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The Potential for Production of Biomass for Biofuel by the Cultivation of Hybrid Poplar and Hybrid Aspen in the South of Sweden

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1. Introduction

More and more people are starting to realize that we must begin *now* to build a society that *does not* affect the environment (Lawson, 2008, Anonymous, 2010). What we are doing today is completely decisive for the development of the society of tomorrow. Two lines in the development of the society of the future are obvious. Either world leaders really start immediately to govern the development of the welfare states in an ecological and sustainable direction, so as to set an example and model for developing countries; or the politicians of the world do nothing and the society of the future will be created from the resultant chaos.

An example of what should be done now is what politicians did 40 years ago. As a direct consequence of the oil crisis in 1973, a new branch of the UN organization for food and agriculture (FAO) was set up in November 1974 on the initiative of Dr. Henry Kissinger, the former Secretary of State for Foreign Affairs in the USA (Anonymous, 2008). The name of this new organization was the International Energy Agency (IEA) and the three objectives were (1) to administrate the need for oil in the Western World and distribute the existing oil resources within this region, if the delivery of oil from the Middle East was interrupted. The new organization's task was also (2) to execute a multilateral program for more effective use of energy and (3) to launch an advanced programme for research on new energy sources. The importance of IEA was strengthened by the next oil crisis in 1978.

Different countries became responsible for different parts of the organization. Sweden was chosen as Operating Agency for Energy from Biomass with Professors Gustaf Sirén and P-O Nilsson at the head, both at the Faculty of Forestry at the University of Agricultural Sciences (SLU) in Sweden (Christersson et al., 2008). Something similar *should* be done today, but compare this thinking with the results of the meeting in Copenhagen and Cancun, Mexico!

In Sweden at that time forestry was one of the most important industries with spruce (*Picea abies*) and pine (*Pinus sylvestris*) as totally dominant tree species. Professor Nilsson worked with the waste products from this forest industry, e.g. tops and branches from clear-cut areas, but also with sawdust from the sawmills, and black liqueur from the paper industry (Doherty et al., 2002).

But Professor Sirén started to think along new lines (Sirén, 1974, Sirén et al., 1983). He had previously battled against encroaching fast-growing seedlings of *Salix* (willow) and *Populus*

(aspen), which suppressed and killed small, newly-planted seedlings of spruce and pine. Why do we not do the opposite and grow these fast-growing tree seedlings as short rotation coppice plantations, harvesting them early as biomass for energy and burn them for heat and electricity, Professor Sirén asked? He first concentrated his effort on willow plantations (Sirén et al., 1983), but later poplar also became involved when Professor Christersson in 1979 came on the scene (Christersson, 2010). In 1988 Dr. B. Ilstedt started breeding research with poplars (Ilstedt, 1996). So it was in Sweden at SLU that the concept "Energy Forestry" was created and developed (Dickmann and Kuzovkina, 2008).

Since the middle of the 1840s, European aspen (*Populus tremula*), the only *Populus* species growing in Sweden, had been used for matches and at the end of the century people concerned with this industry realized that there was not enough wood of this species for further development (Lundström, 1899). In the 1890s, when the paper industry started to develop rapidly, the shortage of wood became apparent for this industry too. So scientists were asked to try to grow some more fast-growing species of *Populus*, originating from the USA and Canada, and its hybrids with the aim of producing more wood for matches and paper (Johnsson, 1953, Werner, 2010). In the match industries Sweden has been the leading country of the world since the beginning of the 1900s. However, when cigarette lighters came on the scene in the 1950s interest in using matches diminished.

Most of the imported poplar clones and hybrids to Europe in the old days originated from Oregon, Washington and Iowa, all states that are located at latitudes that correspond with France and Spain in Europe. Very few came from BC, Canada and Alaska, USA. This meant that most of the imported clones were damaged to some extent by the climate in Sweden (Christersson, 1996) so Swedish activities fluctuated over the years but finally decreased considerably.

However, when the oil crisis developed in the 1970s, interest in growing poplar and hybrid aspen for energy increased again. At first this was with the old poplar clones but later it was with new, imported poplar clones from BC and NWT in Canada and Alaska in the USA, i.e. from equivalent Swedish latitudes (Christersson, 1996, Karacic et al., 2003, Rytter and Stener, 2005).

The advantages of growing poplars instead of willows are that the poplar wood can be used for both energy and paper and even to some extent for construction, willows only for energy. Willows should be grown on very wet areas, poplars on wet areas. The cash flow is also better for those growing willow.

The oil crises hit Sweden particularly severely, because we have no oil, no coal and no gas. But we have district heating systems developed in every village, every town and city and many big combined heat and power plants (CHP) for production of heat and electricity. These mostly used oil as fuel at that time. That means that all the wood we can produce can be used directly to replace all the oil used in an already existing infrastructure. Thus 31.5 % of all energy utilized in Sweden is currently from biomass (Andersson, 2010).

Biomass for energy has been used in Sweden for many years, but for many countries in the European Union this energy source is new. However, the European Union has now decided that the utilization of renewable energy sources should be 20 % by the year 2020 in all their member states. In Sweden the equivalent target is at least 50 % from renewable energy sources (Anonymous, 2009). This figure includes water power. The figure for Sweden for use of renewable energy sources is currently about 45 %.

