1st Place

PORTABLE SOLAR-POWERED AUTOCLAVE

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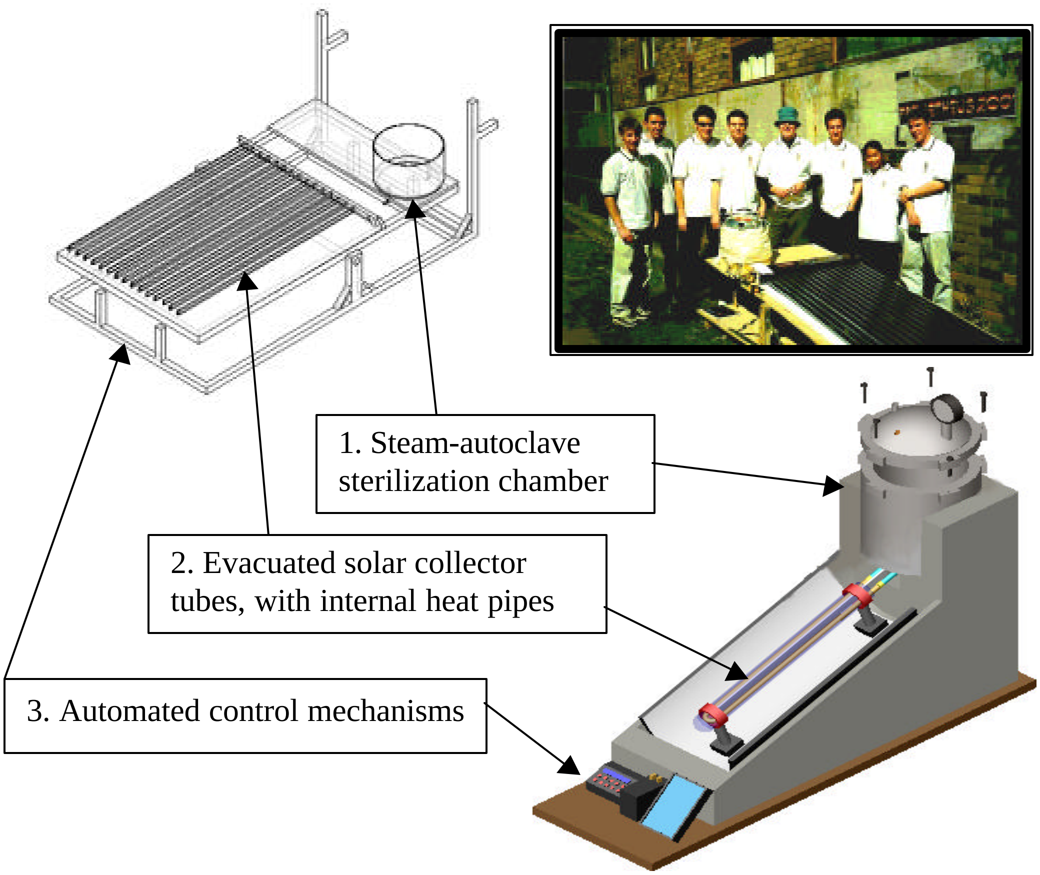
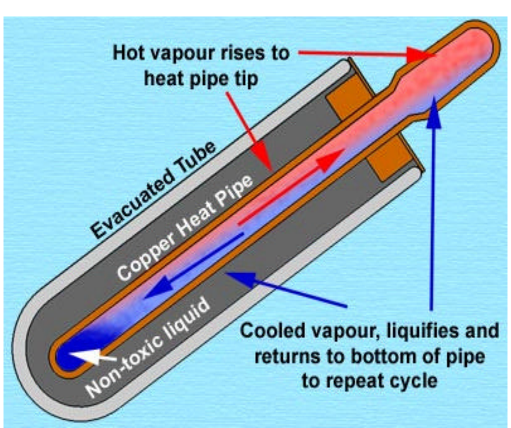
DESIGN CONCEPT

Our design concept is a completely solar-powered autoclave-style sterilizer, which provides cheap, non-burn, portable sterilization to rural areas, and operates in both sunny *and* cloudy conditions. Prototypes using this design have been successfully built and tested by research teams at Sydney University. One prototype is much larger, with a capacity of 14 liters per batch. The other version is more portable, and has a capacity of just 1.5 liters per batch. Both prototypes utilize the same technology, and are shown in the "Technical Illustrations" section.



