

**WORKSHOP  
ENERGY CROPS & BIOGAS/BIOENERGY  
PATHWAYS TO SUCCESS?**

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**Predicted energy crop potentials for biogas/bioenergy  
worldwide - regions – EU 25**

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## **Introduction**

In the conditions of global warming and increasing release of CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O and other greenhouse gasses there is a tremendous need for actions to be taken. Newly tendencies of such actions have started in countries like Germany and Austria, where farmers are starting paradigm shifts from being food and feed producers towards biomass producers, at higher levels of land productivity, for the energy demands and needs, and for nearby future new biorefinery products.

In Europe renewable energy production will constantly increase due to restricted use of fossil carbon resources world-wide and a prosperous future for various renewable energy technologies among others solar power, wind power and biomass based energy systems. At the same time we do not have to forget the need for creation of new employment, as contrast to stagnation, and that EU needs developments towards advanced technology societies, in the context of decentralisation of energy recovery resources, which have to be sustainable, in contrast to the fossil fuel century we have just passed. This summer at an EU-US workshop hosted by US-DOE and EU DG TREN it was concluded that biomass will be the primary energy source for the 21<sup>st</sup> century, like the fossils in the past.

## **How to produce biomass for biorefineries and examples of resource potentials**

In all countries, in temperate, sub tropic and tropic climate zones, there are various medium to high potentials of producing biomass for a broad variety of demands, except in arid and semi arid climate zones, where the deserts and steps are widespread.

If good growing conditions such as sunlight, temperature above 5 °C and sufficient water in the root zone, in the top soils, are available, besides recycling of nutrients from the societies and in some cases addition of chemical fertilisers, we have the basic conditions in place for biomass production from efficient photosynthesis. One do not have to forget the most efficient photosynthesis C-4 plants such as sugar canes, maize (corn), sorghum etc.

In table 1 and 2 a case example for Denmark is given. This is a picture of potentials and possibilities for the future European paradigm shift towards biomass production for energy and new biomass based products.

In earlier decades all efforts were concentrated on production of food and for feeding a growing population and an rising animal production, by all means increasing living standards. At the same time all energy demands and supplies were fulfilled by fossil carbon sources. Have we reached a maturity level, or is it even above in some industrialized countries?

In table 1 an example of how the entire area of Denmark is utilized, including future possible changes, is presented. The survey balances, interests of agricultural, forestry production, nature conservation as well as environmental interests.

Table 1. Utilization of the entire area of Denmark and probable future changes [10]

<b>Area usage; units in 1.000 ha</b>	<b>1995</b>	<b>2005</b>	<b>2025</b>
Arable land	2.290	2.035	1.770
Fallow / brackish	220	150	0
Non-food, single/mutiannual	30	150	300
Permanent grassland	200	325	450
<b>Agriculture total</b>	<b>2.740</b>	<b>2.660</b>	<b>2.520</b>
Forestry / woods	500	550	650
Fences, ditches, field roads	113	123	133
Heath, dune, bog	200	205	210
Lakes, streams	65	75	95
Buildings in rural areas	230	230	230
Cities, roads, holiday cottages	460	465	470
<b>Total area</b>	<b>4.308</b>	<b>4.308</b>	<b>4.308</b>

From 2005 to 2025 the tendency will be that there will be no more fallow land. Part of the arable land resources, in the range of 10-20-30 percent of the categories of arable land, fallow and non-food areas, will in the next two decades be utilized for energy farming, cultivation systems aiming at maximum energy storage in organic biomass with acceptable quantities of medium to high net yielding crops per hectare. These kinds of crops will be grown and handled much more rational than traditional food crops and as cheap as possible at the input side, to gain maximum favorable energy output and balance.

Table 2 depicts Danish gross energy consumption of present years compared with a survey of future scenarios of either light green or dark green scenarios. One scenario features how to run the society without any kind of fossil fuels. In these scenarios highly efficient utilisation of energy sources by all means as well as energy savings at all levels are included.

Table 2 displays the energy net consumption derived from biomass in the span of 119 – 137 PJ of biomass in the year 2030. In combination with 300.000 – 500.000 ha arable land dedicated for energy and biorefinery farming, in the long term it will be more than realistic to reach between 120 – 140 PJ biomass energy production, or even higher, under Danish conditions. This means that such a society can be organized and managed on conditions of between 50 – 100 pct. renewable energy sources. At the same time the dependencies of fossil carbon sources will be minimized throughout the years, as it can be seen in the statistical data from year 1992 and year 2003, where the coal dependency had been decreasing nearly to the half of the consumption in 1992.

