The Realm of Solar Energy
Michigan State University Extension Service
Energy Facts
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Issued August 1983
6 pages

ENERGY FACTS

Cooperative Extension Service
Michigan State University

Extension Bulletin E-1726 August 1983

The Realm of Solar Energy

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SOLAR ENERGY to many of us means heating homes and/or water by solar heat either actively or passively collected. These uses form an important part of solar energy utilization.

However, there is more to solar energy than simply heating space or water. This bulletin explores some of the uses of the sun's energy, including biomass, solar electricity, ocean energy systems, and wind. Emphasis will be placed on passive solar space heating and domestic hot water systems.

SOME BASICS

In English or engineering units, solar radiation is measured in Btu/ft^2 (British thermal units per square foot). The average intensity of solar radiation on the outer edge of the earth's atmosphere is 429 Btu/ft^2. This figure is called **the solar constant.** It is the maximum amount of solar radiation that could be received on the ground, if there were a total absence of cloud cover and atmospheric particles. In actuality, the amount of solar energy received on the ground is usually much less than that of the solar constant.

Normally, part of the radiation (sometimes as high as 35%) is lost from the sun's rays being reflected back into space by cloud cover and atmospheric particles. Of the remaining solar radiation, about 10 to 15% is absorbed or scattered by atmospheric particles and by the ozone layer (2).

Another factor that further reduces the intensity of solar radiation is the path of travel of the sun's rays. When the sun's ray comes in from overhead (or near overhead), it has less atmospheric space to travel through and, less chance of interference. From overhead, the ray also heats a smaller area and therefore provides more heat intensity than when the same size ray comes in from lower in the sky (Fig. 1).

In the same way, locations on or near the equator (where the sun is always near overhead at noon) get a higher intensity of solar radiation than Michigan where the sun is much lower in the sky.

Therefore, the amount of solar energy that actually reaches the earth's surface as usable solar radiation depends not only on the amount of interference from cloud cover, but also on geographical location and is usually much less than the value of the solar constant.

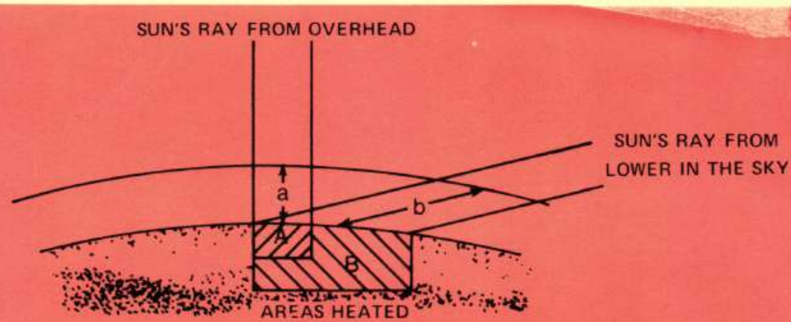

Fig. 1. Effect of the sun's path on radiation intensity.

DIRECT SOLAR

Direct uses of solar energy include active water heating systems, passive systems, and photovoltaics or solar electric generation.

Passive Solar Energy

In Michigan, passive solar energy is probably the most cost-effective use of solar energy for space heating, in comparision with active systems. Passive design is a combination of site selection, climate, building materials, and the sun and its travel patterns. It requires no external energy inputs for collecting, storing, or distributing solar heat. It involves two basic elements: 1) a south-facing glass or transparent plastic (generally called "glazing") to collect solar energy, and 2) a thermal mass to absorb, store and distribute the heat.

The materials used currently to provide a thermal mass are water, masonry, and certain **phase change** materials or eutectic salts. These all perform one function: absorb heat during the day when the sun is shining and release the stored heat to the space to be heated at night.

Passive solar energy devices can be incorporated at fairly reasonable cost in the original design and construction of a house to provide savings in energy. It can also be added to an existing house as a "retrofit". Its design, operation and maintenance can be quite simple.

Solar Water Heating

Solar water heating is another cost-effective way of using solar energy in Michigan. Hot water is used year-round. A well-designed solar water heating system in Michigan should be capable of providing from 40 to 60% of the hot water needs on a year-round basis. A good design requires proper selection of flat plate collectors and distribution systems. Also all water pipes and water storage tanks must be properly insulated.