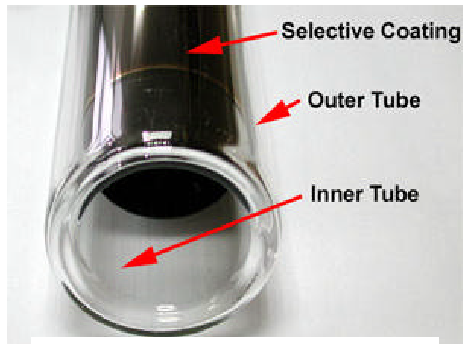


Source: Focus-Solar www.focus-solar.com

The device, nicknamed Prometheus, consists of a sterilization chamber which is directly connected to a set of long copper U-tubes, which in turn are encased in evacuated solar collector tubes. These evacuated tubes are highly efficient collectors of solar thermal energy. The sun's rays strike these tubes, and the energy which is gathered is used to heat water which has been poured into the copper

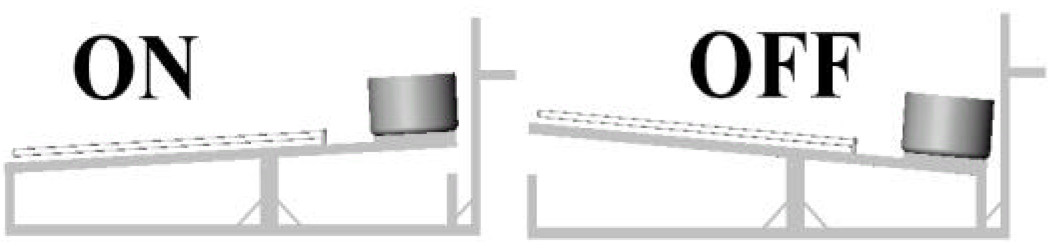
U-tubes inside. A thermosiphon effect is established, which is illustrated opposite. The water continues to be heated until it evaporates, then the steam is superheated until the whole system reaches equilibrium at temperatures between 121°C-134°C, at which steam sterilization can be achieved.[1] The waste load sits in a basket inside the chamber, where the steam can permeate throughout the load and kill any harmful bacteria.

The evacuated solar collector tubes are cheap and readily available from a number of suppliers. The optically sensitive surface of the evacuated tubes allows visible light and UV radiation to pass into but not out of the tubes. The radiation is absorbed as heat. The vacuum between the glass layers acts as an extremely effective thermal insulator, such that at least 92% of energy absorbed is transferred to the copper U-tubes. The glass in the tubes is strong enough to withstand impact from hailstones up to 25mm in diameter.[2] However, the most remarkable property of these tubes is their ability to operate in cold, cloudy and even in rainy conditions, although sunny conditions are clearly optimal. This is because the vacuum does not allow heat loss due to conduction or convection. The effectiveness of the tube depends mainly on the insolation level of the location, which is a measure of the amount of solar radiation striking an area.[3] This means that even in areas with cold, cloudy, windy winters, it is possible to use the technology all year round.



Source: Focus solar www.focus-solar.com

The heat supply to the pressure chamber can be automatically controlled by the use of a small micro-controller and actuator. An electronic thermocouple wire runs from the chamber of the device to the controller, delivering information about the operating temperatures. As soon as the temperature reaches the required level, the heat supply is cut off to avoid overheating. For a large device with 10 or more evacuated tubes, this can be accomplished by using the motor to tilt the evacuated tubes in the opposite direction, so that the thermosiphon effect is halted.