Table 2. Comparison of Danish gross energy consumption with two future scenarios [11]

Unit: PJ per year	1992 (*)	2003 (*)	2030 Light green scenario	2030 Dark green Scenario
Oil	348	342	246	0
Coal	324	176	22	0
Natural gas	95	191	146	0
Biomass	54	88	119	6-7 (137)
Biogas	<1	4	-	45 (90)
Liquid biofuels	-	2	-	22 (47)
Solar heating	<1	<1	4	40
PV (Solar cells)	-	-	4	25
Windpower	3	20	32	90
Net power import	13	- 31	0	0
<b>Total</b>	<b>776</b>	<b>793</b>	<b>573</b>	<b>229 (429)</b>

\*) Figures from the Danish Energy Authority

The future will be much more diversified, where regenerative carbon sources will be based on biomass sources of various kind, naturally adapted to the different growing conditions in the changing climate conditions and with a broader utilisation of biomasses for food, feed, fibres, fuels, fertilisers etc, after passing different, pre-treatment technologies before biorefining.

Table 3 contents registered data of total area of land use for 25 European Countries (EU-25). Areas of specific interests for biomass production conditions are the columns of arable land, and partly forest areas and permanent grassland areas. The fallow areas will quite soon be integrated in arable land or non-food areas.

Table3.Data of total area and areas of interest for biomass production for each member of EU25[12]

Unit: 1 000 ha	Total area	Agriculture area	Arable land (% of total area)		Forest (% of total area)		Permanent grass (% of total area)		Fallow
Country									
Austria	8 387	3 374	1 379	16	3 260	39	1 917	23	106
Belgium	3 053	1 393	833	27	607	20	536	18	28
Cyprus	925	137	87	9	N/A	N/A	1	<1	7
Czech Republic	7 887	3 652	2 767	35	2 643	34	839	11	83
Denmark	4 310	2 676	2 479	58	473	11	186	4	205
Estonia	4 523	698	613	14	2 251	50	67	1	25
Finland	33 815	2 236	2 204	7	22 487	66	27	<1	211
France	54 909	29 556	18 275	33	15 403	28	9 972	18	1 280
Germany	35 703	16 974	11 791	33	10 531	29	4 970	14	835
Greece	13 196	3 897	2 211	17	N/A	N/A	146	1	441
Hungary	9 303	5 867	4 516	49	1 772	19	1 063	11	195
Ireland	7 027	4 372	1 177	17	N/A	N/A	3 193	45	18
Italy	30 134	15 546	8 384	28	6 856	23	4 379	15	617
Latvia	6 459	1 596	973	15	2 862	44	610	9	94
Lithuania	6 530	2 903	1 639	25	1 997	31	1 203	18	193
Luxembourg	259	128	62	24	89	34	65	25	2
Malta	32	10	9	27	N/A	N/A	N/A	N/A	0
Netherlands	4 153	1 949	1 011	24	353	9	892	21	30
Poland	31 269	16 899	13 067	42	9 090	29	3 562	11	2 302
Portugal	9 191	3 846	1 589	17	3 465	38	1 468	16	539
Slovakia	4 903	2 236	1 377	28	2 002	41	799	16	4
Slovenia	2 027	505	168	8	1 283	63	307	15	1
Spain	50 532	25 289	13 081	26	16 493	33	7 125	14	3 195
Sweden	41 034	3 140	2 680	7	22 323	54	482	1	269
United Kingdom	24 291	16 352	6 397	26	N/A	N/A	9 906	41	33
<b>Summary, EU-25</b>	<b>393 849</b>	<b>165 229</b>	<b>98 765</b>	<b>25</b>	<b>126 239</b>	<b>32</b>	<b>53 715</b>	<b>14</b>	<b>10 710</b>

J.B. Holm-Nielsen, P.O. Popiel & M. Madsen, Department of Bioenergy, SDU, Denmark (2005)

From table 3 can be surveyed the biomass potentials for biorefinery purposes. E.g. Germany, a large central European country, has 11.8 mil. ha of arable land. Future biomass potentials in Germany for energy crops are stipulated to be up to 2.0 mil. ha or 17 pct. of the arable land in medium to long terms. From this area can be derived and produced a corresponding energy production of 40 pct. Of the fuels needed for transportation or 20 pct. of the primary energy net consumption.

As an example: if only 10 pct. of arable land is used for energy production at poorly developed yield condition, there will be 1778 PJ production for the whole EU-25. That would be more than the double of the demand for the entire Danish energy consumption for a whole year (which is +/- 800PJ).

