

# **Construction Designs for Greenhouses in High Altitude Areas**

Field Visit – May 2003

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**Report by:** Sjoerd Nienhuys, Senior Renewable Energy Advisor, SNV-Nepal

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## **ABSTRACT**

Review of several design options for greenhouses in High Altitude Areas in Nepal. Use of Silpaulin, bamboo frames and soil insulation made from PP foam and plastic waste materials. Use of thermal wall and construction against existing house. Application in combination with High Altitude Biogas Reactor.

**Note:**

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SNV-Nepal  
P.O. Box 1966, Kathmandu, Nepal  
Tel: 00977-1-5523444  
Fax: 00977-1-5523155  
E-mail: [snv@snv.org.np](mailto:snv@snv.org.np)  
Website: [www.snvworld.org](http://www.snvworld.org)

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## List of Abbreviations

ACAP	Annapurna Conservation Area Project.
BSP	Biogas Support Programme, project of SNV-Nepal.
Dokha	Bamboo woven basket, carried on the back, holds about 30 kg biomass.
EPS	Expanded Polystyrene. Light, white insulation material used in package industry.
EPE	Expanded cellular polyethylene foam. Closed cells expanded with LD PE resins.
HABR	High Altitude Biogas Reactor (over 1800 m altitude).
HDPE	High Density Polypropylene. Plastic used in water and sewerage piping.
LD	Low Density, terminology used in plastic industry.
NRs	Nepalese Rupee. One Euro = NRs. 85 (at date of report date).
PE	Polyethylene plastic with density 0.91–096. May be burned, non-poisonous.
PET	Polyethylene Terephthalate, used for fully transparent water and soft drinks bottles.
PP foam	Polypropylene foam, commonly sold as under-carpet in Nepal, 5mm and thicker.
PV	Photo Voltaic, solar light to electric current.
PVC	Poly Vinyl Chloride plastic with density 1.2 -1.55. Poisonous burning gasses.
RABR	Remote Area Biogas Reactor (more than one day's walking from road head).
RMP	Red Mud PVC, red mud is a by product of the aluminium industry.
SNV-Nepal	Netherlands Development Organisation, Nepal office.
SPCC	Sagarmatha Pollution Control Centre.
SWH	Solar Water Heater.
UV	Ultra-violet. Short frequency solar radiation destroying binders in plastics.

# 1. INTRODUCTION

In two earlier reports, namely, the “Mission Report of the High Altitude Biogas Reactor in the Khumbu Region, Nepal” dated October 2002, and the “Mission Report – Greenhouse Applications – Jomsom” dated 17 March 2003, an assessment was made of some greenhouses visited in those areas. The interest of the population and the importance of better food production at high altitudes has led to the current document.

This paper provides details of a possible greenhouse construction that can be realised either over a High Altitude Biogas Reactor (HABR) or independently in different sizes. The report is linked to the report, “Construction Options for RABR Remote Area Biogas Reactor”, dated June 2003.

About 9% of the population of Nepal (about 2 million) lives in the high mountain areas. This population is highly dependent on importation of food resources from lower areas, especially fresh vegetables during the winter season when no local crops can be grown in these high altitudes.

In addition, many Nepalese in the high altitude areas live in remote to very remote areas, meaning that it requires several days’ walking to reach the villages. The direct effect is that all food being brought from the lower regions to the remote villages becomes very expensive in labour (walking, carrying) costs. The indirect effect is that these low-income populations depend greatly on dried and staple foods, which can be stored during the winter periods, and hardly have any supply of fresh food. This has a negative effect on their general health.

Many smallholder farms have two buffalos to assist them in agricultural activities, such as tilling the land, and for milk supply. These buffaloes are usually kept in stables. Their daily food supply during the winter period consists mainly of hay along with some dry agricultural residues, having a very low nutritious value. Supplementing the fodder with fresh greens is practically out of the question. This results in a serious degradation of the health situation of the cattle, including a very limited milk production.

## **Biogas Reactors and Greenhouses**

With the consideration of developing better biogas reactors for high altitudes (above 1800m), the improvement (and simplification) of the greenhouse designs has become a focal point because high altitude biogas reactors will only would work efficiently with dung from cattle that are well fed and kept warm at the same time. In this respect the combination biogas reactor and greenhouse becomes an essential symbiosis and a benefit to the farmer’s family and the cattle.

Renewable Energy (RE) management at a national scale should include the construction and promotion of greenhouses and related food production for remote (high altitude) areas. For all trekking areas food production in local greenhouses can be an important income generating activity. Excess produce can be solar dried and the vegetable waste can serve as fodder for cattle. The greenhouse production of beans and alfalfa will regenerate soil nutrients and provide an important food source for people and cattle respectively.

The remote people in Nepal are also the most economically disadvantaged people and require special attention under all types of national development programmes to reduce the inequity. There exists a strong relation between the development of local energy resources and economic development. For this reason both the further penetration of biogas reactors into remote areas and the development of a sustainable greenhouse technology with local food production are of high importance.

## 2. HABR AND GREENHOUSE CONSTRUCTION

For the HABR the greenhouse addition is important for the farmer economically and for the health of the family and livestock. Improved fodder for cattle will indirectly improve the dung quality, which in turn will lead to better biogas production.

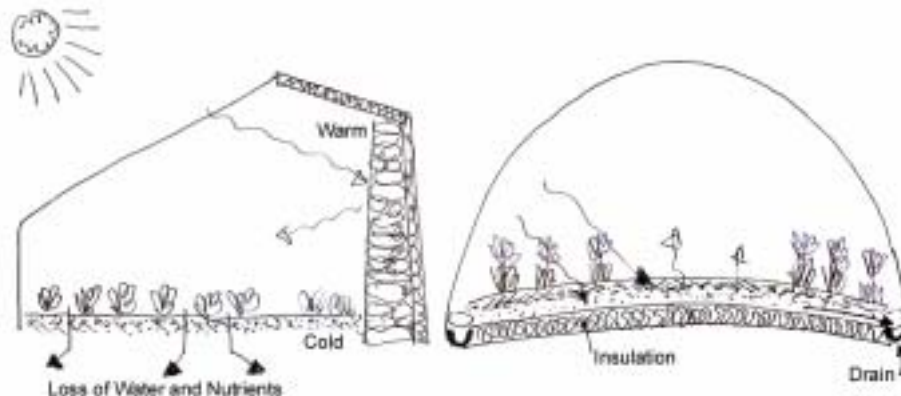
While a greenhouse built over the biogas reactor and outlet will reduce excessive heat loss from the topside of the biogas reactor, it will not warm the biogas reactor or the slurry inside the digester or outlet. Heat moves upwards, but not downwards. The temperature records from the two test greenhouses showed that although the air temperature inside the greenhouse rose to 20° Celsius and higher, the temperature of the top layer of soil remained almost as low as the underground. The topsoil temperature will only rise if solar radiation is projected onto the ground. But even then it will not warm an underground construction.