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[1] Cole E., Pierson T. et al. *Guidance for Evaluating Medical Waste Treatment Technologies*. Report for the United States Environmental Protection Agency, 1993. pp25
Available at http://www.epa.gov/epaoswer/other/medical/download.htm

[2] For a chart of worldwide insolation levels, see http://www.focus-solar.com/insolation_levels.htm

[3] Cole, Pierson et al, 1993, pp3

When the chamber is above the collector tubes, a thermosiphon is created, and superheated steam is generated in the pressure vessel. If the tilt is reversed, the thermosiphon effect ceases, and no more heat is supplied.

In the smaller device, the heat supply can be cut off by programming the motor to pull a retractable cover over the evacuated tube and parabolic mirror. In keeping with the environmentally friendly nature of the technology, the micro-controller and actuator are powered by a 12V battery, which is constantly recharged by a small solar electrical panel. For further heat control mechanisms and safety features, please the section “Safety Procedures and Maintenance.”

TECHNICAL ILLUSTRATIONS

A) Large capacity device

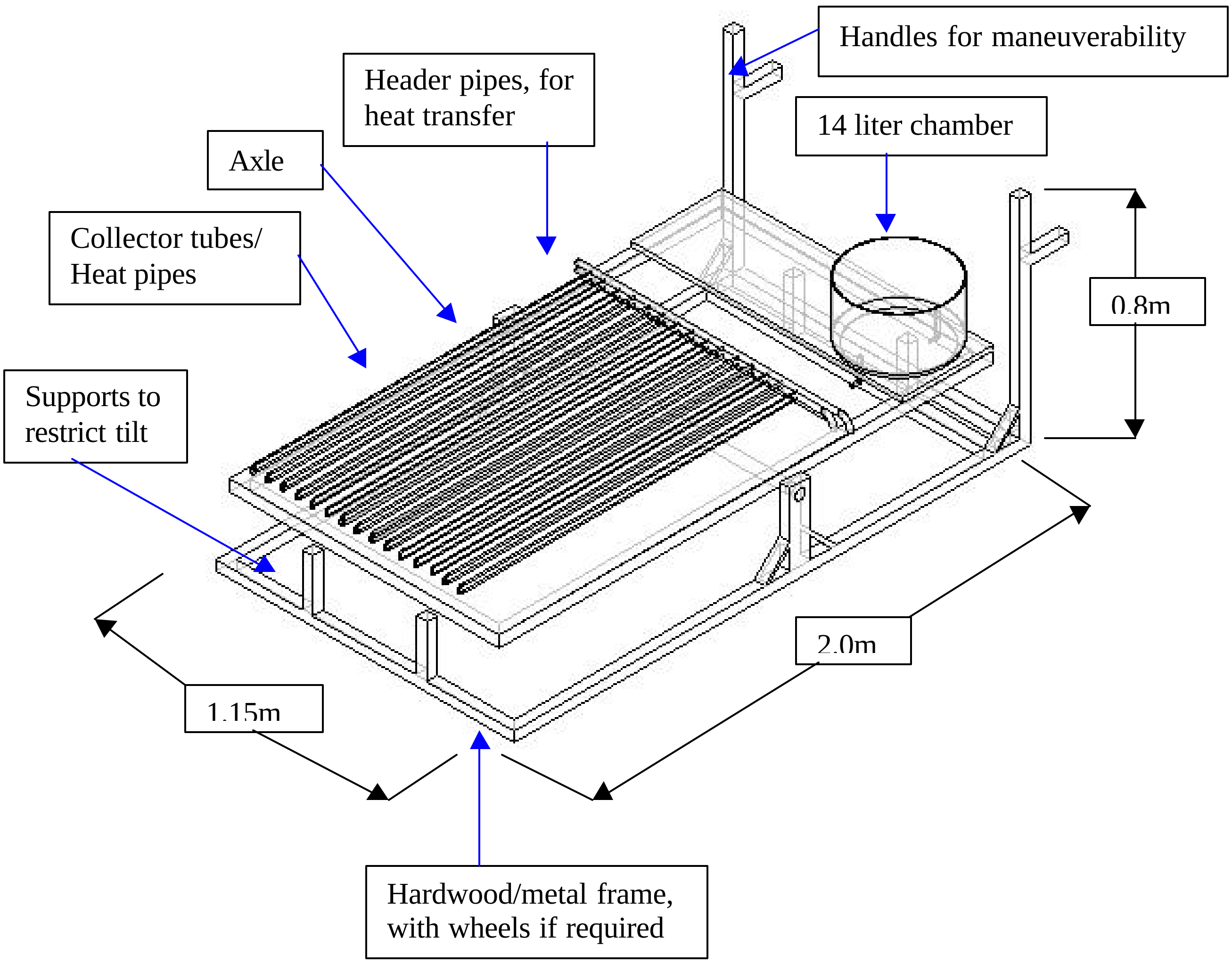


Table 2.1: Vital statistics for large capacity device

Processing capacity	14 liters per batch
Number of evacuated collector tubes	15-20

Average power output from collectors	300-400W
Operating conditions inside chamber during sterilization	Temperature: 121°C – 134°C
	Pressure: 98kPa – 212kPa (gauge)
Time period for one sterilization cycle	55-80 minutes
Cost of construction per unit	US$1694