In the tables 3a & 3b scenarios of area utilisation of arable land from 25 EU countries for energy crop production and the potentials of energy recovery form these areas expressed as mill. tons of oil equivalent at 3 different crop yielding levels are shown.

Table 3a. Scenarios of area utilization of arable land for EU-25 in PJ

Area used for energy prod.	10 % of arable land in EU-25	20 % of arable land in EU-25	30 % of arable land in EU-25
Yield pr. ha			
10 t TS pr. ha	1 778 PJ	3 556 PJ	5 333 PJ
20 t TS pr. ha	3 556 PJ	7 111 PJ	10 667 PJ
30 t TS pr. ha	5 333 PJ	10 667 PJ	16 000 PJ

\* 1 PJ equals  $10^{15}$  J

Note: The total area of the arable land in the EU-25 is assumed to be in the order of 98.765.000 ha (according to Eurostat figures 2002)

Table 3b. Scenarios of area utilization of arable land for EU-25 in MTOE

Area used for energy prod.	10 % of arable land in EU-25	20 % of arable land in EU-25	30 % of arable land in EU-25
Yield pr. ha			
10 t TS pr. ha	40 MTOE	79 MTOE	119 MTOE
20 t TS pr. ha	79 MTOE	159 MTOE	238 MTOE
30 t TS pr. ha	119 MTOE	238 MTOE	357 MTOE

\* MTOE: Million Ton Oil Equivalent. 1 MTOE equals 44.8 PJ

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Table 4 presents total and agriculture area as well as arable land, permanent crops, pasture, and forests and woodland expressed in hectares and as a percentage of the total area. The table contains data for the whole world, continents and the most attractive countries for biomass production.

Table 4. Total area and areas important for biomass production in the world, subdivided in continents and the most interesting countries [13]

Unit: 1 000ha	Total area	Agriculture area	Arable land (% of total area)		Permanent crops (% of total area)		Permanent pasture (% of total area)		Forests and woodland (% of total area)	
<b>World</b>	13 427 880	5 012 266	1 404 130	10	136 578	1	3 471 729	26	4 172 435	31
<b>Africa</b>	3 030 974	1 110 974	184 905	6	25 792	1	900 448	30	712 676	24
Algeria	238 174	40 065	7 665	3	600	0	31 800	13	3 950	2
Cameroon	47 544	9 160	5 960	13	1 200	3	2 000	4	35 900	76
Ethiopia	110 430	30 671	9 936	9	735	1	20 000	18	13 300	12
Morocco	44 655	30 283	8 396	19	887	2	21 000	47	8 970	20
Nigeria	92 337	72 200	30 200	33	2 800	3	39 200	42	14 300	15
South Africa	121 909	99 640	14 753	12	959	1	83 928	69	8 200	7
Sudan	250 581	133 833	16 233	6	420	0	117 180	47	42 000	17
<b>Asia</b>	3 186 692	1 683 886	511 701	16	61 686	2	1 110 499	35	556 747	17
China	959 805	553 957	142 621	15	11 335	1	400 001	42	130 518	14
India	328 726	181 177	161 715	49	8 400	3	11 062	3	68 500	21
Indonesia	190 457	44 877	20 500	11	13 200	7	11 177	6	111 774	59
Japan	37 789	5 190	4 418	12	344	1	428	1	24 621	65
Kazakhstan	272 490	206 769	21 535	8	136	0	185 098	68	9 600	4
Pakistan	79 610	27 120	21 448	27	672	1	5 000	6	3 480	4
Thailand	51 312	20 167	15 867	31	3 500	7	800	2	14 500	28
Turkey	77 482	41 690	25 938	33	2 585	3	13 167	17	20 199	26
<b>Europe</b>	2 297 649	486 858	287 221	13	16 772	1	182 865	8	947 276	41
Belarus	20 760	8 924	5 606	27	124	1	3 194	15	7 200	35
Bulgaria	11 099	5 325	3 355	30	228	2	1 742	16	3 348	30
Romania	23 839	14 837	9 398	39	501	2	4 938	21	6 680	28
Russia	1 707 540	216 651	123 465	7	1 835	0	91 351	5	765 912	45
Serbia & Mont.	10 217	5 586	3 397	33	327	3	1 862	18	1 769	17
Ukraine	60 370	41 396	32 544	54	913	2	7 939	13	9 239	15
<b>North &amp; Central America</b>	2 272 494	621 403	257 273	11	15 094	1	349 036	15	823 914	36
Canada	997 061	67 505	45 660	5	6 455	1	15 390	2	453 330	45
Cuba	11 086	6 655	2 668	24	1 120	10	2 867	26	2 608	24
Mexico	195 820	107 300	24 800	13	2 500	1	80 000	41	48 700	25
Nicaragua	13 000	6 976	1 925	15	236	2	4 815	37	3 200	25
USA	962 909	411 863	176 018	18	2 050	0	233 795	24	295 990	31
<b>South America</b>	1 783 361	642 482	112 642	6	13 952	1	515 888	29	931 570	52
Argentina	278 040	177 000	33 700	12	1 300	0	142 000	51	50 900	18
Bolivia	109 858	36 937	2 900	3	206	0	33 831	31	58 000	53
Brazil	851 488	263 580	58 980	7	7 600	1	197 000	23	555 000	65
Paraguay	40 675	24 815	3 020	7	95	0	21 700	53	12 850	32
Peru	128 522	31 410	3 700	3	610	0	27 100	21	84 800	66
<b>Oceania</b>	856 440	466 663	50 388	6	3 282	0	412 993	48	200 252	23
Australia	774 122	447 000	48 300	6	300	0	398 400	51	145 000	19
New Zealand	27 053	17 235	1 500	6	1 872	7	13 863	51	7 667	28

