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BIOMASS PRODUCTION - POSSIBILITIES FOR NORTHERN LATITUDES

On renewable energy resources

The excess of solar energy exists throughout the world. The developing countries have the greatest potential, but the industrialized world itself is not lacking opportunities either. Even the most densely populated countries with a high standard of living, such as the Netherlands or the U.K., consume energy which is equivivalent to no more than 1-2 percent of the energy received from the sun. Evidently, a lack of solar energy would not limit activities aimed at utilizing the solar radiation. This is also the case in such northern countries like Finland, even in the latitudes beyond the arctic circle.

Hydropower, wind and biomass are our most abundant renewable energy resources. They all are essentially based on a flowing process: flow of water is behind the hydropower, flow of air behind the windpower and flow of photons behind the photosynthesis and the biomass.

The watercycle concentrates solar energy in the rivers, and especially in the waterfalls. The energy flux density in favourable conditions can be as high as one megawatt per square meter. A certain concentration takes place also in the process of wind although the energy flux density is far below that of a waterfall. The average velocity of the wind near to the earth´s surface, 5.85 meters per second, produces an effect of 130 watts through one square meter of a vertical windfacing area.

The effect of solar radiation on horizontal soil surface, in turn, has an annual world average of about 200 watts per square meter (the respective figure for Finland is about 100 watts). Even in the sunniest region of the world, the Red Sea area, the annual average of the solar flux density is no higher than 280 watts per square meter. In solar and wind energy the respective flux densities are of the same order, although the total incoming flux of the solar energy is grater than that of the wind by a factor of 50. This points out the fact that unlike hydropower and wind, the solar radiation in nature has no mechanism of concentration.

The high flux density greatly explains why renewable energy is today preferably extracted from the flow of water instead of more abundant resources such as the wind and especially the sun. A dense energy flux tends to render the energy production economically feasible. Unless we can break this relationship, the solar driven energy will continuously remain expensive.

Another limitation in the utilization of direct solar energy is the temporal variation - where to get the power when the sun is not shining. The intermittent and diurnal variations can be levelled off by incorporating a variety of energy storing systems. The seasonal variation is a more difficult problem. This is most significant in the temperate zones at high latitudes. Finland, for example spends 60 percent of her total energy consumtion for space heating. Using direct solar radiation for this purpose is difficult because one quarter only, out of the total annual radiation is received during the winter.

When the two major limitations in the utilization of direct solar radiation are comprehended, the following conclusions emerge: (i) the system should be one that is easily spread over wide areas, and (ii) the system should be able to store the energy.

Green plants capture and store solar energy

When the solar rays hit the leaves of a green plant they start the most important photochemical process in nature: photosynthesis or assimilation. In the leaves, the electromagnetic solar energy is first transformed into small electric charges, which in turn split water molecules into hydrogen and oxygen. Oxygen flows into the atmosphere; the energy-rich hydrogen gives power to the plant in building her stem, leaves and roots from inorganic compounds.

As a final result of photosynthesis and growth, the plant stores solar energy as chemical bond energy in her tissues. It is worth notifying that nature plant utilizes the advantage of both electricity and hydrogen in her energy economy, but only instantaneously. It is the chemical bond which has been evolved for storing energy over longer periods.

Unlike the artificial solar energy collectors, like mirror-systems or photovoltaic devices, the natural solar cell of a green plant is easy to build: once sown or planted the plants build themselves selfregulatorily. They also maintain themselves selfregulatorily by, for example, growing new foliage above the exhausted old foliage. The use of green plants is a way to cover soil surface areas wide enough to collect significant energy yields from the diffuse solar radiation. Simultaneously, the plants also fulfill the demand for storage.

Energy crop ideotype

When considering the question "what plant materials are appropriate for intensive biomass energy production?" one is faced with a multitude of possible candidates. It may be easier to start with another question "what is the optimum theoretical model or ideotype for such a biomass plant, given a particular environment?" In fact, agronomists are today constructing such ideotypes for grain crops, utilizing basic research results to avoid the hit-and miss approach.