B) A small, portable device

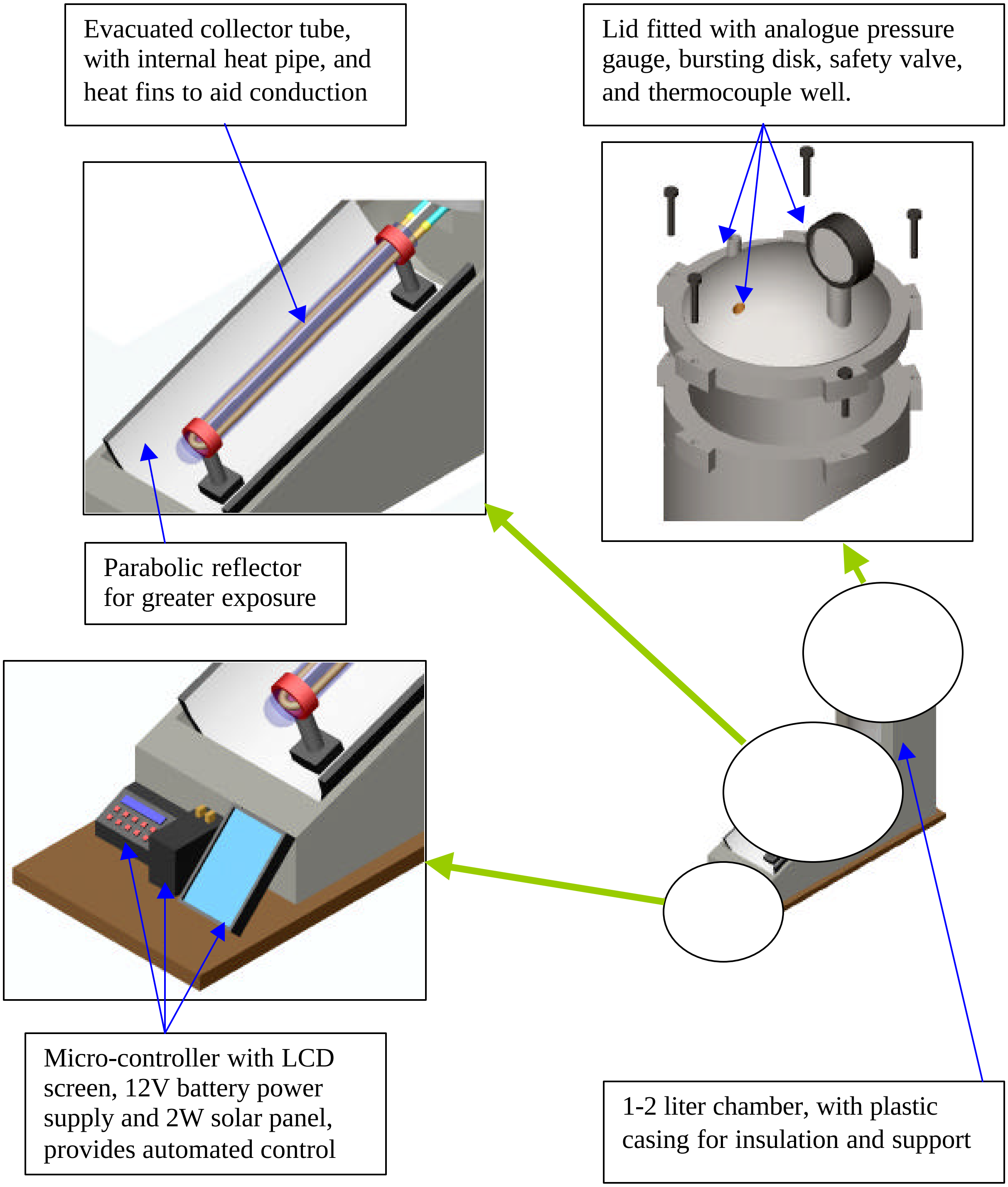


Table 2.2: Vital statistics for portable device

Processing capacity	1.5 liter
Number of collector tubes	1
Average power output from collectors	80-120W
Operating conditions inside chamber during sterilization	Temperature: 121°C – 134°C
	Pressure: 98kPa – 212kPa (gauge)

Time period for one sterilization cycle	40-65 minutes
Cost of construction per unit	US$650

DISINFECTION

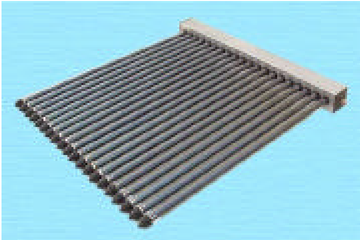
Steam sterilization has very effective microbial inactivation levels. It satisfies both of the widely accepted high-level benchmarks: the death of 10^4 Bacillus subtilis spores and the death of 10^6 Bacillus stearothermophilus spores. Bacillus stearothermophilus is regarded as the most resistant bacterium to moist heat, and as such represents the highest level of microbial inactivation efficacy for steam autoclaving.

The speed at which these results are achieved is dependant on steam temperature. At the minimum steam temperature of 121°C, acceptable levels of inactivation can be assured after 30 minutes of continuous operation. As the temperature rises, inactivation becomes more efficient. At steam temperatures greater than 134°C, complete sterilization occurs in just 5 minutes of continuous exposure.

If the device is fitted with an electronic thermocouple and automated control, the temperature can be monitored so that the process can be terminated at the most efficient time.

MATERIALS FOR CONSTRUCTION

All materials required for this technology are readily available, but greater cost minimization could be achieved by taking responsibility for the manufacturing of certain components, such as the sterilization chamber for small capacity models of the device in particular. An itemized list of required components, and the source from which they can be obtained, is provided in the table below.

