show some of the gussets and elbows used for connecting corners of the framing together.

B.2. Making PVC-to-PVC connections

When making threaded PVC connections for the network included on the SWP test bench, always include plumber's tape in between each connection, which helps to seal each connection to be water-tight. The plumber's tape should be wound around the male PVC adapter only, and it should be wound and applied in the same direction that the adapter will be twisted onto the female adapter. When applying plumber's tape, ensure it's not too thick- the threading outline can still be seen through it- but not too thin- the color and actual threading can't be seen through it. See the Figures 36 and 37 above for examples.

Below, there are additional resources on how this can be done.

1. https://www.youtube.com/watch?v=V9oixkb3xts

6. Appendix C- Published resources related to SWP testing

1. https://www.clasp.ngo/updates/developing-test-methods-for-solar-water-pumps/
2. Global LEAP SWP Test Method, version2: https://verasol.org/publications/swp-test-method

7. Appendix D- Total cost estimates

Table 11. Total cost estimate for equipment and materials needed to build SWP test bench

Item	**Cost Estimate***
All equipment	$49,000
Software (LabView)	$528/year (subscription)

**note that the cost estimate may not be inclusive of every item a lab may need and may vary based upon vendor and location of purchase. The cost estimate is inclusive of the Chroma and all of the recommended items for testing SWPs.*

8. Appendix E- Chroma specifications

Below, are the Chroma specifications for the model integrated into the SWP test bench. Due to observing some response time issues between SWP controllers and the Chroma, it is recommended that the specifications shown below be the maximum response times and minimum slew rates required for a solar array simulator in order to successfully be able to test most SWPs.

Table 12. Chroma 62150H-600S-220V Specifications

Accuracy	0.1% + 0.1% F.S.*
Programming response time: Rise time 50% F.S. CC**Load [ms] Fall time: 50% F.S. CC Load [ms]	 30 100
Output Voltage [V]	0-600
Output Current [A]	0-25
Output Power [W]	15000
Voltage Slew Range Range [V/ms]	0.001-20
Current Slew Rate Range [V/ms]	0.001-0.1
Minimum Transition Time [ms]	0.5

**F.S. is full scale*

*** CC is constant current*