These targets should be looked upon in the light of the situation that all developed regions of the world have so far been completely dependent on access to cheap sources of energy for

their development. Until now, oil has served as such a source, but many people fear that coal will become the main energy source in the future, now that the price of oil is increasing (Azar, 2008).

In some countries people are using one hundred times more energy per capita than in others, and some countries, China for example, are building large rock storage chambers in their mountains, in order to stockpile currently cheap oil, bought from developing countries. However, in many countries, particularly the smaller ones there is increasing realisation that a more ecological approach towards energy policy is needed in order to be able to achieve sustainability.

Sweden has 300,000 to 500,000 ha of productive agriculture land available for growing biomass for biofuel (Lindroth and Åkerblom, 1984, Anonymous, 2006), and if the economics are good, many more hectares of fertile forest land can be used (Skogsstyrelsen, 2008). In many other countries the situation is the same. From the Ural mountains to the Atlantic there are 25 million hectares of set-aside, fallow or abandoned agriculture land not now used for food production (Andersson, 2010). One way of utilizing all this land area for producing biomass for energy is to cultivate fast-growing poplar, willow and hybrid aspen clones. These types of plantations have been shown to be one of the most efficient transformers of solar radiation energy to chemical energy in the form of wood (Christersson, 1987, 2006, 2010, Rytter et al., 2011).

In the literature (Stanton, 2009), growers of poplar are advised to plant them on mineral soils (Dickmann and Kuzovkina, 2008). But new results show that on organic soil with a pH above 6 poplars and hybrid aspen are doing very well (Christersson, 2010).

In the present investigation the results are given for cultivation of hybrid poplar and hybrid aspen plantations from four farms and from different soil types in the south of Sweden. It is a direct continuation of the investigation published by Christersson in 2010 and the results should also be valid for Denmark, Northern Germany, Poland and the Baltic States.

2. Materials and methods

On four farms in the south of Sweden and on different soil types, hybrid poplar and hybrid aspen were planted as bare-root seedlings in 1991 -1993 (Table 1). All the details are given in Christersson, 2010 and summarized in Table 1 - 3.

Location	Lat. °N	Long. °W	Altitude. m	Type of landscape	Annual precipitation mm	Year of plantation	Type of seedling
Kadesjö	55	13	30	level field	611	1991	bare-root
Näsbyholm	55	13	40	carex peat bog	623	1991	bare-root
Sturup	55	13	50	undulating field	650	1993	bare-root
Torup	55	13	60	slope	628	1993	bare-root

Table 1. Overview of the plantations

The four farms, Kadesjö, Näsbyholm, Sturup, and Torup, are located almost side by side in the southernmost part of Sweden, 10-20 km north of the Swedish south coast. The distance between the furthest apart is not more than 33 km. Further detailed information is given in Table 2 and 3. Some thinning was carried out at Kadesjö and Sturup.

All the poplar plantations are located on a bed rock of chalk. The soil is Baltic moraine clay of Scania. This is characterized by easily crushed rocks, almost without stones, often heavy clay (Lundegårdh et al., 1967). There were some differences between the soils of the four farms (Table 2).

Location	Bedrock	Soil type	pH (H ₂ O)
Kadesjö	chalk	clay loam	6.4
Näsbyholm	chalk	clay, very rich in humus	6.1
Sturup	chalk	clay loam, with high humus content	5.9
Torup	chalk	heavy clay	6.3

The soil analyses were performed by Dr Stig Ledin, SLU, Uppsala, Sweden)

Table 2. Bedrocks and soil types of the four farms

During the preceding 10 years the diameters of 43 -78 trees were measured along a line through the whole plantations; the height was measured of 10 randomized tree. The diameter measurements were accurate to one mm and the height to one metre, with the exception of the most recent year for Kadesjö and Näsbyholm, when the accuracy was one dm. For the height measurement it was difficult the most recent year to really see the top of the trees in the dense and very tall plantations. So in 2010 specialists were hired to make a more precise height measurement. The wood production was calculated by using the equation of Johnsson, 1953. The weight of one m³ dry wood is 0.335 ton (Stener, 1998) and the weight of the top of the tree and the branches is estimated to 15 % of the stem weight (Karacic, 2005).

The Kadesjö plantation will be clear cut in 2011. In the Torup plantation some trees were felled and the annual height growths were measured for the last 11 years. The mean annual height growth was 1.6 m per year with a slight decrease in recent years.

The poplar plantations were fenced for the first 10 years at Kadesjö, Sturup and Torup but not at Näsbyholm. After that the fence was moved to other plantations in order to allow normal hunting. No damage by wild animals was observed.

It is planned to be harvest all the plantations after 20- 25 years when the price of the wood is favorable.