PART	**SUPPLIER**
Pressure vessel (the chamber in which sterilization takes place)	All American Autoclaves (Wisconsin Aluminum) www.wafco.com/wafopening.html There are three sizes available: 1915X model – 14 liters (15 Qt). 1925X model – 23.6 liters (25 Qt). 1941X model – 33.8 liters (41 Qt).
Solar evacuated tubes and heat-pipes. 	Pre-manufactured collector arrays: Focus-solar www.focus-solar.com Powertech solar www.powertech-solar.co.uk/index.htm Solar design www.solar-design.demon.co.uk This is a very competitive industry, and there are many more suppliers of these arrays. Individual collector tubes: Himin solar energy www.himin.com/english/index.htm

	Contact Sydney University Applied Physics Department for information: d.mills@physic.usyd.edu.au
Pressure fittings used to connect the array to the pressure vessel.	Any valve or fitting company.
Wooden frame: • 2 large sheets of 19mm plywood. • 40x60x1000mm piece of hardwood. • 2 trolley wheels • 4 metal braces • Metal axel and fittings • Screws	All components available at a local hardware store or timber yard
Pressure verification tape	Any health care supplies company
Optional components required for complete automation of device	
Electronic thermocouple	Local electronics store.
Micro-controller	Intel
Printer	We used a DP1000, available from DedLines: www.ded.co.uk
Actuator	Local electronics/hobby store
12V battery	Local electronics/hobby store
30W solar cell	Local electronics/hobby store
Circuit components	Local electronics/hobby store

The All American autoclaves appear to be the cheapest and most versatile pressure chamber available. They are designed to be used with an auxiliary heat source, and come fitted with a pressure gauge, safety release valve, and emergency blow-off disc, which prevents catastrophic failure. Alternatively, it would be possible to order custom made pressure chambers either from Wisconsin Aluminum or any other metal casting company.

CONSTRUCTION OPTIONS

The most skill-intensive process involved in the construction of this technology is construction and/or modification of the sterilization chamber itself. There are two options:

1. Use pre-manufactured stove-top sterilizers, such as the All American 1915X, as we did for our large 14 liter prototype. The only modification required is the drilling of two holes in the base, so that the vessel can be connected, through the use of pressure fittings, to the solar collector array. It is important that this procedure is performed by a skilled workshop machinist, to ensure that the structural integrity of the pressure vessel is not compromised. This modification can be made in less than an hour.
2. Manufacture custom-designed, as we did for our small 1 liter prototype. This procedure must be performed by a certified boilermaker, since the vessel will be pressurized. As suggested above, the best solution would be to contract the services of a metal casting/forging company. However, in terms of financial and temporal cost, this strategy would probably only be viable for mass-production of units.

Based on our experience, it seems that the best strategy would be to use the pre-manufactured vessels for large capacity devices, and to produce custom made chambers for smaller devices.

There is a similar choice to be made with regards to the solar collector array. It can either be bought pre-fabricated, or constructed from individual tubes, which would require more skilled labor. Again, we would recommend that for the larger (10-20 liter) devices, a complete array of 15-30 tubes be purchased. For small devices with a capacity less than 3 liters, it would be more economical to use a single evacuated tube with a parabolic mirror constructed from sheet aluminum.

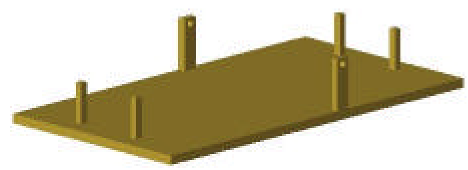
The wooden frame used for the larger prototype was constructed by a student with rudimentary high-school knowledge of woodworking, and hand tools, in approximately 7 hours. In a workshop with power tools, construction time could be as little as 2-3 hours. The pressure fittings can be attached within one hour by a single person. The only tool required is an adjustable wrench.

The total time for construction will depend on the choices made with regard to components, and on shipping times. With all components pre-manufactured, each unit could be constructed within 1-2 days. However, even if the pressure vessel and collector array are constructed to a custom design, the device should be able to be completely fabricated within 1-2 weeks.

BASIC STEPS FOR CONSTRUCTION

The following guide details the procedure required to build a solar powered medical sterilizer, with automated control and a 14 liter processing capacity per batch. It assumes that all the components listed have been obtained.