Solar water heaters have three basic components. The first is a solar collector, which is usually a flat plate that can be placed on the roof, against a wall or on a separate frame. In its basic construction, pipes are soldered onto an absorbing surface. Header pipes join the soldered pipes at both ends of the collector and the unit is placed underneath one or more transparent surfaces. The back side of the collector is insulated and the whole unit is put in an insulated, weather-tight box (see Fig. 2). For maximum absorbing capability, the collector surface must be as dark as possible. (see Table 1).

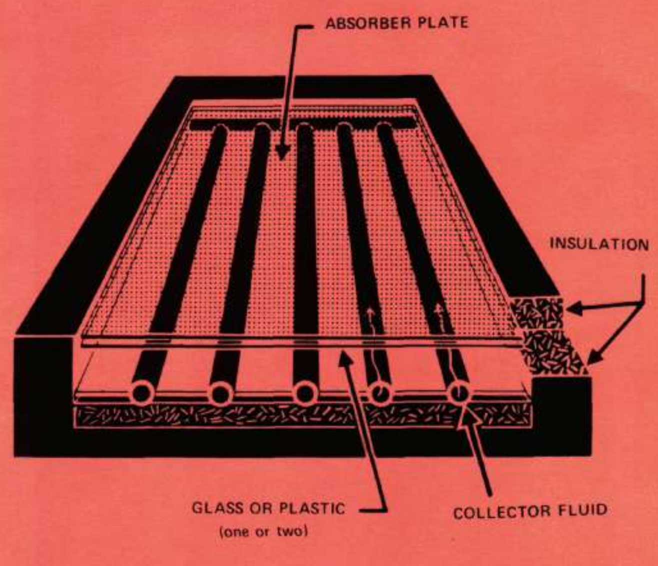

Fig. 2. Components of a Solar Collector.

The second and third components of solar water heating are storage and circulation. Either one or two tanks may be used for storage. In a one-tank system, the regular water heating tank is used, and the original heating element becomes the "back-up" heater. A double tank system uses a second tank (the preheater) in addition to the regular water heater. In some drainback systems (see below) the second tank is used to house a heat exchanger.

For either a one- or two-tank system, further variations are the direct (open-loop) system or the indirect (closed-loop) system. The circulation methods most frequently used in direct systems are thermosiphoning and pumping. In a thermosiphoning system, water flows down to the collector by gravity. As the water is heated in the collector, it becomes less dense and rises, thus setting up a natural convective loop between collector and storage (Fig. 3a). Because the water is fed to the collector by gravity, the storage (or feed) tank must be placed on a higher level than the collector. This makes it harder to locate the components. In addition, this system

Table 1. Solar Radiation Absorbed by Various Surfaces

Surface	% Absorbed
Reflective	20
White, smooth	25-40
Gray to dark gray	40-50
Green, red & brown	50-70
Dark brown to blue	70-80
Dark blue to black	80-90

Source: (2)