Location: South of Skåne, Sweden

General characterization: previously cultivated agricultural land

Latitude: 55° N

Longitude: 13° E

Altitude: 30-60 m asl

Mean annual temperature: 8.6° C

Mean temperature: May-August 14.2°C

Lowest temperature in winter: -26.3°C
Temperature sum of the year: 1547 daydegrees
Temperature sum of the growing season: 1132 daydegrees
Annual rainfall: 611 - 650 mm
Rainfall during the growing season: 426 mm.
Annual solar radiation: 1150 kWh/m²
Solar radiation during growing season: 820 kWh/m²
Start of the growing season (>5°C) day no 102 (12/4)
End of the growing season <5°C day no 319 (17/11)
Length of the vegetation period (>5°C-<5°C): 220 days
Size of the plantation: 3-10 ha
Soil type: see special table
Bed rock: limestone, chalk
pH: 5.9 - 6.4
Level of ground water: 0.2 - 1 m
Previous crops: wheat, oat, spring rape
Production: 5-7 ton grain/ ha, yr
Planting preparation: ploughing, harrowing
Species: h-poplar (OP 42), h-aspen (Ekebomix),
Planting method: by hand, spade
Time for planting: 1991-1993
Design: varied
Thinning: on Kadesjö and Sturup
Fencing: present for the first 10 years
Survival: > 90%
Weed management: none
Fertilisation: no
Irrigation: no
Rotation time: 20 years
Damage: wind throw
Utilisation of the wood: paper and energy

Table 3. Location, climatic and cultivation conditions for the four farms

3. Results

All the plantations are located very close together and at the same latitude; thus the climatic conditions are the same for all four. All are located on productive agriculture fields with a production capacity of 5 -7 ton grain of wheat per ha and year. The analysis shows that the pH of the soils varies between 5.9 and 6.4 (Table 2) with the highest value for Kadesjö and the lowest for Sturup. The highest clay content was in the field in Torup and the highest organic content was at Näsbyholm, which is a Carex peat bog. Näsbyholm also has the highest ground water level and part of it is flooded almost every winter. The field in Torup is on a slope with movable ground water. In Sturup the field is undulating with low areas with high organic content alternating with small sandy hills, which have a negative influence on the growth rates.

The highest wood biomass production was achieved at Näsbyholm for hybrid aspen (Table 5), probably because of the largest number of stems per hectare. However, the high

growth rate is also dependent on very good water conditions on that field and on a nutrient- rich soil, caused among other things by the location of the plantation between intensively fertilized agriculture fields and a ditch. This plantation is something that we can call a 'vegetation filter' (Perttu and Kowalik, 1997, Elowson, 1999). There is a difference in growth rates between the hybrid poplar and the hybrid aspen clones but the difference is not significant. A future problem at Näsbyholm could be the high water table, which creates a loose soil with a risk of wind throw, particularly during winter when large areas are flooded, and because intense autumn storms are frequent in this part of Sweden. The production for both the poplar clone and the mixed hybrid aspen clones at this location reached 30 - 40 m³/ha, yr, when there was canopy closure after some years. However, in some years with favorable climatic conditions the production reached over 40 m³/ha,yr.

The poplar plantation at Kadesjö (Table 4) is interesting, because it is located on a very good and traditionally agricultural field. The conventional crops for this land would be wheat, sugar beet and rape with high to very high production rates, depending on the amount of the fertilization. The final woody biomass production of Kadesjö is slightly less than that of Näsbyholm but the differences are not significant.

The diameter growth at Näsbyholm (Table 5) of the hybrid poplar was always a little higher than for hybrid aspen, but the height of the trees was the same. The same trend for the diameter growth can be seen at Kadesjö (Table 4) initially, but it disappeared during later years. At Kadesjö the height of the hybrid poplar was always about 2 m more than that of the hybrid aspen clones. It is planned to harvest the Kadesjö plantation in 2011 so here it will be possible to compare the actual harvest with the calculated one and thus to evaluate the growth equation used.

At both Sturup (Table 6) and Torup (Table 7) only hybrid aspen clones were planted. The growth rate at Sturup was the same as for Näsbyholm and Kadesjö at the lower parts of the plantations, but much less on the hills. This is one of the reasons why the mean production rate is significantly lower here, even if we take into consideration that the plantation was two years younger. The other is that the thinning was applied very early so that canopy closure was delayed.

The lower results at Torup (Table 7) are caused by the very dense plantation.

All the four plantations were astonishingly free from damage. Only the wind throw on the loose soil at Näsbyholm was troublesome, and some of the same at Kadesjö. But it should be remembered that all the plantations were fenced, with the exception of Näsbyholm, for the first ten years and that the moose population in this part of Sweden is very low. But there was almost no damage caused by leaf rust or by insects (Steenackers, 1990.) Such damage can be devastating on many plantations in the rest of the world. At Torup the soil of the whole plantation was grubbed up by wild pigs, but whether this has a bad or good effect we do not know.