Step 1: Build the frame:



Construct the frame (as illustrated) from wooden materials using the dimensions specified on page 3 as a guide. The axle, upon which collector array is placed, should be located approximately half-way along the length of the device. When all the other components are added, the device should lean towards the off position, as shown on page 2. Only a small force should be required to tilt the collector array into the on position.

Step 2: Modify the pressure vessel:

Drill two holes through the bottom of the vessel. The holes should be of appropriate size to accommodate two stainless steel bulkhead fittings. These fittings will provide the connection between the header pipes of the collector array and the pressure chamber.

The top of the pressure vessel also needs to be slightly modified. Remove the analogue pressure gauge from the lid, and insert a stainless steel T-connector into the thread which it previously occupied. Now re-attach the analogue gauge to one port of the T-connector. In the other port, attach a thermocouple well, which can be obtained from most pipe and fitting companies along with the other pressure fittings.

Step 3: Attach the collector array and pressure vessel to the frame:

This step is self-explanatory. The collector array should have holes in it that can be used with screws or nuts and bolts. If it doesn't, it can be modified. Connect the header pipes of the collector array to the bulkhead fittings which are now protruding out of the bottom of the pressure vessel.

Step 4: Program the automatic control:

The micro-controller will require programming, but nothing more complicated than can be achieved by a first year university student. Add the printer, battery, solar panel, and electric motor to the circuit. The motor should be as close to the end of the device as possible, so as to increase the lever arm and reduce the torque required from the motor to reverse the tilt on the collector.

The device is now complete. For operation, the header pipes of the collector array should be filled with water to a level such that water just begins to overflow out of the bulkhead fittings inside the pressure chamber.

CYCLE TIME

These calculations provide an estimate of the time taken per cycle in poor condition (insolation level less than 3), for a large and small capacity device. The time of each cycle ranges from about 40 minutes through to 2 hours, and depends heavily on the total weight of water in the system. An increase in water means an increase in thermal mass, and a longer cycle time. Therefore the process will be most efficient if the amount of water used in a cycle is strictly controlled.

Volume of water (mL)	*x* quality	Total input energy (kJ)	Time to temperature	Time of cycle (minutes)
100	0.0170779	51.717	**10.77**	**40.77**
200	0.0076145	99.692	**20.8**	**50.8**
300	0.0044597	147.666	**30.8**	**60.8**

Values applicable to small scale sterilizer, 1.1 liter volume, assuming net input 80W

Volume of water (mL)	*x* quality	Total input energy (kJ)	Time to temperature	Time of cycle (minutes)
1000	0.0248225	532.491	**29.6**	**59.6**
2000	0.0114863	1012.233	**56.2**	**86.2**
3000	0.0070494	1492.025	**82.9**	**112.9**

Values applicable to large scale sterilizer, 15.5 liter volume, assuming net input 300W

SAFETY PROCEDURES AND MAINTENANCE

a) Personnel Protection Equipment

When loading or unloading the device, it is important that the operator takes care to wear proper protective equipment. The operator should wear the following protective equipment:

- A coat that resists liquids, for protection from steam that may rush out when the release valve is opened.
- Gloves that are heat and liquid resistive, to protect the hands against hot surfaces and steam.
- Protective goggles and/or face shield, again mainly to protect from the brief burst of steam then the vessel is opened.

Caution should be taken when opening the chamber and the contents should be left to cool slightly before they are handled.

b) Hazardous surfaces or materials

Due to the high absorption and low radiation of the solar collector tubes, and the vacuum between the glass layers, the collector array remains cool to the touch even at the highest operating temperatures. The pipes and fittings between the collector tubes and the pressure chamber can be covered with basic rubber insulation tube to protect the user. However the metal pressure vessel will become very hot during operation. Care should be taken not to touch any metal surfaces and only to remove the lid by its rubber handle, while wearing protective gloves. Warning signs and stickers on the vessel will serve as a reminder not to touch these metal surfaces during operation. Standard medical waste procedure should be followed in order to protect the operator from hazardous materials which are part of the load, such as sharps.