In the boreal zone the growing season is short but rather favourable. There is plenty of solar radiation available due to the long summer day, and the daily temperatures are moderate. The winter is severe. There is no need to conserve water. In general, and especially for boreal environment, the energy crop ideotype should possess for example the following properties:

1) Easy to establish and regenerate. Site preparation and establishment of a stand usually are the most expensive operations for the crop production. The costs will be even greater for the high plant densities anticipated for intensive culture. Reliance on vegetative modes of reproduction (cuttings, sets, coppice after harvest) will ease establishment problems and allow retention of favourable genetic material.

2) Rapid juvenile growth. Obviously, in an intensive mode, the energy crop must get off to a rapid start and avoid a lag period after field establishment. The rapidity also helps in spreading the leaf area over the soil surface to collect the solar rays as early as possible. This is the prerequisite in combatting the weeds, too.

3) Efficient photosynthetic apparatus. The ideotype should have efficiently photosynthesizing foliage ready in the spring when the temperature is high enough for carbon fixation. The crop should maintain a high growth rate throughout the summer up to the onset of winter frosts. Naturally, adaption of photosynthetic apparatus to low temperatures is an asset in northern latitudes.

4) Upright, excurrent habit. The important consideration here is concentration of growth on a single stem; a species, which exerts a high degree of apical control leading to pronounced excurrent form, is preferred.

5) Steep branch angle, narrow compact crown. Research with field crop grown under high densities has demonstrated that the most efficient utilization of solar energy occurs when leaves are oriented at an angle from the horizontal. Thus, if the plant is branching, the branches should angle steeply. The

resulting narrow crown also would allow the plants to be grown at denser spacings without physical interference.

6) Favourable relationship between growth and development. In most of the plant species flowering and growth exclude each other. Therefore, in her ontogeny, the plant should have longer vegetative phase than the growing season in the respective climate. In a way, the biomass crop should behave like a cancer: the cells should just divide and elongate through all the summer without aim of flowering and maturing.

7) High shoot to root ratio. The stem is the most easily accessible and highest quality source of biomass also for energy. Therefore, practices that promote accumulation of dry matter in the stem and selection of species with this inherent tendency are desirable.

8) Wintering should be certain. Most of the stem should overwinter. In a very severe climate the minimal requirement is that the stools (roots) can overwinter as sheltered by the snow cover.

9) Acceptable biomass properties. Tons of raw material produced per hectare and per year will be of little benefit if its quality is so marginal as to render it practically unusable. Today for example, good combustion propertics are required at least after a pre-processing. However, new technologies such as anaerobic digestion, alcoholic fermentation or gasification may be able to adapt to a variety of biomass sources.

10) Free of major insect and fungal pests. Genetic diversity in suspectibility to pests does exist and can be exploited to build-in resistance to their attack. But pests also can adapt to new hosts through genetic shifts, and the spectre of vast, once-resistant, monoclonal plantations devastated by epidemic pest outbreaks is real. Thus, selection for resistance, while at the same time maintaining genetic diversity in plantations, is the optimum goal.

Obviously, none of the present-day, conventionally grown crops meet all these requirements. The search for such a crop starts with screening large number of wild material and selection of suitable candidates. Combining of superior genes through plant breeding is the logical follow-up of wild-type selection. In many cases sizable growth gains can be realized in first-generation (F_1) progeny through hybrid vigour.

Case willow

Promising plant material for energy plantations can be found among the 300 willow species of the world. Some of these species for instance Salix viminalis and S. dasyclados have been grown for a number of years for basket industry in Europe.

The selection of willows for basket making and tannin industry has been carried out during several years but effective breeding methods, like planned hybridization, have been applied only in a minor scale. However, most of the species cross freely in the nature and the number of hybrids is already now overwhelming.

Energy willow farming has been developed in the Nordic countries in the mid seventies. It has its modern origin in the concept of mini-rotation forestry. Initially the aim was merely to produce more raw material for the pulp industry, using methods as intensive as those used in agriculture.

The first field experiments in Finland and Sweden were established in 1973. Already during the first summer after establishment a Danish willow clone, Salix "Aquatica Gigantea" produced in the latitude of the arctic circle a dry matter yield of about 10 tons per hectare.