4. Discussion

Energy, water, and food are the most substantial and essential resources for human beings; all energy has its origin from the sun and food is a kind of energy. The energy radiates from the sun to the earth; it is absorbed by green plants, utilized by all living creatures and disappears out into the atmosphere as heat. Water, on the other hand, does not disappear

OP 42 (Populus maximowiczii x P.trichocarpa)										
Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Age	11	12	13	14	15	16	17	18	19	20
Diameter, cm	18.9	20.8	21.8	23.0	23.6	24.6	25.1	25.9	26.7	26.9± 4.5
Height, m ³	15	17	18	20	22	23	24	26	27	28.3±1.5
Tree volume, m ³	0.1890	0.2568	0.2974	0.3653	0.4207	0.4765	0.5164	0.5931	0.6531	0.6933
No. trees/ha	657	657	657	657	657	657	657	657	657	657
Total prod./ha, m ³	124	169	195	240	276	313	339	390	429	455
Prod./year, m ³		45	26	45	36	37	26	51	39	26
Running 3 year period, m ³ /yr				39	36	39	33	38	39	39
<i>Calculated pulp production: MAI during 20 years= 23 m³/ha,yr</i>										
<i>Calculated energy wood production: 23 x 0.335 + 0.15 x 23 x 0.335= 9 ton TS/ha,yr</i>										
Hybrid aspen (P. tremula x P. tremuloides)										
Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Age	11	12	13	14	15	16	17	18	19	20
Diameter, cm	15.7	18.2	20.1	21.7	23.0	24.4	25.0	25.8	26.7	27.9± 3.0
Height, m	12	14	15	17	19	20	22	23	25	26.0±1.5
Tree volume, m ³	0.1065	0.1645	0.2134	0.2793	0.3480	0.4106	0.4716	0.5236	0.6068	0.6873
No. trees/ha	659	659	659	659	659	659	659	659	659	659
Total prod./ha, m ³	70	108	141	193	229	271	311	345	400	453
Prod./year, m ³		38	33	52	36	42	40	34	55	53
Running 3 year period, m ³ /yr				41	40	44	39	39	43	47
<i>Calculated pulp production: MAI during 20 years= 23 m³/ha,yr</i>										
<i>Calculated energy wood production: 23 x 0.335 + 0.15 x 23 x 0.335= 9 ton TS/ha,yr</i>										

Table 4. Kadesjö, planted 1991

OP 42 (Populus maximowiczii x P. trichocarpa)										
Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Age	11	12	13	14	15	16	17	18	19	20
Diameter, cm	20.8	21.7	22.8	23.2	23.7	24.3	24.8	25.2	26.2	26.8±5.7
Height, m	14	15	17	18	20	21	22	24	25	26.2±2.8
Tree volume, m ³	0.2142	0.2484	0.3081	0.3364	0.3876	0.4266	0.4642	0.5204	0.5845	0.6393
No. trees/ha	718	718	718	718	718	718	718	718	718	718
Total prod./ha, m ³	154	178	221	242	278	306	333	374	420	459
Prod./year, m ³		24	43	21	36	28	27	41	46	39
Running 3 year period, m ³ /yr				29	33	28	30	32	38	42
<i>Calculated pulp production: MAI during 20 years 23 m³/ha,yr</i>										
<i>Calculated energy wood production: 23 x 0.335 + 0.15 x 23 x 0.335=9 ton TS/ha,yr</i>										
Hybrid aspen (P.tremula x P. tremuloides)										
Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Age	11	12	13	14	15	16	17	18	19	20
Diameter, cm	19.1	20.2	21.4	22.2	22.9	23.5	23.9	24.6	25.1	25.9±5.3
Height, m	14	15	16	18	20	21	23	24	25	26.1±2.1
Tree volume, m ³	0.1809	0.2156	0.2567	0.3083	0.3622	0.3992	0.4500	0.4962	0.5364	0.5953
No. trees/ha	868	868	868	868	868	868	868	868	868	868
Total prod./ha, m ³	157	187	223	270	314	347	391	431	466	517
Prod./year, m ³		30	36	47	44	33	44	40	35	51
Running 3 year period, m ³ /yr				38	42	41	40	39	40	42
<i>Calculated pulp production: MAI during 20 years 26 m³/ha,yr</i>										
<i>Calculated energy wood production: 26 x 0.335 + 0.15 x 26 x 0.335=10 ton TS/ha,yr</i>										

Table 5. Näsbyholm, planted 1991.

Hybrid aspen										
Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Age	9 thin.	10	11	12	13	14	15	16	17	18
Diameter, cm	12.6	14.4	16.3	17.4	18.5	19.7	20.3	21.5	22.2	22.7± 4,8
Height, m	13	14	15	17	18	19	21	22	23	24
Tree volume, m ³	0.0749	0.1040	0.1413	0.1808	0.2152	0.2563	0.2990	0.3500	0.3890	0.4233
No. trees/ha	1100	729	729	729	729	729	729	729	729	729
Total prod./ha, m ³	82	76	103	132	157	187	218	255	284	309
Prod./year, m ³			27	29	25	30	31	37	29	25
Running 3 year period, m ³ /yr					26	28	29	33	32	30
<i>Calculated pulp production: MAI during 18 years =17 m³/ha,yr</i>										
<i>Calculated energy wood production: 17x 0.335 + 0.15 x 17 x 0.335=7 ton TS/ha,yr</i>										