In the Jomsom area greenhouses were constructed with a heavy stone wall inside the greenhouse on the northern side. The stone wall absorbs the solar warmth during the day and releases the warmth during the night<sup>1</sup>. The massive stone wall has a stabilising effect on the inside air temperature and humidity level, but the increased wall temperature (after absorbing solar light) does nothing to increase the soil temperature. The heavy stone wall construction appeared to be rather costly and involved a lot of work for the farmers. A cost-benefit analysis of the construction and improved crop production was not made.

Crops or vegetables require the following elements to grow:

- Seedlings for transplanting into the greenhouse plant beds.
- Water in the substrata (or soil) containing the nutrients.
- Nutrients from compost, biogas slurry, fertilizers and humus rich soils.
- Minimum air temperature and air humidity; varying needs per type of crop.
- Minimum ground temperature to stimulate plant growth or for the absorption of nutrients.
- Well-drained soil substrata, avoiding stagnant water
- Soil rich in organic matter to provide nutrients and avoid rapid drying out of the plant beds.

To increase the soil temperature and allow early transplanting of seedlings into the plant beds of the greenhouse, the topsoil may not be cold nor lose its heat to the underlying soil. An insulated layer of topsoil will have a better thermal storage effect than the heavy stone wall construction. The insulated soil will be warmed during the day by the sun radiation and maintain the warmth, releasing it slowly during the night into the air. The heat storage wall will only warm the air in the greenhouse and not warm the ground. When the soil temperature is low, plant growth will be slow.



<sup>1</sup> See "Mission Report – Greenhouse Applications – Jomsom", 18 March 2003, by Sjoerd Nienhuys, SREA.

The topsoil must contain sufficient organic materials in order to retain water and nutrients. The layer of planting topsoil (maximum one-foot deep) should have good drainage and the excess water collected in a gutter. This will avoid water containing nutrients from seeping too deep into the underground. To achieve these conditions, earth can be mixed with compost. The latter can be made through aerobic composting of farm residues with the slurry from the biogas reactor.

Bamboo sticks can be used for the framework of the greenhouse. The most readily available bamboo sticks at high altitudes are about one inch in diameter, being too weak to provide a sufficiently strong bow and girder construction to span 400cm in width and 220cm in height. Bundles of three or more bamboo sticks can be tied together to serve as bow-ribs and girders (fixed to the ribs). UV-resistant plastic cord should be used to make durable connections.

The bow-rib and girder construction of the greenhouse should be adequately strong to hang strings to support vegetable growth, such as tomatoes, cucumbers and beans.



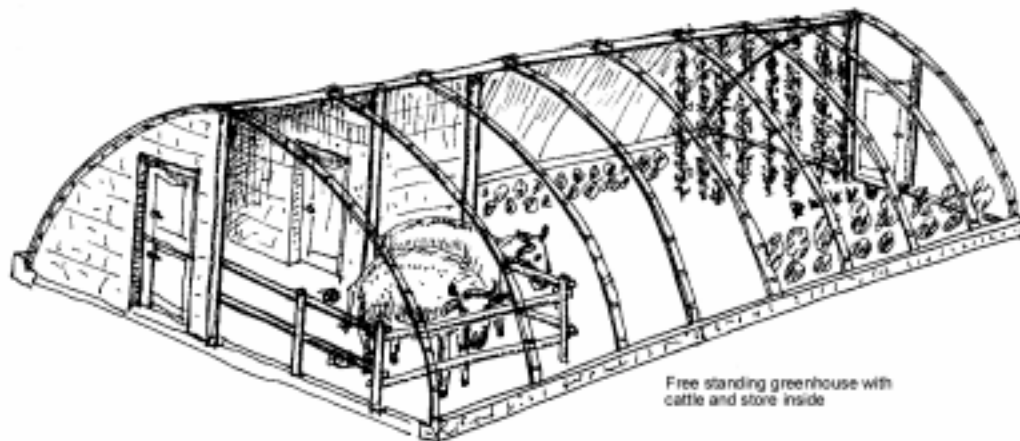
The bundles of bamboo together make a strong frame of ribs and girders. In the above 250cm high construction the side facing the strong winds is closed with a loosely piled stone wall, providing also stability to the construction.



### 3. RECOMMENDATIONS ON GREENHOUSES

The following list of recommendations can be considered in relation to the development of local greenhouses in high altitude areas:

- A. The greenhouse needs to be constructed on a piece of land (from a landowner) and stay in that location for at least 7 to 10 years, the estimated lifespan of the UV-resistant foil (Silpaulin<sup>2</sup>, 120 gr/m<sup>2</sup>). The greenhouse is a semi-permanent construction and its location should be selected with care. For greenhouses around High Altitude Biogas Reactors (HABR), the estimated lifetime of the biogas reactor is well over 25 years, implying that the plastic foil may need to be renewed three or more times, depending on the wear.
- B. The greenhouse should be in close proximity to the farmer's residence because it requires close monitoring of crops and cattle (HABR). Seedlings and crops inside the greenhouse may have a high value, depending on their size and the season. In situations where greenhouses were constructed at some distance from the farmhouse, some farmers complained of seedlings and grown vegetables being stolen during the night.
- C. When the greenhouse is a component of the HABR, care must be taken to avoid damage to the UV foil by the cattle. In this case a low wall or wooden fence can be constructed inside the greenhouse to confine the cattle to an area where they can neither eat the crops nor poke a hole in the foil with their horns. Keeping the cattle inside the greenhouse during the winter will keep them warm and therefore healthier than in a cold dark stable. In the summer shading should be provided for the cattle or the UV foil rolled up for total ventilation.

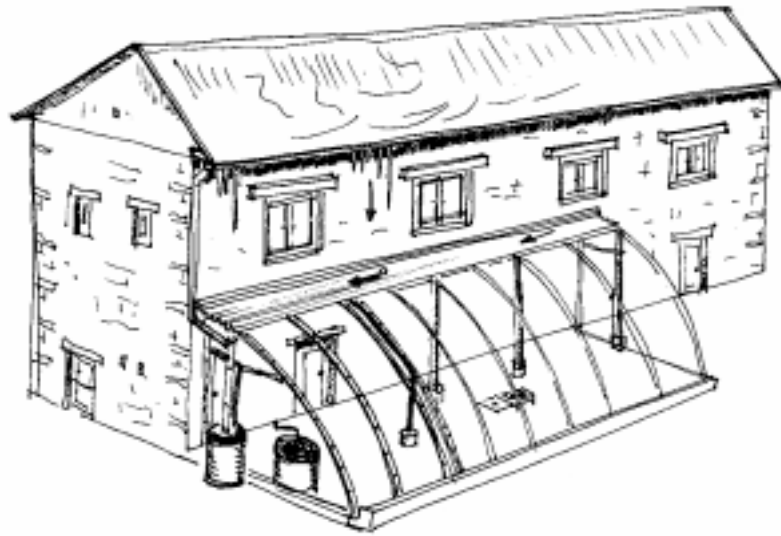


- D. In very high altitude areas (over 3000m) it is recommended to build the greenhouse as a fixed attachment to the residential house on the southern side. This will assist in warming the house during the entire winter period and strongly reduce space heating demands (firewood needs). The outside wall of the farmhouse then becomes the inner wall of the greenhouse and will greatly stabilize the air temperature inside the greenhouse. Building the greenhouse against the main farmhouse will also reduce the amount of foil required.