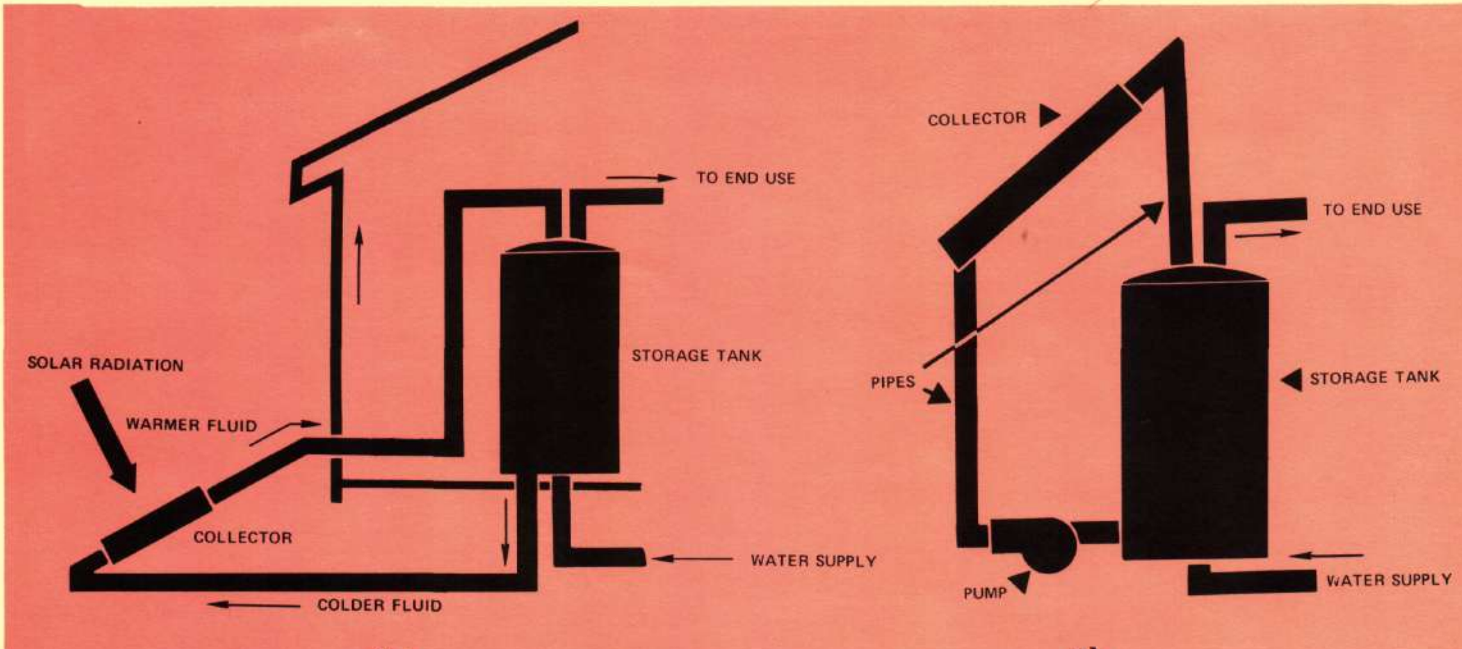

Fig. 3. Solar water heating — direct systems.

has very limited, if any, applicability in Michigan during most of the year, because of lower solar radiation levels.

The pumping system is completely flexible in locating the collector and the storage media (Fig. 3b). However, it has the disadvantage of requiring energy to pump and circulate water from storage to collector and back to storage.

The distinguishing feature of the direct system is that the water that goes through the collector is the same water eventually in the house. In the indirect system, the liquid (water or antifreeze) from the collector never comes into direct contact with the household water.

Figure 4 shows the antifreeze indirect system. The system usually employs two tanks. The first one houses a heat exchanger, and the second stores the heated water. The household water is circulated from the regular storage tank into the heat exchanger tank and back. The heated water from the collector goes into the heat exchanger tank where it gives up some of its heat to the household water. Under normal operation, the two liquid streams do not come into contact.

In the drainback system, when the level of solar radiation is below a predetermined standard, the pump stops, and the water from the collector drains back into the heat exchanger tank. This prevents water from freezing inside the collector. If water freezes inside, the collector may be damaged severely since the water volume increases. If you buy a drainback system, get a warranty covering correct operation. Repairs can be expensive.

To get around this problem, a variation of this system uses an antifreeze as the collector fluid. The system employs a small heat exchanger, usually holding not much more than 5 gallons of antifreeze. Propylene glycol, which is non-toxic, is recommended for antifreeze rather than ethylene glycol. Normally, there is little chance of contamination, but, if it occurs, ethylene glycol can be toxic.