Table 6. Sturup, planted 1993

Hybrid aspen (P. tremula x P. tremuloides)										
Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Age	9	10	11	12	13	14	15	16	17	18
Diameter, cm	11.8	12.9	13.1	13.8	14.3	14.6	15.1	15.2	15.6	15.9±2.8
Height, m	9	10	12	14	16	18	19	21	22	23±2
Tree volume, m ³	0.0466	0.0611	0.0748	0.0957	0.1165	0.1357	0.1525	0.1700	0.1870	0.2025
No. trees/ha	1792	1792	1792	1792	1792	1792	1792	1792	1792	1792
Total prod./ha, m ³	83	109	134	171	209	243	273	305	335	363
Prod./year, m ³		26	25	37	38	34	30	32	30	28
Running 3 year period, m ³ /yr				29	33	36	34	32	31	30
<i>Calculated pulp production: MAI during 18 years =20 m³/ha,yr</i>										
<i>Calculated energy wood production: 20 x 0.335 + 0.15 x 20 x 0.335=8 ton TS/ha,yr</i>										

Table 7. Torup, planted 1993

from the earth; it merely circulates from the earth (as water vapour) to the sky and back again (as rain). The problem is that human beings pollute it and destroy it for themselves and for all other living organisms and to clean all the waste water would cost a lot of energy Many scientists consider that fresh water is the Achilles heel of our society. Only 3 % of all water is fresh water. There is a lot of water on our planet, but it is salt water and energy is needed for desalination

Access to energy and pure water are the limiting factor for the development of a welfare state. Furthermore, most wars of to-day are actually caused by access to energy in the form of oil and many people fear that the next world war will be about access to fresh water. But even though the further development and well-being of the world are completely dependent on energy, there are few resources that exist in such large amounts as energy on our planet. Ten thousand times more energy radiates to the earth from the sun than is utilized (Cooper, 1975, Cannell, 1989). Expressed in another way, in half an hour the earth receives the same amount of energy as solar radiation than is used in a whole year. This fact is the greatest paradox of our time.

In this context let us try to analyze the result of the present investigation and concentrate on the energy effectiveness of a productive poplar plantation and compare the effectiveness of poplar with that of other tree species and food crops. The investigation has shown that the above-ground woody biomass production can reach a mean value of 10 ton dry matter per ha and year and that such results can be considerably higher in some very favorable years (Table 4-5). We estimate that the amount of leaves developed is 3 ton dry matter per ha and year, giving a total amount of produced biomass of say 20 ton as the absolute most. To be certain not to underestimate the amount of root biomass, we assume that the production of biomass in the soil is the same as above ground. So in the most favorable situation there may be a total biomass production of about 40 ton dry matter per ha and year.

The heat value of 40 ton dry biomass is $40 \text{ ton} \times 4.5 \text{ MWh} = \text{about } 180 \text{ MWh}$ per ha and year. The radiation from the sun during the growing season in the area is 820 kWh per m^2 (Table 3). One hectare is $10\,000 \text{ m}^2$, giving a radiation per hectare during the growing season (May-August) of 8200 MWh . 180 MWh is little more than about 2 % of 8200 MWh . The majority of the most productive agriculture crops are similar (Börjesson, 2007). All the remaining energy, about 98% of the incoming solar radiation, sooner or later radiates out into the atmosphere as heat. If the energy effectiveness of the plants can be increased by just a small amount, it will mean a lot for the energy and food supply of the world. This is the reason why ecophysiological and genetic research is so important; particularly today when we know that the human population will increase by 50% by 2050, and when most people are aware that climate change cannot be prevented, only limited.

The discussion above is about the effectiveness of plants in absorbing radiation energy from the sun. The energy efficiency of a crop or a tree plantation is a completely different story. In this case we are calculating how much energy we must put in to produce so much biomass. If we do this calculation we find that spruce is the most efficient crop we can grow in Sweden (Figure 1) and that poplar and willows are second and third. Normal agriculture crops achieve only half these values.

However, spruce grows much more slowly than poplar and willow and has a rotation period of 50-60 years. The rotation period for willow is 2-4 years and for poplar 15-20 years. So if we have limited time and limited area to grow biomass for energy, poplar and willows are to be preferred (Christersson et al., 2008). Even the Cash flow is also more favourable for poplar and willow growers. However, new ideas and new plant materials are on their way with respect to plantation of different species of the genera *Picea* and *Abies* in the south of Sweden (Bo Karlsson, per. com). For conifers the problem is their influence of the fertility of the soil on which they grow and their effect on the biodiversity and appearance of the landscape. The advantage of poplar plantations over willow plantations is that poplar wood can be used both for energy and paper.