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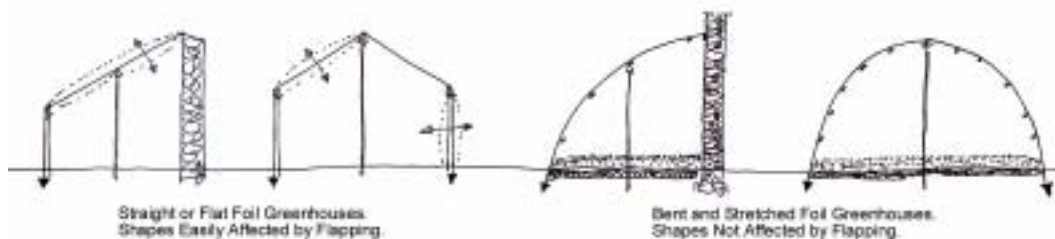
<sup>2</sup> Silpaulin is manufactured in India and commonly used for greenhouses (translucent, 120 gr/m<sup>2</sup>) or for pond lining (blue, 200-250 gr/m<sup>2</sup>). The sheets measure 180cm wide (6 ft.). It can be factory welded to make large sheets. With given dimensions the exact shape can be pre-manufactured and transported to the site, ready to install. This will minimise the amount of work needed on the site and provide good connections between the sheets.

E. When a greenhouse is built against the main dwelling of the farmer, it must be avoided that ice, which may be formed on the roof of the house, can fall onto the greenhouse and punch holes in the UV foil. This will partly depend on the slope and orientation of the roof of the main building. The section of the greenhouse directly under the roof needs to be protected with corrugated plastic glass-fibre reinforced sheets.



F. The orientation of the greenhouse and surface of the UV foil should allow maximum sun intake and not be in the shade of a house or tree. The south-east and south sun should have good access to the greenhouse. The morning sun will warm up the greenhouse and stimulate plant growth. The lower sky path of the winter sun, as compared to the summer sun, should be taken into consideration. A balance should be sought between shielding the greenhouse from strong winds and shading.

G. The durability of the greenhouse depends largely on the durability of the UV-resistant foil. The commercially available Silpaulin (120 gr/m<sup>2</sup>) lasts about 7 years or more when properly fixed to the supporting construction. The tightening of the foil in a bow shape is very important because flat stretching inevitably will lead to flapping of the foil in the wind, which damages the foil and will strongly reduce its life. For areas where sometimes strong wind gusts are expected, a thicker foil can be used; reducing slightly the light transparency.



H. The UV foil needs to be tied down onto the ribs and girders of the frame with flat packing straps<sup>3</sup> anchored into the ground with stones. The straps come in rolls of 4 kg (NRs 480). The approximate length is 140 m/kg (560 m/roll) for the 12mm width. For greenhouses the light coloured straps (white, yellow) are recommended above the transparent (natural) type because these are less affected by sunlight. The coloured straps have a high UV resistance.

<sup>3</sup> “Packing Belt” and “Box Strap” are user names of the woven polypropylene bands used for strapping cardboard and other boxes. The straps come in rolls of various widths (12mm, ¾ inch) and colours (natural, white, red, green, blue and yellow). Thickness is 0.6 – 0.7mm.

The packing straps keep the foil in place. This will be improved when the shape of the greenhouse is rounded. This greenhouse is built in a very shielded area with little wind.



I. The application of transparent glass-fibre reinforced corrugated or flat sheets is recommended in all areas having very high wind load or on sections of the construction subject to high wind impact. This can be the side facing the wind, for example, placing the sheets at the lower side located on the ground. Flat sheets can also be used for doors to give them more strength. The plastic resin sheets have a lesser transparency than the Silpaulin foil and are ten times more expensive per square meter. Risk calculations on wind damage and cost calculations may determine the most appropriate material for a windy location.

J. The owner requires training/information about crop production, the best growing seasons and commercialisation. It is recommended that for each crop type fact sheets be made available in the local Nepali language. These should explain the best time and method to grow each crop with the prevailing climatic conditions (altitude, temperature) and good pest control. The marketing of excess produce would be essential for any new greenhouse or HABR to offset the relatively high investment costs. Contracts can possibly be made with regional hotel owners for the supply of certain crops during specific periods, thus allowing timely planning of the seedbeds.



K. The growth of crops is related to soil and air temperatures, water and nutrients. The ground temperature can only be improved if the topsoil layer is thermally insulated from the underground. This is the case in some of the designs presented in this paper. During the day the sun will warm the soil, whereas this warmth will not be lost to the underground. This gives a higher soil temperature and earlier plant growth. Seedlings can be grown on low tables. This makes the tending to small plants easier.

L. The greenhouse exploitation should be an economic activity, geared to generating additional benefits from growing vegetables and other crops for own consumption or marketing. Personal consumption will improve health and reduce health-related expenses. Sale of produce may improve family income. Improved fodder for cattle will improve milk production and dung quality. The contracting of a greenhouse should therefore be based on a small business plan. The business plan should consider the expected lifetime of the foil (7 years).

M. Several types of plants, such as tomatoes, cucumbers, beans, peppers and other climbers, should not be left laying on the ground but instead suspended upwards along climbing strings. This will optimise the surface area of the greenhouse and allow easy control of the plants and harvesting of the produce. For this purpose strings can be fixed on all the ribs and girders of the greenhouse, allowing the plants to grow towards the roof. The ribs and girders need to be strong enough to carry the additional load and the roof should be at least 220cm high or higher. Several types of plants may grow higher, but can be trimmed. Along the lower sides of the greenhouse, short plant varieties can be grown, such as spinach and greens.



The winding of climbing vegetables around strings hanging from the framework of the greenhouse allows better control of growth while using less floor space inside the greenhouse.

N. Access to good quality seeds and knowledge about (i) composting and vermiculture<sup>4</sup>; (ii) humidity and plant nutrients; (iii) plant growth and tying up of plants; and (iv) simple pest control, are all important factors for successful greenhouse production. Educational programmes and information services need to be available on these subjects in areas where greenhouses are being promoted. A group of farmers in one community should be able to exchange practical information and experience on plant production from which all farmers can benefit. Combined marketing of farm produce may reduce marketing costs.