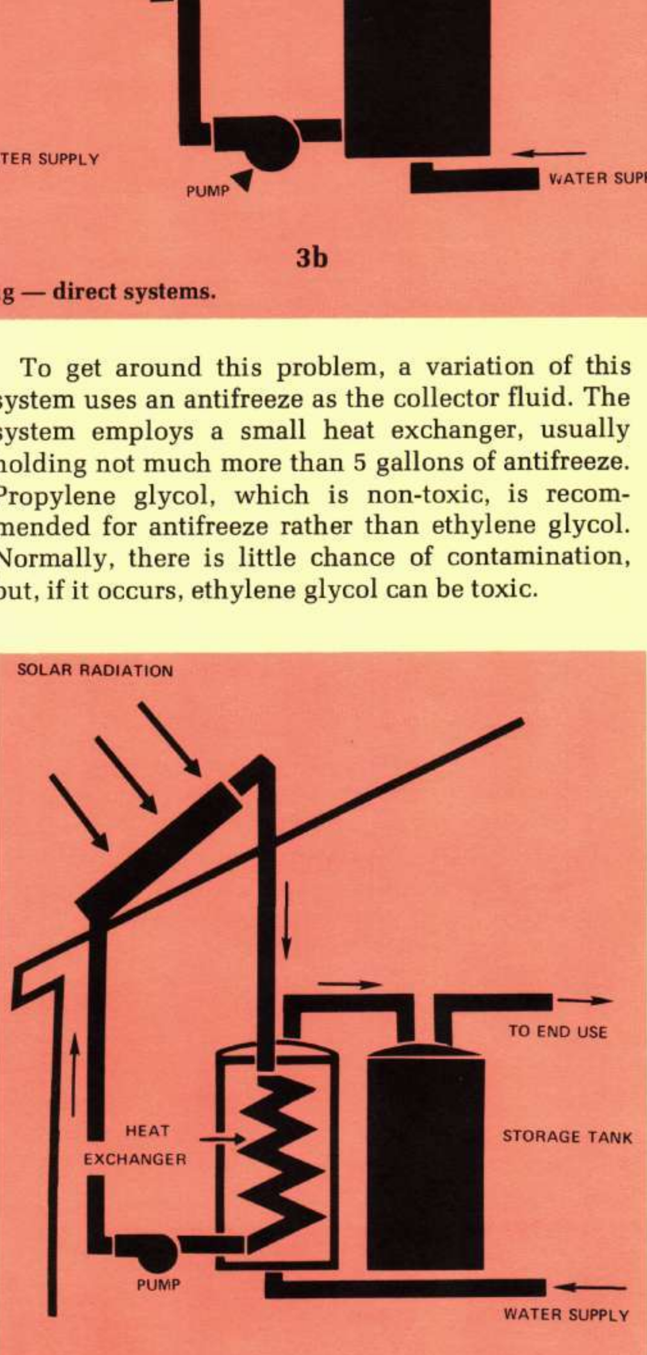

Fig. 4. The indirect system using antifreeze.