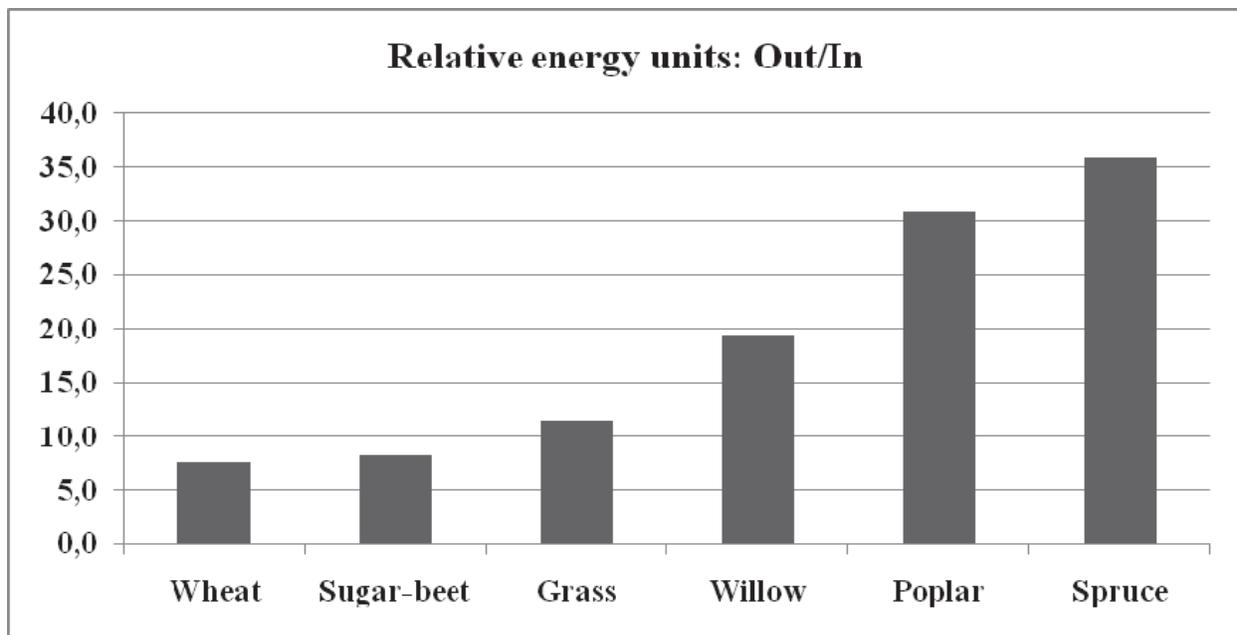


Fig. 1. Ratio between total energy output and input (energy balance quota) for some agricultural and forestry crops (data from Börjesson 2007, recalculated by K.Perttu).

The fertility of the soil of the four farms is similar. The soils are all clay but there are some differences in the amount of organic matter. The soil of Näsbyholm in particular is very rich in humus, which may explain the slightly higher production for hybrid aspen at that farm (Table 9). However wind throw is more frequent on this soil, because of its looser consistency. The small difference in the pH between the four farms is supposed to have only a slight effect. The lower woody biomass production of Sturup and Torup is partly because these two plantations are 2 years younger than the other two and partly because Sturup was thinned too early and the Torup plantation has very dense spacing.

	Poplar		H-aspen	
	m ³ /ha.yr.	ton/ha.yr.	m ³ /ha.yr.	ton/ha.yr.
Kadesjö	23	9	23	9
Näsbyholm	23	9	26	10
Sturup			17	7
Torup			20	8

Table 9. Summary of the above-ground woody biomass production (MAI) of the four farms in ton/ha.yr. and in m³/ha.yr.

The great disadvantage of growing poplar in the south of Sweden is the high risk of damage by browsing animals and by wind throws. Both moose and all types of deer will damage not only young plants but also thick stems by stripping the bark. Thus it is necessary to protect poplar plantations in some way. Currently the plantations are fenced, or every stem is netted, but these measures are very expensive. Development of some type of cheap protection is a prerequisite for introduction of poplar plantations on a large scale in Sweden.

In earlier investigations (Christersson, 2010) it has been found that damage from stem rot, caused by bacteria or viruses, seems to be mitigated by fertilization. Nor does this type of

injury occur on fertile soils. There are also large differences between clones in resistance to such diseases. So great care is needed in the choice of clones of poplar for plantations, particularly if the soil is poor.

Surprisingly little damage by fungi or insects has so far been found on poplar plantations in Sweden. It is only attack by leaf rusts, *Melampsora* and *Massonina* fungus that have had a negative effect on biomass production. However, such attacks have occurred only relatively late in the autumn and it is believed that the damage caused is only limited. Nevertheless, entomologists and mycologists warn of a forthcoming build up of large populations of both insects and fungi, if poplar plantations are introduced on a large scale (Steenackers, 1990).

The climate of Sweden is completely governed by the Gulf Stream and by winds from the south west. But sometime, even in summer, the wind direction changes and cold winds come to Sweden from the Arctic. This is a common phenomenon, particularly at the beginning of June. The temperature can then be as low as - 4 to - 6 degree Celsius, even in the most southern part of Sweden (Christersson, 1987). At that time spring-planted seedlings of poplars are in full growth and large parts of the growing shoots are killed, sometimes the whole plant. But most often it is only in low-lying parts of the fields that such low temperatures occur, so such areas should be avoided for poplar. This problem can be solved by planting long cuttings (see below).

5. Visions

5.1 Future plantations

Concerning future energy supply and politics in Sweden, the Government has decided (Proposition 2008/09:162) that by 2020 the emission of greenhouse gases should have decreased by 40 % and that the amount of renewable energy used in Sweden in 2020 should reach at least 50%. That figure for 2008 was about 45 % (Andersson, 2010). The total energy use in Sweden of to-day is almost 400 TWh and a 5 % increase would be 20 TWh. With a production of 9 ton dry matter per hectare and year (Table 9), we need an area of 500 000 ha of poplar plantation to produce 20 TWh energy in the form of heat (9ton x 4,5MWh x 500 000 ha =about 20 TWh). In an inventory of available productive agriculture land for biomass production for energy, it was found that 3-500 000 ha is currently available and could be used for this type of cultivation (Anonymous, 2006). Furthermore, millions of hectares of agriculture land in Sweden have been planted with trees since 1950, particularly with spruce. It will soon be time to harvest these plantations; the next generation of forest on this land should be deciduous trees, because of problems with spruce root rot and with the fertility and pH of the soil.