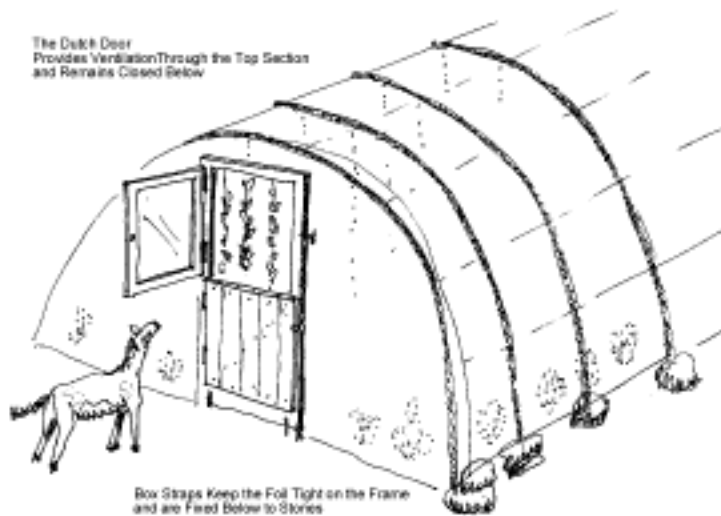
O. Warmed-up air inside the greenhouse has no effect at all on a construction under the ground (such as a biogas digester). If the HABR construction and the ground temperatures need to be maintained during the night, thermal insulation from below the digester and slurry outlet will be required. This can be accomplished by applying a 10cm thick layer of waste plastic and used plastic PET bottles stuffed into bags under and alongside the entire digester and slurry outlet.

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<sup>4</sup> Vermiculture is the process of composting biodegradable components and kitchen waste with earthworms, an ecologically sound system of eliminating wastes and obtaining high quality natural fertilizer.

- P. In strong wind areas it must be avoided that the greenhouse cools down at night when the plants grown inside the greenhouse will be negatively affected by such a cooling effect. This may be particularly the case with new seedbeds. The entire greenhouse can be furnished with a night curtain, creating an additional layer of insulating air on the inside of the UV foil (see Jomsom report). It is recommended to have a minimum-maximum thermometer inside the greenhouse to keep track of the critical temperatures, especially when plants need to be grown during winter.
- Q. The temperature inside the greenhouse may not rise to over 35° C.<sup>5</sup> because this may badly affect (negatively) the plants in the greenhouse. A heavy stone and mud thermal wall may reduce the daily air temperature fluctuations. Shading part of the greenhouse externally with grass mats during the hottest summer period is a possibility. Shading with bamboo mats is not recommended because the sharp edges of the bamboo can easily damage the UV foil, making it useless. Ample cross ventilation is essential to avoid possible overheating inside the greenhouse during very sunny days. One full height door on either side of the greenhouse for cross ventilation may be adequate in many situations. Depending on the altitude and location other roof hatches for ventilation may be needed. This can be determined by closely monitoring the inside air temperatures with the aid of a minimum-maximum thermometer.

- R. Doors can be one piece (see cover page) or a Dutch door by which the upper half can be open separately. The advantage is two-fold: the amount of air and ventilation can be regulated and animals (dogs, goats, cows) cannot easily enter the greenhouse. Care must be taken that the doors and/or windows close fully against the framework to avoid air leaks during the night. This can be done by attaching flaps of foil over the joint on both sides (inside and outside). Any draft or wind will automatically press the flaps closed.

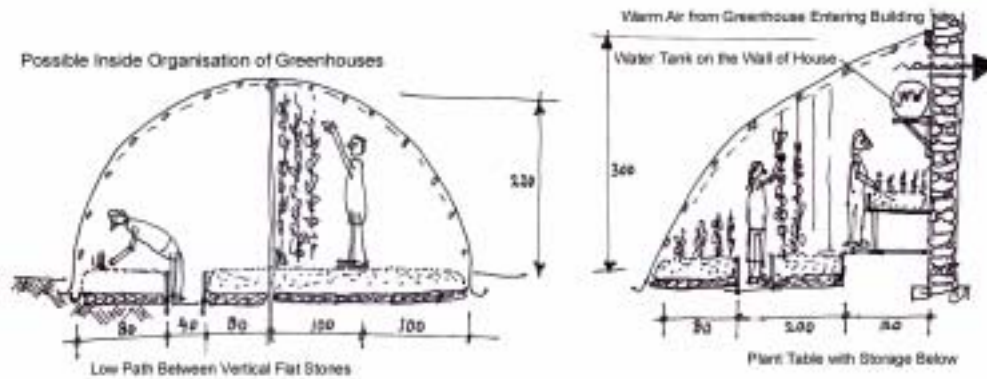


- S. In many high altitude farms water is a daily problem and needs to be collected, demanding considerable time of the farmer's family. Water harvesting can be realised from the roof of the farmhouse and the foil of the greenhouse, depending on the raining pattern of the area. Under all circumstances the greenhouse UV foil needs to be cleaned daily of all snowfall because the light bamboo structure of the greenhouse will not support large snow loads. Snow can be brought inside the greenhouse for melting. This is an option to be considered in such areas as Kumjung (3500m), where water/ice needs to be collected from far during the winter months.
- T. Water storage should be kept inside the greenhouse so the water can warm up to the greenhouse temperature before being administered to the plants or put into the biogas digester<sup>6</sup>. Fresh cow-dung (*gobar* or slurry) may be added to the water, depending on the nutrient needs of the plants.

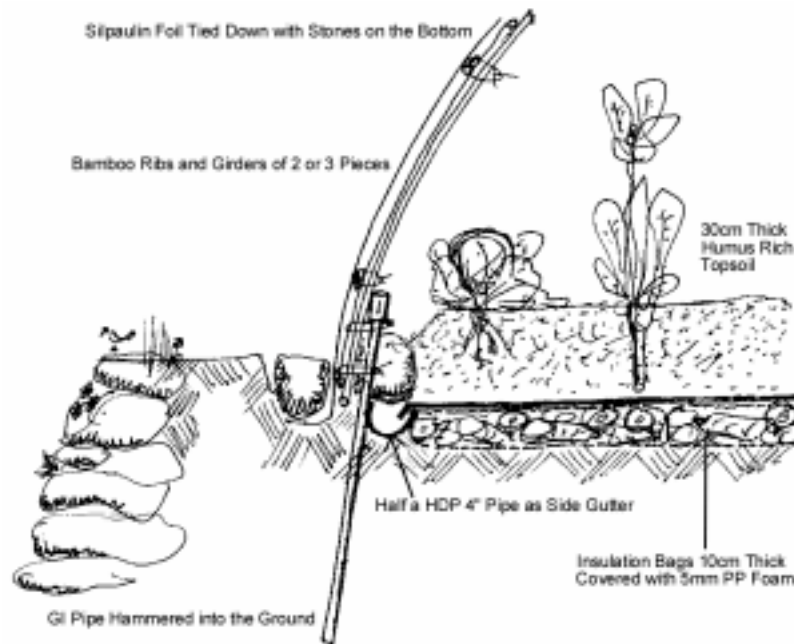
<sup>5</sup> With temperatures over 40° C. most vegetables will get heat burn and lose their leaves.