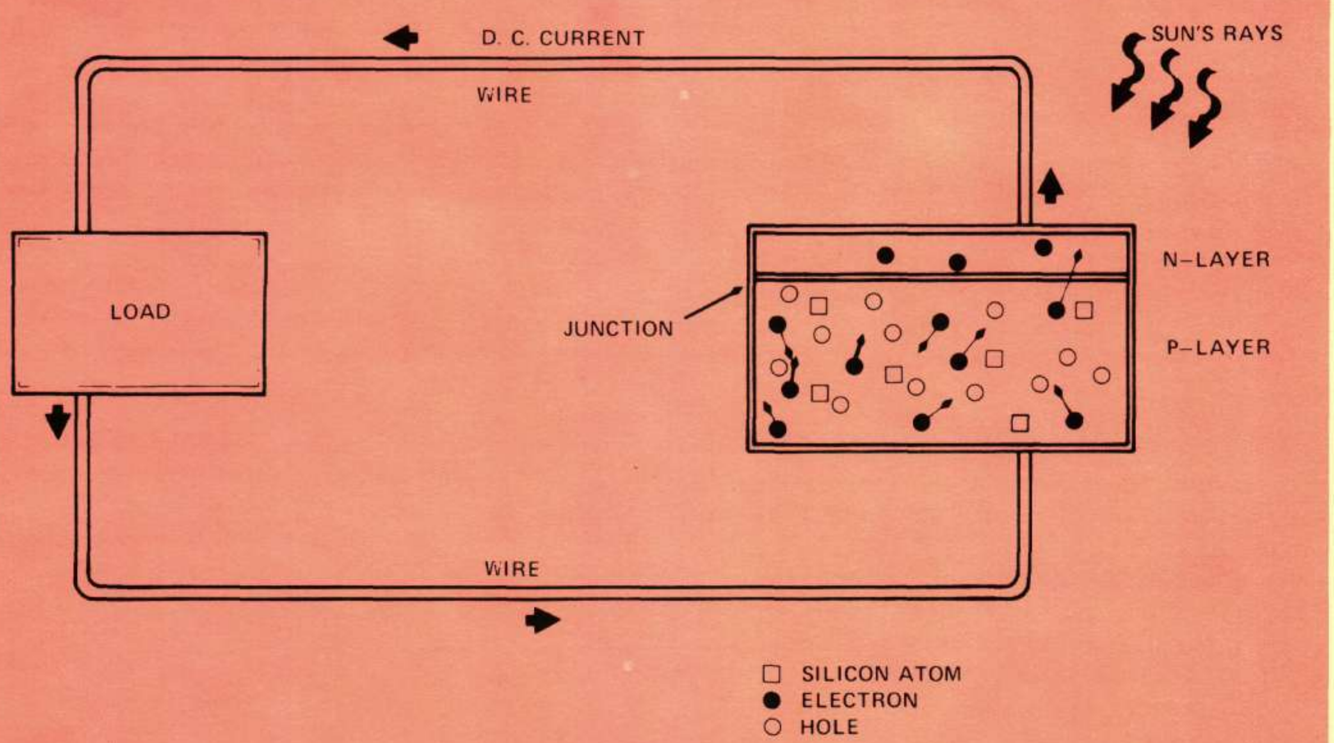

Fig. 5 — Silicon solar cell.

Electricity

Solar cells are constructed from semi-conductor materials to convert sunlight into electricity. They work on the principle that an electric charge is developed when light strikes the junction of dissimilar materials. Semi-conductor materials include silicon, gallium arsenide, germanium, cadmium sulfide, cadmium telluride, indium phosphide, and gallium phosphide.

Figure 5 shows a typical two-layer construction of a solar cell. The n-layer is made of silicon duped (made impure) with phosphorus, while the p-layer has silicon duped with boron. When the sunlight strikes the n-layer, electrons are "energized". Movement of electrons then occurs with electrons coming in from the p-layer to fill the void created by the movement of electrons in the n-layer. This sets up an electrical current from the cell to the load. Since only a direct current (DC) is developed, a converter is needed if alternating current (AC) is required.

Another way of producing electricity from solar energy is solar thermal conversion. The system design is similar to conventional electricity-generating systems except that the sun provides the heat source to produce the required steam. The high temperatures needed to produce the steam require mirrors (or lenses) to focus the sun's energy into metal pipes (1). By focusing with mirrors, the intensity of solar radiation received (Btu/ft^2) is increased.

USING SOLAR ENERGY

Solar energy is virtually free, but it costs money to install an operating system. Thus every design or purchase should aim at cost-effectiveness. One way to decide on the suitability and cost-effectiveness of a system is to insist on a written payback analysis from the designer or dealer.

A payback period is the number of years it will take to realize enough savings from reduced water heating (or space heating) bills to pay for the system. A good payback analysis should include interest on any loans needed to put the system in and any tax credits awarded by the state and/or federal government.

A simple analysis will yield a good estimate of the payback period. For example, assume that after allowing for federal and state tax credits on your system, the cost of the system is $1,800. If you decide to take out a loan at 15% interest for the whole amount for 6 years, your monthly payment will be about $38.06. Local banks will supply information on monthly payments on a loan. If you wish to compute your own monthly payment to determine the cost of a loan to you, a simple formula to use is:

$$A = \frac{P\,(1-(1+r)^{-n})}{r}$$

Where:

A = the loan principal

P = the monthly payment

r = the interest rate per payment period

n = total number of payments (72 in the example)

Therefore r = 0.15/12 in the example.

To estimate your payback period, follow these steps:

1. Multiply n by P to get the total cost of your loan.
2. Multiply the estimated monthly savings in energy costs that will **result from putting the system in** by 12.
3. Divide your answer in Step 1 by your answer in Step 2.

The result gives an estimate of your payback period.

For the example, the payback period would be 7.6 years if the system saved $30 per month on energy costs. It means that in 7.6 years you would realize enough savings on your energy costs to pay for it.

This analysis is only an estimate. A more complete analysis would include inflation and any anticipated changes in interest rates and energy prices. As a general rule, the shorter the payback period, the better the investment.

Shop around before you purchase a solar space or water heating system. Talk to several dealers. If possible, talk to their past customers and try to find out the dealer's reputation. Find out how much maintenance the system requires. How long is the warranty? Is it a limited warranty or a full warranty? How realistic is the warranty offer? Obtain some proof that the product will perform in the manner described by the salesman.

Retrofits

Many current solar installations are retrofits. The following are some important considerations that help make decisions in retrofitting.