5.2 Long cuttings

The trait of poplar-wood to form adventitious roots very readily is well-known and used in many nurseries and for establishing poplar plantations. Commonly, 10 - 30 cm or one-meter-long cuttings are used. In Sweden another method is now being developed: cuttings 3.5 m long are drilled one meter down into the soil in densely spaced plantations (2 x 2m) (Figure 2). The first harvest will take place after 15 years and the expected yield with newly bred plant materials will be 200 ton TS/ha (500 m³). The second generation of such a plantation

will consist of shoots from the stumps and from the roots of the first generation. This second generation will be harvested after another 15 years with the same or higher production. The plantation will be fenced for the first 10 years. The economy of such a plantation will not be much more than even for the first generation because of the cost of the fence. It is the second generation that will be profitable for the growers.

The second generation will not need to be fenced because the amount of new shoots from the stumps and from the roots is so enormous and because the shoots grow so fast that a normal population of moose and deer can be allowed to browse on the plantation without reducing wood production.

There are two advances in particular with this method of cultivation. The first is that it is possible to avoid a long establishment period of several years for a poplar plantation, always needed for half-meter long rooted plants or 30 cm cuttings. It is a question of achieving canopy closure as soon as possible. The second advantage is that even very fertile land areas subject to summer frosts can be used. These summer frosts are close to the soil surface and the growing points of the long cuttings, which are the most frost-sensitive, are located above the layer with temperatures below zero during a summer night frost.



Fig. 2. 3.5 m long cuttings, drilled one metre down into the soil. The plantation will be harvested for the first time after 15 years when the yield is expected to be 200 ton dry matter per hectare (500 m³).

Other advantages are that no preparation of the soil is necessary and even in existing scrubby vegetation these long cuttings can be planted without clear-cutting the scrub. Even if the scrub is taller than the cuttings, only small light gaps need to be cleared. The growth rate of the poplar is so rapid that it soon suppresses the competing scrub.

There is one very important point to be remembered in producing the 3.5 m long cuttings. Normally two or three year old shoots are used. All the lateral branches should be removed and not more than three buds should be left at the apex. Thus most of the one year old top shoot should be cut off because at the beginning of the development of the cuttings it is important that the ratio of leaf surface to root is not too high. If it is, the cuttings will die from drought.

5.3 The pump

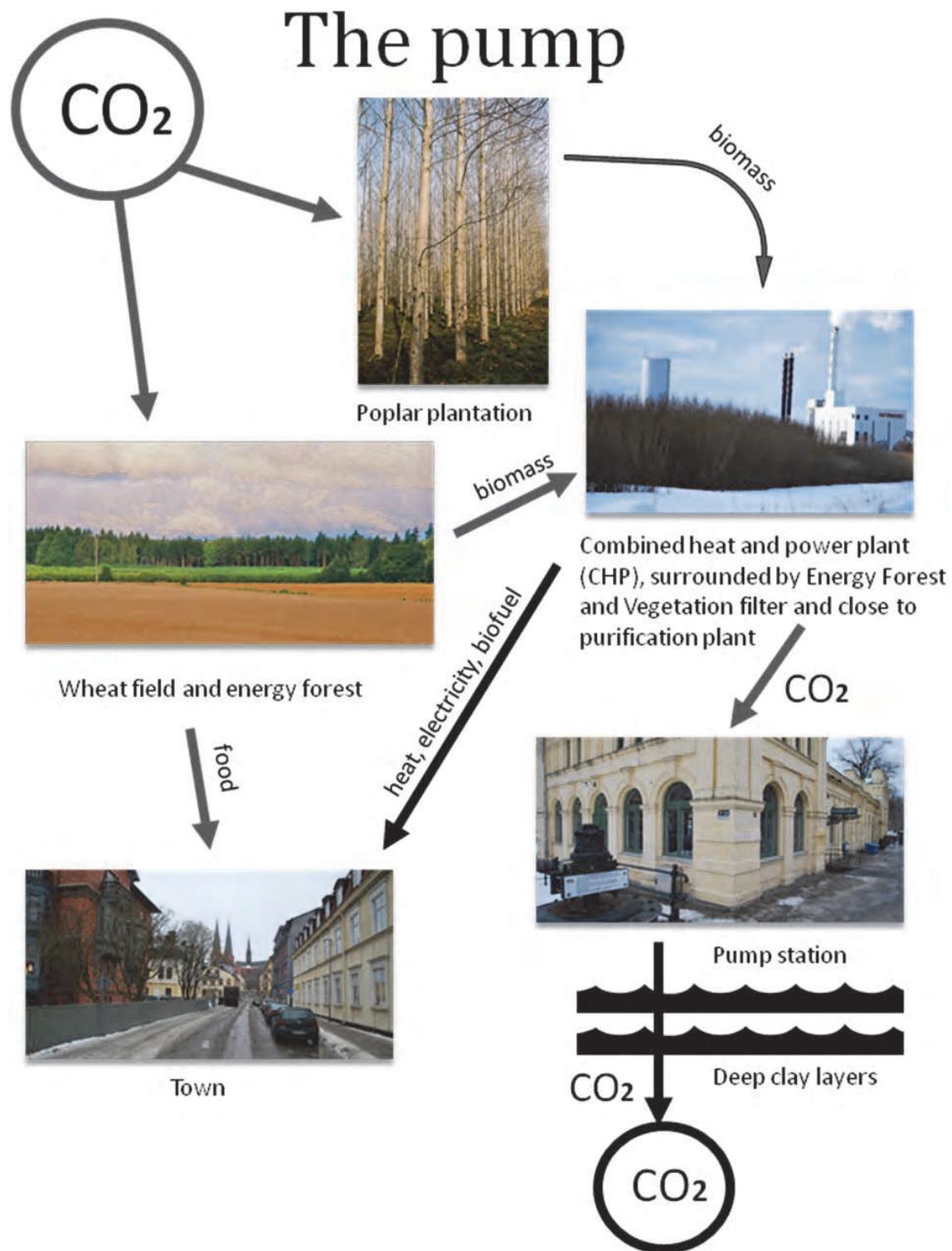
Most scientists agree that the increased carbon dioxide content of the air is caused by human activities and that this increase is the reason why the temperature of the atmosphere is rising (Johansson, 2009). This process is the so-called Anthropogenic Global Warming, AGW. But there are also different opinions (Karlsson, 2008) even if so far they are rather few and taciturn .