<sup>6</sup> For HABR over 2500m pre-warming of the water by means of a Solar Water Heater (SWH) may be required during the winter. The definite SWH design for this purpose, which should be manufactured locally, has not yet been determined; one of the reasons why the HABR will presently not be promoted above the altitude of 2500m. Additional research is required.

Mosquito breeding must be avoided (depending on altitude and temperature) by keeping the water barrel tightly sealed.



- U. Water with nutrients should not leak into the underground, but instead should be captured and collected for re-use. Plant soils should both drain well and be able to maintain a fair amount of moisture in its organic matter or compost. To achieve this, a waterproof layer of PP foam can be placed over the insulation layer, sloping slightly towards a side drain (HDP pipe, lengthwise cut in half) which collects the water into a bucket. This prevents root rot from over watering and excess water (with nutrients) is not lost.



- V. When production of vegetables and herbs is good, excess produce can be solar dried for future personal consumption or marketing. Solar drying equipment for green vegetable and herb drying should avoid direct solar light, otherwise the green colour will be destroyed and food items lose nutrients and appearance. Knowledge should be made available on herb and vegetable blanching, drying and storage. Dried vegetables, such as spinach, can be easily reconstituted by soaking these in clean water one day prior to consumption. Dried herbs have a high market value, but should be marketed through a cooperative organisation, assuring organic growth and quality control before packing.

- W. Local information needs to be readily available on the various greenhouse designs, vegetable growing and where to buy the “imported materials” not locally available, including solar driers. This information must be written in the local language and illustrated. They must be available in centrally known places, such as local NGOs, banks, DDC offices, etc. As part of the information package a simple budget planning sheet should be included on which the farmer can make calculations about the economic benefit of a particular size of greenhouse.
- X. Local information can include detailed do-it-yourself construction manuals to guide the handy farmer through all the steps necessary for a durable greenhouse construction. In addition the information can include addresses of local manufacturers who can deliver the entire greenhouse package and local specialists who can erect the greenhouse at the desired site and give advice about its use. This will stimulate local employment. The same persons can provide maintenance, and service contracts can be realised. It will be important to have the expertise locally available for both construction and vegetable growing.
- Y. Local Micro Finance Institutes (MFIs) and banks should be able to extend credit for greenhouse operation and solar drying. It may be possible for IREF under AEPC to include financing of small RE applications in its portfolio and AEPC to extend its subsidy policy to greenhouse constructions in remote areas to offset the additional transport costs.
- Z. Although greenhouses (and solar driers) are important support for local food supply in remote and high altitude areas, the drive to develop this knowledge and the market for products and services need to come from locally interested parties. These can be local manufactures of the components and NGOs specialized in the subject. A combination of technology and management organisation is desirable because manufacturing, delivering, construction, operation and marketing are all components linked one to the other. In this context the government can play only a facilitating role in stimulating the delivery and implementation processes.



## 4. CONSTRUCTION OPTIONS

A greenhouse needs to comply with the desires, economic feasibilities or time constraints of the owner. A large investment should not be made when it cannot adequately be utilised or insufficient experience is available to exploit the greenhouse beneficently. This benefit can be in the form of additional food production for personal (or cattle) consumption or from the income generated from the sale of the produce.

In many cases it may be advisable to start with a small greenhouse to get the right experience for crop production at the available location considering sun intake, wind, temperature, etc, before one starts enterprising with a large or specially insulated construction.

Example of Growing of Spinach or Greens (*Saag*) (S) at 2500m

Months of the Year	Ja	Fe	M	Ap	May	Jn	Jy	Au	Se	Oc	No	De
Nothing grown in a greenhouse					*	S	S	S				
Only seedlings (*) grown in greenhouse				*	*S	S	S	S				
All grown in greenhouse				*S	*S	S	S	S	S	S		
All grown in floor-insulated greenhouse		*	*S	*S	*S	S	S	S	S	S	S	
Trekking season (TS) in the mountains			TS	TS	TS				TS	TS	TS	

Per greenhouse improvement, the growing period may possibly be extended for an additional two months, allowing excess crops to be sold to small hotels located along trekking routes. The additional time and financial investments needed for soil insulation should be considered in this context.

- ❖ *First make a choice as to what type of greenhouse or business you want and if you can maintain that business for seven or more years.*
- ❖ *Then decide on the actual construction materials of the greenhouse, based on the expected growing season of the plants.*

### 4.1 Winter Cover Nursery for Saplings at High Altitudes

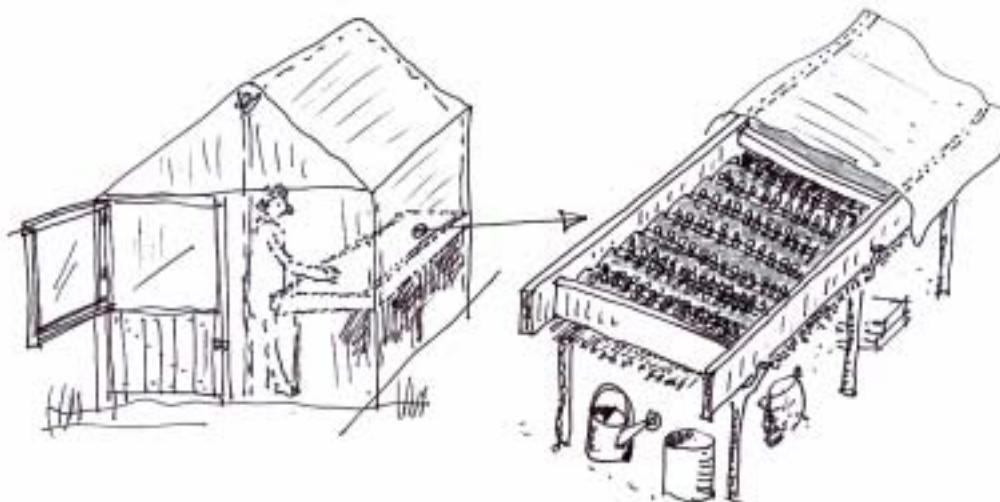
Tree saplings grow better and faster in a greenhouse. However, when dealing with large quantities as in reforestation programmes, the greenhouse needs to be free for the following year's saplings production. When saplings are kept outside during the winter, they will not grow and the period before they can be transplanted into the hills will be extended for an additional year<sup>7</sup>. When saplings are protected during the winter, they will restart their growth sooner. Constructions that are simple, low and strong enough to withstand a load of snow are required.



<sup>7</sup> Experience shows that fir and pine trees saplings need to be planted when they are at least three years old, otherwise they get eaten by grazing animals.