1. Location is important. A southern exposure is needed for the collector or passive window. You don't need a true south location. Up to 20° east or west of due south may still provide up to 90% of the available solar radiation for your location. The area must be as free of shade as possible, especially between the hours of 9 am. and 3 p.m., when sunlight is most intense.
2. If you plan to put collectors on the roof, be sure the roof is structurally sound and the collector well anchored. Remember that the roof has to bear the weight of both the collector and any snow.
3. An active system for space heating probably will save money if it is compatible with the current heating system. However, prospects for an active heating system that is cost-effective in Michigan are not good.
4. If you have to remodel to install a solar system, add a good cost estimate to your solar installation cost before doing your payback analysis.
5. If you do it yourself and buy components rather than complete packages, be sure that all the components are compatible. The same thing should be true if a dealer selects and installs the components for you.
6. If you decide to do it yourself, be sure the warranties still apply with self-installation.

INDIRECT SOLAR

Indirect uses of solar energy include biomass, wind energy and ocean energy generating systems.

Biomass

Biomass can be broadly described as any vegetative growth or other organic matter. Sunlight drives the photosynthesis process in plants. Through that process, a plant uses less than 1% of the solar energy available to convert carbon dioxide and water into carbohydrates. Thus, when we convert biomass to an energy source — as in agricultural production — or use it for food, fiber, or energy, we are using solar energy indirectly.

Biomass Processes Direct combustion involves burning material with an unlimited supply of oxygen. Direct combustion occurs with a fireplace or woodburning stove. On the other hand, pyrolysis involves burning material with a limited oxygen supply. Depending on the pyrolysis temperature, the product will be a solid (e.g. charcoal), liquid (e.g., fuel oil), or gas. Solids require the lowest temperatures while gases require the highest. Destructive distillation is a process of pyrolysis commonly used to produce methanol. Anaerobic fermentation is a biomass process that uses yeasts to convert sugars to alcohol.

With these processes, all energy forms that we are currently familiar with can be produced from biomass materials, using either a dry (thermal) or wet (biological) conversion (Table 2). In thermal conversion, the biomass material is broken down into useful products through the application of heat, while biological materials (yeasts, enzymes, etc.) are used to achieve a similar result in wet processes.

Selected Products and Processes of Biomass Conversion

Product	Process(es)
Electricity	direct combustion
Heat	direct combustion
Steam	direct combustion
Substitute Natural Gas (SNG)	gasification
Medium Btu gas	gasification
Fuel oil	pyrolysis
Charcoal	pyrolysis
Ammonia	gasification
Methanol	destructive distillation
Ethanol	anaerobic fermentation
Methane	anaerobic digestion

Source: (3)

Wind

The sun is responsible for the wind. Solar energy heats the earth's surface unevenly, thus making some places warmer than others. Since warm air "rises" and cold air "falls", this uneven heating of the earth's surface creates the prevailing wind patterns. Historically, wind energy drove sailing vessels and powered windmills to pump water. Today, wind energy is still an alternative energy source that can be used to produce both mechanical and electrical energy.

The Ocean

The ocean has been termed a storehouse for solar energy. The sun is responsible for ocean waves and currents, the result of the uneven heating of the ocean mass. Waves can be harnessed in much the same way as rivers to produce electricity.

Another way to use the ocean is through ocean thermal energy conversion (OTEC). The ocean surface is relatively warm while the depths are relatively cold. This temperature gradient, or difference in temperature, can be used to generate electricity. One system uses ammonia as the working fluid (1). As ammonia is evaporated by the warm surface water, it expands and drives a turbine to produce electricity. The ammonia is then condensed by the deep colder water and recirculated. The generated electricity is transported back to land, using underground electric cables.

SUMMARY

Before you install any solar heating system, make sure your home or hot water system is energy-efficient. If it is not, it will extend your payback period and may make the system uneconomical. Although solar energy is diffuse and intermittent and has a high initial cost (compared with traditional systems), current knowledge suggests that it is inexhaustible, available everywhere and environmentally safe.

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Issued in furtherance of cooperative extension work in agriculture and home economics, acts of May 8, and June 30, 1914, in cooperation with the U.S. Department of Agriculture. Gordon E. Guyer, Director, Cooperative Extension Service, Michigan State University, E. Lansing, MI 48824.

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