c) Over-heating

Since the technology involves the build up of steam to reasonably high temperatures and pressures, it is important to take measures to prevent over-heating, which might cause pressure build-up and catastrophic failure, resulting in injury and damage. The Prometheus device is fitted with three separate heat control and safety devices:

1. The heat in the device can be controlled by adjusting the angle of tilt of the thermal collector array. Once the steam in the device reaches the required temperature, the evacuated tubes are tilted in the opposite direction, and the thermosiphon effect in the heat tubes is halted, thereby cutting off the heat supply to the sterilization chamber. If the temperature begins to drop down towards the 121°C threshold, the tubes can be tilted back into the "on" position, to ensure that the temperature remains high enough to achieve sterilization. Thus the heat can be controlled without jeopardizing the operating effectiveness of the device. The array is balanced on a pivot, so that the gravitational forces acting upon it cause it to revert to the "off" position. If the small electronic actuator, which controls the angle of tilt and moves

the array into the “on” position, should happen to fail, then the heat supply will be cut off from the device.

2. If this first control system should fail for any reason, and the pressure in the device begins to rise above acceptable operating levels, the device is fitted with a safety check release valve. This valve is calibrated to open as soon as the internal pressure reaches a predetermined limit, which is approximately 30psi gauge pressure. There will be an audible release of steam. If steam begins to escape through this valve, the device should be manually shut down and checked for the source of failure of the control system.
3. As a final safety measure, the vessel is fitted with a rubber bursting disk. This disk is the weakest point in the structure of the pressure chamber. If the safety check valve fails, and the pressure builds to even higher levels, the bursting disk will pop out before there is sufficient pressure to crack or damage the chamber. All steam will immediately be released from the machine. If this occurs, the device should not be used until it has been thoroughly examined and repaired if necessary.

d) Maintenance

Some regular maintenance will be required to keep the machine running effectively. Once a week, the sterilization chamber, fittings, and header pipes of the solar array should be flushed with water and mild cleaning solution, in order to prevent blockage due to build up of dirt or other contaminants. The check valve, which releases excess steam build up from the pressure chamber, will require scheduled maintenance and testing, as specified by the manufacturer. However, these valves are very reliable and this will not be necessary more than once a year.

e) Verification and Quality Assurance

This technology uses the standard verification and quality assurance procedures for steam-autoclave sterilizers, which have been well documented and defined.[4] There are two procedures in widespread use, which are required to ensure that the sterilizer is working effectively.

The first and most regular test involves placing a simple heat and pressure sensitive strip inside the autoclave along with a load of medical waste. The strip is sensitive to the conditions inside the chamber, and will change color when exposed to sufficiently high temperatures and pressures for a certain period of time. When the load is removed, the operator simply checks to see whether the color change of the strip has been satisfactory. The strip should be placed deep in the center of the load, so as to verify that the steam is permeating throughout the entire load, and complete sterilization is being achieved. This procedure is carried out on a weekly basis.

The second test is conducted bi-annually. It requires that separate spore strips with an average certified population of 10,000 B. stearothermophilis and 1,000,000 B. subtilis spores be placed in the autoclave for the duration of one sterilization cycle. These spores

[4] For a full definition of steam autoclave quality control requirements, consult European Standards EN285 and EN554.

must be placed inside special glass containers, which are provided with the strips. After the cycle is complete, the strips must be tested to guarantee that all the spores have been killed. They should be incubated for a certain period (follow the instructions supplied with the strips), and then checked for any growth. As long as there is no spore growth after incubation, the device is working satisfactorily. The examination of the strips can be carried out on site if the necessary equipment is available, or the specimens can be sent away to a laboratory for testing. There are a large number of commercial organizations which regularly perform this service for autoclave operators. A full guide for this procedure is available from the Regulatory Compliance Office at Colorado State University, or by visiting the website at http://www.research.colostate.edu/rcoweb/ib/ib_hb_autoclave.htm