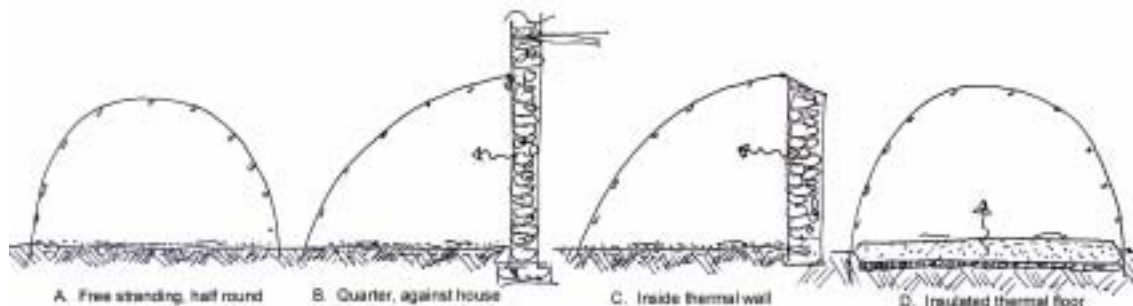
## **4.2 Seedling Production**

To produce seedlings for planting outside in the “cold” soil, a small greenhouse of about 2m x 2.5m floor surface should be sufficient (5m<sup>2</sup>). The sides that do not face the sun can be made with double foil for additional thermal insulation. On the inside a night curtain can be fixed or a second Silpaulin can be pulled over the small greenhouse for protection during cold nights, taking care that a layer of air remains between the two foils. The seedlings should be planted in trays placed free from the “cold” soil and covered with a fully transparent foil to retain warmth and moisture.



## **4.3 Kitchen Greenhouse (Small)**

For personal consumption of vegetables and herbs, flowers and for producing seedlings, a small kitchen greenhouse can be made with a floor surface of 2.5m x 4m (10m<sup>2</sup>), about two times the size of the seedling greenhouse (paragraph 4.2). The 2.5m width allows for one narrow path through the centre of the greenhouse for walking space. A choice can be made of either insulating the whole greenhouse bottom for 100% planting in the soil or having a combination of seedling trays and planting in the “cold” (non-insulated) greenhouse soil. The plants put in the “cold” soil will mature later than those planted in an insulated soil. Therefore, it will depend on the need for crops and the time of the year whether or not the owner wants to insulate the greenhouse floor.



### **4.4.a Medium Greenhouse**

In order to compare cost prices of materials for medium-size greenhouses, all designs have been calculated on the basis of the same ground dimensions as the greenhouse built in Jomsom (table page 17 refers). That greenhouse had an inside surface useful for planting of about 18m<sup>2</sup>.

### **4.4.b Medium Greenhouse Leaning Against House**

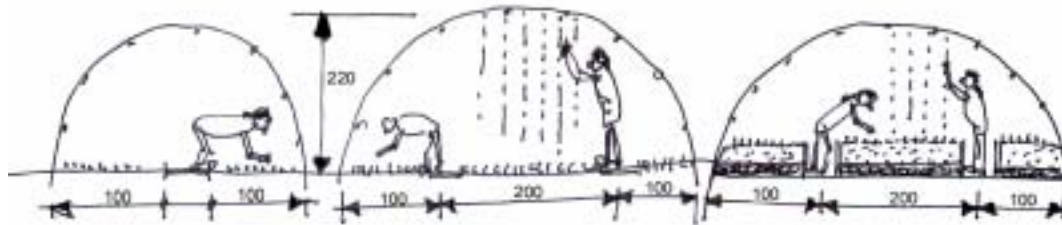
The cost differences between a free standing greenhouse and a greenhouse leaning against the house have been estimated. When the greenhouse is built against the southern side of the house, it economises foil and the house wall will serve as thermal storage, stabilizing the air temperature.

#### **4.4.c Medium Greenhouse with Inside Thermal Wall**

When a greenhouse with a thermal storage stone wall is built separately from the house, construction costs will increase and additional labour for making the wall will be required. The thermal wall provides additional strength and stability in the event of strong winds.

#### **4.4.d Medium Greenhouse with Insulated Ground**

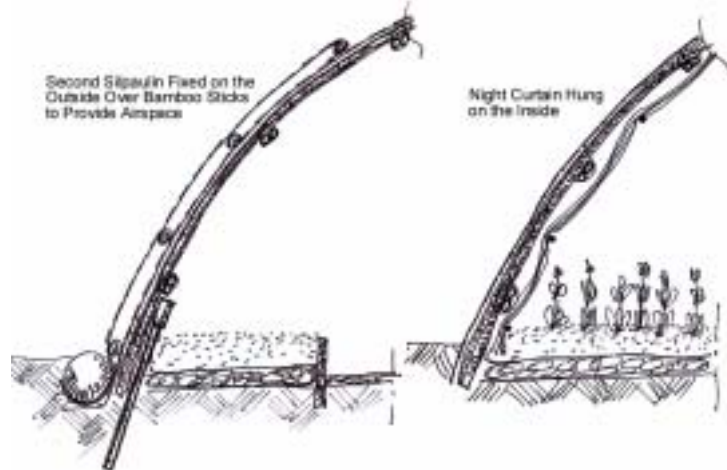
This model does not have the inside wall nor the benefit of the wall from the house. In this case insulating the ground is far more cost efficient and energy efficient than the built-up stone wall but is more vulnerable to strong winds.



#### **4.5 Food Production Greenhouse**

A farmer who wants food production for personal use, cattle fodder and marketing needs a greenhouse surface large enough to allow several crops to be grown in several stages and in reasonable quantities. Fodder can be grown for cattle as a supplementary food source. Contracts can be made with hotels for supplying vegetables, but this would require timely seeding. A minimum size is suggested of 4m x 10m (40m<sup>2</sup>).

The 4m width requires two small parallel paths, combining minimum path area with easy access to the plant beds. It is recommended to have an insulated floor in the food production greenhouse. As an alternative, this larger greenhouse can be partitioned with one section having an additional insulated night curtain and planting trays for seedling production. On the northern side a second Silpaulin can be fixed with an airspace to provide better insulation.



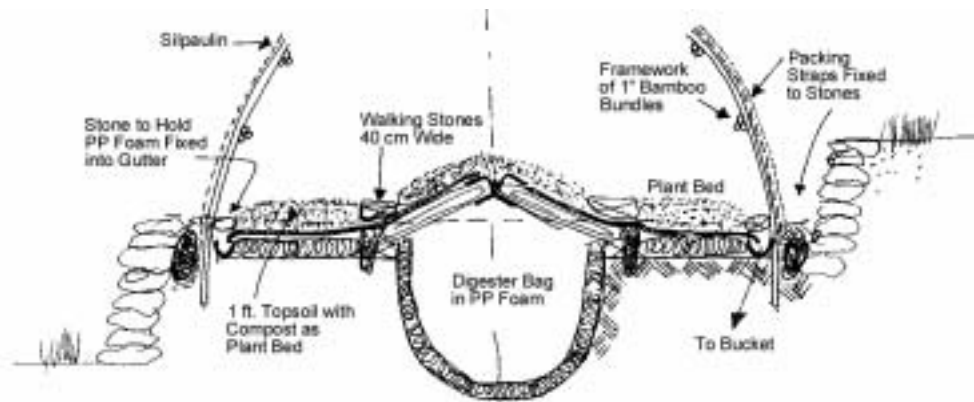
#### **4.6 High Altitude Food Production Greenhouse<sup>8</sup>**

Above 3000m very few vegetables will grow without a greenhouse; and if they grow at all, it will only be for two months at the most. People depend on (expensive) green vegetables brought from lower altitudes during most of the year or go without; the latter having a negative effect on their general health. These larger, more permanent constructions require strong support structures. Large (8-12cm) diameter bamboo poles, split in two, can be permanently anchored into the walls of the house. These greenhouses can have part of the soil insulated, while the production of seedlings can be done in trays placed above the ground. A small section inside can be additionally insulated to avoid heat loss during the night.