More willow species have been screened in subsequent experimetns. The annual yields have been maintained at their high level. As high yields as 17-32 tons per hectare per annum have been reported including the harvested stemwood only.

Definite explanations why the willow species grow so fast have not yet been found. There may be special properties involved with many processes such as gross photosynthesis, respiration, root metabolism, seasonal cycle, development of the canopy architecture, or hormonal response to the long summer day. More likely, however, the rapid growth is a result from a favourable combination of all these factors, a combination which makes willows to adapt wee particularly to the northern environment.

For improving the willow growth further, the modern botany serves promising tools. Ecophysiological modeling of willow stands has been started, although the models, at the present stage of the work, can not yet describe the growth well enough in order to offer operational programs for willow husbandry or breeding. Hence, the growth improvement has to begin with conventional field experiments - a much more laborous, slow and restricted methodology.

Aspects of willow husbandry. Energy willow farming can be carried out in two ways. If the clones used are completely frost resistant they can be grown like any other deciduous crop; the rotation cycle will vary between 2-5 years. If the shoots do not survive the winter, but the stumps and roots do, a one year rotation period is used.

With a rotation period of a number of years, dormancy reduces the level of photosynthesis in the autumn, but in early summer the foliage develops rapidly on the already existing shoots. During the year of establishment the growth early in the growing season is lower. However, if there is no need for winterhardening, the leaves continue to fix carbon at a high rate right up until the onset of the autumn frosts. The active period of willow under one year rotation lasts until October. The period is about one month longer than that for indigenous birch.

In the central and southern parts of the Nordic countries 2-3 year rotation will probably give the highest yields. Moreover, perennial crops seem to produce shoots with higher wood density. The design of the cutting devices of future harvesting machines has to be adapted to size and geometry of the stand.

One advantage of energy willow is that it can be clonally propagated. The crop is established using cuttings. On moist soils the rooting is safe. After the first harvest the willow will coppice 5-20 shoots per cutting, depending on the clones.

The stand density, which is greatly determined by the coppicing ability, has a strong effect on the yield. The main rule holds that the larger the number of vigorous shoots, the greater the yield will be. As a practical compromise, we aim at 30 rods per square meter in one year crops. With this density a fully closed foliage is established within 30 days in the spring.

Row cultivation can be carried out in such a way that ordinary tractors can operate in the fields without damaging the stools. Planting as well as harvesting can be mechanised at little cost.

In fertilization wood ash plays an important role, which makes it possible to recirculate nutrients. If the energy crop is burned in a heating plant, most of the nutrients can be returned to the plantation in the ash. The major nutrient which escapes to the atmosphere, is nitrogen; minor potassium losses have also to be compensated for.

As the experimental fields in Finland are small, covering altogether no more than 15 ha, there is little experience about ecological risks, deseases and insects. Avoiding drawbacks requires concern to be put on genetic variation. Clone mixtures and long periods for field tests are the means in efforts to ensure an ecologically stable farming.

Challenge of biotic solar energy

Above we have preferred green plants to relatively efficient artificial means for collecting solar quanta. At the same time we have defended intensive energy farming against less efficient traditional forestry. The view, in our opinion, is not ambivalent.

The input of material and labour seems to be tolerable as long as the solar energy system uses the ability of the plants to grow and maintain automatically their structures for collecting, converting and storing energy.

Artificial solar strategies, such as photovoltaic cells or photosynthesis imitators do have a change in ninproductive areas, but elsewhere the superiority of technological systems in the net energy gain may well be too small to compensate the increased requirements of building and operating the system.

The net energy dynamics in an energy farm vary especially according to the rotation cycle. In a one year rotation the investment, including machinery and owens will be paid back in one growing season, i.e. in about six months (of course, this does not hold in methanol production or other industrialized wood energy conversion). With longer rotation periods the net energy dynamics of energy farms will be less superior to artificial systems.

Energy farming still contains many gaps between theory and practice. However, a period of more than two decades has passed since 1950's with hardly any scientific efforts on biomass energy issues. Somehow, resembling plans for nuclear fusion it is early to state today whether new energy crops will be only a good trial, or a succes. For the people now working on this field it means quite a pressure.