So far, the most important human activity in this respect is the utilization of oil, but it is expected that in the future it will be the utilization of coal and fossil gases that will be the major contributors to the increased carbon dioxide in the atmosphere (Azar, 2008). In some countries scientists are discussing and working to develop an economic method to store carbon dioxide securely deep in the underground (Johnsson, 2009). In a joint project, named BECCS (Bio-Energy with Carbon Capture and Storage), scientists in Norway and Sweden are collaborating to develop methods for a combination of biomass utilization and geological carbon dioxide storage (Karlsson et al., 2009). In one of the biggest enterprises in Sweden, Vattenfall , the possibility of trying to store carbon dioxide from burning coal in some deep clay layers is being investigated. Similar research is taking place in Austria and the USA.

If such underground storage can be expected to be able to hold the carbon dioxide permanently, an interesting situation will emerge. When we are growing biomass, as for example with fast-growing willows and poplars, the carbon dioxide of the air is bound in organic compounds in the leaves. In this way the carbon dioxide content of the atmosphere will decrease. The more fast-growing species there are, the more carbon dioxide is taken away from the atmosphere. The carbon dioxide is normally released again to the atmosphere, when we burn, eat or ferment the biomass or when it rots.

But if, in future, it becomes possible to pump the carbon dioxide, released from burning of biomass, to deep clay layers in the soil and retain the carbon dioxide there, we have created a pump of carbon dioxide from the air to the soil via the plants, and for the first time in history human beings will have developed a method to actively decrease the carbon dioxide in the air (Figure 3).

From the biomass energy we produce biofuels, electricity and /or heat and the wonderful situation arises that the more energy we use, the more biomass we must utilize, the more cars we drive, the more biomass must be grown, the more carbon dioxide disappears from the air and we can keep global warming, the AGW, to a minimum.



Illustrator: R. Reutler

Fig. 3. The pump. Poplar plantations, energy forest, vegetation filters and even agricultural crops such as wheat, take up CO₂ from the air and store the carbon molecules in the biomass. After harvest the biomass is transported to a combined heat and power plant (CHP), the biomass is burned and the energy is transformed into biofuels, electricity and/or heat for the community. At the same time CO₂ is released and pumped deep down into soil layers that can retain the molecules permanently.

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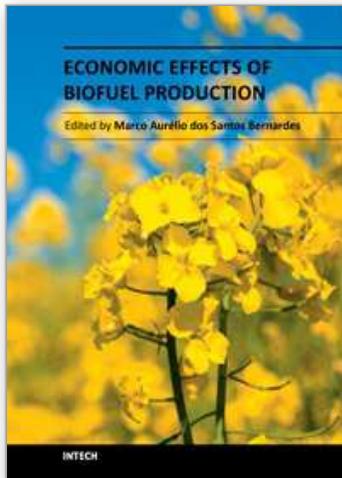
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This book aspires to be a comprehensive summary of current biofuels issues and thereby contribute to the understanding of this important topic. Readers will find themes including biofuels development efforts, their implications for the food industry, current and future biofuels crops, the successful Brazilian ethanol program, insights of the first, second, third and fourth biofuel generations, advanced biofuel production techniques, related waste treatment, emissions and environmental impacts, water consumption, produced allergens and toxins. Additionally, the biofuel policy discussion is expected to be continuing in the foreseeable future and the reading of the biofuels features dealt with in this book, are recommended for anyone interested in understanding this diverse and developing theme.

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