<sup>8</sup> On the Tibetan plateau, where many farmers live at an altitude of about 4000m, the long façades of all new farm buildings are facing south and have attached large bow-shaped greenhouses built against that southern façade for vegetable and fodder production. These constructions are made with large size bamboo brought from lower valleys.

#### **4.7 HABR Greenhouse**

A biogas reactor above 1800m requires thermal insulation in the ground around the entire digester and slurry outlet. This will prevent cooling down of the content and with that maintain reasonable gas production during winter<sup>9</sup>. The greenhouse may do little to warm the reactor, but it will retain some of the warmth rising from the reactor, creating an improved micro-climate for plant growth. Cattle housed inside the greenhouse remain comfortably warm during the winter. This three-way symbioses during the winter is important because good fodder will produce good dung for more biogas. Besides, with the large greenhouse the farmer can supply his/her own kitchen as well. During the summer the greenhouse will be too hot for the cattle; shading and ample ventilation will be required depending on the altitude. In addition to insulating the reactor, it is advisable to insulate the ground inside the greenhouse so that in early spring crops can be grown. The total length of the greenhouse depends on the size (length) of the biogas reactor and whether or not the cattle shed will be included.



#### **4.8 Commercial Greenhouses**

Commercial greenhouse should be based on a business plan. Durability and minimum maintenance will be important. Risk reduction to avoid damage from strong winds or heavy hail is equally important. It is not only the greenhouse that can be destroyed, but also the crop/plants inside; sometimes having a higher value than the greenhouse itself. Water supply, irrigation, hydroponics, monoculture, pest control, illumination, product processing, packaging and marketing are all elements that need to be considered for commercial enterprises.



A few hotel owners have made their own greenhouses to have fresh salads for guests.

<sup>9</sup> All farmers having a fixed-dome design biogas reactor observe reduced gas production during the winter. This is caused by inadequate dung feeding before and during the winter and the lower temperature of the reactor during the winter. Inadequate dung feeding is a combination of the lesser quantity and the drier quality of the cattle food during the winter.

The following table gives an overview of several designs. It excludes the large commercial projects because greenhouses for such a purpose need to be specifically designed, based on a business plan.

Type and Description of Greenhouse	Size of Greenhouse Useable Ground Area	Cost of Silpaulin NRs 8/sq.ft.	Support Structure <i>No material costs, but labour for collection in number of days (nD)</i>	5mm PP Foam + 4" Plastic Waste	Cost Silpaulin + PP + Insulation <i>With labour at NRs 200/day</i>
1. Winter cover nursery for saplings	1m x 10m = <b>10m<sup>2</sup></b>	20m <sup>2</sup> NRs 1,800	Low tent structure with bamboo or sticks (1D)	n/a	NRs 180/m <sup>2</sup> NRs 200/m <sup>2</sup>
2. Seedling production	2m x 2.5m = <b>5m<sup>2</sup></b>	26m <sup>2</sup> NRs 2,500	Square boxed wood/ bamboo frame/roof (4D)	n/a	NRs 500/m <sup>2</sup> NRs 660/m <sup>2</sup>
3. Small kitchen greenhouse, free	2.5m x 4m = <b>10m<sup>2</sup></b>	36m <sup>2</sup> NRs 3,500	Square boxed wood/ bamboo frame/roof (6D)	n/a	NRs 350/m <sup>2</sup> NRs 370/m <sup>2</sup>
4a. Medium size greenhouse, free standing	2.5m x 7.5m = <b>18m<sup>2</sup></b>	50m <sup>2</sup> NRs 5,000	Half round bamboo frame, two doors (4D)	n/a	NRs 280/m <sup>2</sup> NRs 325/m <sup>2</sup>
4b. Medium size leaning to south wall of house	2.5m x 7.5m = <b>18m<sup>2</sup></b>	40m <sup>2</sup> NRs 4,000	Quarter round bamboo frame, two doors (7D)	n/a	NRs 225/m <sup>2</sup> NRs 300/m <sup>2</sup>
4c. Medium size (free standing) + thermal wall <sup>10</sup>	3.3m x 5.5m = <b>18m<sup>2</sup></b> (net)	50m <sup>2</sup> NRs 5,000	Stone masoned walls on three sides, ¾ round frame (50D)	n/a	NRs 280/m <sup>2</sup> NRs 850/m <sup>2</sup>
4d. Medium size (free standing), insulated soil	3.3 x 5.5m = <b>18m<sup>2</sup></b>	50m <sup>2</sup> NRs 5,000	Half round bamboo frame, two doors (8D + 4D)	18m <sup>2</sup> NRs 2,375	NRs 410/m <sup>2</sup> NRs 550/m <sup>2</sup>
5. Food production for local use	4m x 10m = <b>40m<sup>2</sup></b>	90m <sup>2</sup> NRs 9,000	Half round bamboo frame, two doors (9D)	n/a	NRs 225/m <sup>2</sup> NRs 270/m <sup>2</sup>
6. High altitude food production, soil insulation	4m x 10m = <b>40m<sup>2</sup></b>	90m <sup>2</sup> NRs 9,000	Half round bamboo frame, two doors (18D + 9D)	40m <sup>2</sup> NRs 5,280	NRs 360/m <sup>2</sup> NRs 500/m <sup>2</sup>
7. High Altitude Biogas Reactor, insulated soil	4m x 15m = <b>60m<sup>2</sup></b>	130m <sup>2</sup> NRs 13,000	Half round bamboo frame, two doors (12D + 13D)	30m <sup>2</sup> NRs 4,000	NRs 300/m <sup>2</sup> NRs 370/m <sup>2</sup>

Comparison of greenhouse costs for purchased Silpaulin + box strap, and PP foam + insulation. Thermal insulation bags with plastic waste are locally collected and stuffed. The estimated market value is about equal to the value of the PP foam or NRs 6/sq.ft.; together NRs 12/sq.ft.

From the table it can be assessed that the investment cost per square meter goes down when the size increases. Building the thermal wall inside the greenhouse is the most expensive solution; attaching the greenhouse to the main house is the cheapest solution.

<sup>10</sup> This model was constructed in Jomsom. Outside it measured 4m x 8m, but useable inside surface for planting was only 18m<sup>2</sup>. The cost of this design was on average NRs 30,000, but included skilled labour, purchased materials and transport of these materials. For this table only about 50% of the cost has been taken (NRs 15,000) because the other figures are also based on self-help construction.

## 5. COST ESTIMATE

The estimate below is based on a 15m x 4m greenhouse. The relatively large size is based on the size of the biogas reactor, including the slurry outlet and cattle area (placed inside). Smaller designs are possible and it is recommended to make special drawings for each size (design) and include a detailed cost estimate of materials and labour.

The 10cm thermal insulation material can be made from plastic waste material, such as empty PET bottles and other (non-sharp) plastic waste (PVC, bags), stuffed into PP fibre agricultural sacks.

- A 4m wide greenhouse fits on most terraces in mountain areas. UV foil is 16m x 8m.
- Silpaulin roof  $130\text{m}^2 \times 120 \text{ gr/m}^2 = 16 \text{ kg}$ . Cost price of 1430 sq. ft. @ NRs 8 = NRs 11,500.
- The 5mm PP foam<sup>11</sup> has a surface of  $60\text{m}^2$ .  $180 \text{ gr/m}^2 = \text{about } 11 \text{ kg}$ . Cost price @ NRs  $60/\text{m}^2 = \text{NRs } 3600$ .
- Second hand PP bags (*bora*) at about NRs 6 each. Total  $150 \times \text{NRs } 6 = \text{NRs } 900$ . Value plastic waste = about NRs 2,500.
- The 15m (optional) HDP 4" pipes for the side gutter weighs about 15 kg. Thin quality @ NRs 80/kg = NRs 1,200.
- Bamboo girders and ribs to be collected from local forest, length 350cm. One week's labour.
- The greenhouse frame structure is made from one-inch bamboo sticks, bent in shape and bundled in threes to obtain sufficient strength. Total construction: one week with two persons.
- Packing strap (½"), half a roll = about 280m = NRs 240. Weighs about 2 kg.
- String of 3mm PP = NRs 40/kg = 110m. For about 550m = NRs 200. Weighs about 5 kg.
- Total transport cost of 50 kg = about NRs.10 per kg per day. One day's walk = NRs 500; two days' walk = NRs1000 and three days' walk = NRs 1500. Depending on the region.
- Total cost of imported materials as per cost price in the city = about NRs 20,000. Additional are the local material costs (bamboo) and labour.

1	Length of greenhouse (width 4m)	15m
2	Width of greenhouse UV foil	800cm
3	Mid height of greenhouse inside	220cm
4	Width of excavation trench	400cm
5	Depth of excavation 10cm + 30cm	40cm
6	Volume insulation 0.1m x surface	6m <sup>3</sup>
7	Number of 40 L bags plastic waste	150 bags
8	Bamboo for ribs (3 pc each) of 1" @ 60cm centre to centre	150 pc x 350cm
9	Bamboo for girders (3 pc each) of 1" @ 60cm centre to centre	450m total
10	Total filling of compost soil 30cm	18m <sup>3</sup>
11	PP plastic (dark) string for fixing girders and ribs, pieces 1m/knot	250 x 1m x 3mm
15	PP plastic (dark) string for hanging plants from greenhouse roof	150 x 2m x 3mm
16	5mm PP foam covering insulation	60m <sup>2</sup>
17	HDP drain pipe 4" (sawn in half)	15m
18	Silpaulin for outside greenhouse	13 m <sup>2</sup>
19	Silpaulin for two doors	4m <sup>2</sup>
20	Packing straps for tying down foil	200m
21	Water barrel for storage	200 L
22	Two door frames with hinges and lock and double doors inside	2 each
23	Minimum-maximum thermometer	1 pc
24	Total weight of imported materials, including HDP pipes, Silpaulin, PP foam, string and straps only.	150 kg

<sup>11</sup> PP is expanded cellular polyethylene foam, usually used as under-carpet and by some trekking agents as insulating mattresses. The thin foam layer will protect the Silpaulin against damage from the thermal insulation material. The PP foam consists of multiple small and sealed cells that do not allow water absorption.

## 6. PLASTIC WASTE AS THERMAL INSULATION

In remote mountain areas, especially where tourists are trekking, several types of plastic waste may be easily available. The PET drinking bottles have especially been causing aesthetic pollution to the mountain environment along the trekking routes, but also wrappings of such food items as dried noodles and plastic shopping bags are proving to be a litter eyesore. In some of the mountain areas prohibiting the importation of plastic bottles or bags is being enforced to curb the pollution caused by these waste materials. In other areas collection and either burying or burning of the waste material is being practiced.

The same plastic waste material, however, can be perfectly used for thermal insulation, especially empty PET bottles because they already contain air. The air inside the bottle is the thermal insulator, whereas the plastic material is the inert material holding the air in place.

Many goods are transported into the high and remote mountain areas in plastic fibre bags (stretched fibre PP). These bags can be used for collecting and containing the plastic waste. The bags (called *bora*) are sometimes reused. However, if left exposed to UV sunlight, these bags will structurally fall apart in about three months and become waste. Second-hand *bora* cost between NRs 4 and 8, whereas new *bora* cost about NRs 15-20, depending on their size (20-40 litre).

To use the plastic waste as a soil insulator or around the biogas digester, the waste material does not have to be washed clean. It can be stuffed directly into *bora* bags to make packages of 10-15cm thick. Plastic shopping bags, food wrappers, etc. should not be put flat into the bags but rather they should be crumpled up and propped in between the bottles.

A flatly filled bag of 45cm (1½ ft.) wide x 75cm (2½ ft.) long = 1/3m<sup>2</sup>. This bag filled to 12.5cm (5") may contain 40 litres and has a very high thermal insulation value. This is comparable in insulation value with 8cm glass wool. The cost of 8cm thick glass wool in the city is about NRs 200/m<sup>2</sup>. In comparison to the above 1/3m<sup>2</sup> bag filled with plastic waste, a piece of 1/3m<sup>2</sup> x 8cm glass wool would cost about NRs 65, exclusive of transport costs to remote areas. This means that a part of this value can be paid for collecting and making the insulation bags filled with plastic waste.

Builders of greenhouses and biogas reactors can negotiate with local people to collect the required number of bags of thermal insulation material (plastic waste) and at the same time be cleaning up the environment and stopping plastic waste from being incinerated. Especially PVC releases poisonous gasses when burned.

When placing the stuffed (waste plastic) insulation bags into the ground, consideration must be given to the fact that the pressure of the weight of the soil or the slurry from the biogas reactor will cause the bags to compact. For this reason it is recommended that the PET bottles directly under and along the sides of the biogas digester have their caps on and are pressure resistant<sup>12</sup>.

Materials that should NOT be put in these insulation bags are: sharp pieces of hard plastic, glass bottles or jars, metal or aluminium cans, cotton or wool clothing, cardboard and any organic materials.

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<sup>12</sup> Glass wool, although an excellent thermal insulation material, will be compressed and would not be a suitable material for the insulation of the digester bag or under the greenhouse soil.