J.B. Holm-Nielsen, P.O. Popiel & M. Madsen, Department of Bioenergy, SDU, Denmark (2005)  
Data from 2002 (forests and woodland – 1994)

As expected, from the above table it can be easily noticed that the highest percentage of arable land is in Asia, and then in Europe and North & Central America. Moreover, the arable land areas in Asia are over  $\frac{1}{3}$  of the total world arable land. Therefore, countries like China or India are together covering around 300 000 000 ha of arable land. These countries might become the most vital biomass - and consequently bioenergy - producers.

In Africa, although the priority is food production, the need of energy is necessary as well. Biomass agriculture might significantly positively influence on the national economies of developing countries, especially in tropical and sub-tropical regions: countries like Cameroon or Nigeria in which area of arable land as well as woodland is main part of the country. Furthermore, the South Africa, which is the only one African country ranked as a developed country [13], might be also interested in energy crop production due to its high energy requirements.

In Europe, apart from EU countries, Ukraine might play a significant role in biomass production; Russia with huge potential for biomass production and of course its vast forestry area could play a major role in energy crops, forestry/agriculture industry.

USA and Brazil are already gaining profits from bioethanol production from maize and sugar cane, respectively. Other American countries, like Canada or Argentina with significant agriculture areas, might join them in the near future, with suitable well adopted crop types.

Tables 4a and 4b consist of calculated energy recovery expressed in PJ and TOE, respectively. The values for the whole world and different continents are computed for three diverse crop yielding levels and three different percentage of assumed area for energy production.

Table 4a. Scenarios of area utilization of arable land at the world and particular continents for energy crop production expressed in PJ

	Area used for energy production	10% of arable land	20% of arable land	30% of arable land
	Yield pr. ha			
<b>World</b>	10 tTS/ha	25 274 PJ	50 549 PJ	75 823 PJ
	20 tTS/ha	50 549 PJ	101 097 PJ	151 646 PJ
	30 tTS/ha	75 823 PJ	151 646 PJ	227 469 PJ
Africa	10 tTS/ha	3 328 PJ	6 657 PJ	9 985 PJ
	20 tTS/ha	6 657 PJ	13 313 PJ	19 970 PJ
	30 tTS/ha	9 985 PJ	19 970 PJ	29 955 PJ
Asia	10 tTS/ha	9 211 PJ	18 421 PJ	27 632 PJ
	20 tTS/ha	18 421 PJ	36 842 PJ	55 264 PJ
	30 tTS/ha	27 632 PJ	55 264 PJ	82 896 PJ
Europe	10 tTS/ha	5 170 PJ	10 340 PJ	15 510 PJ
	20 tTS/ha	10 340 PJ	20 680 PJ	31 020 PJ
	30 tTS/ha	15 510 PJ	31 020 PJ	46 530 PJ
North & Central America	10 tTS/ha	4 631 PJ	9 262 PJ	13 893 PJ
	20 tTS/ha	9 262 PJ	18 524 PJ	27 785 PJ
	30 tTS/ha	13 893 PJ	27 785 PJ	41 678 PJ
South America	10 tTS/ha	2 028 PJ	4 055 PJ	6 083 PJ
	20 tTS/ha	4 055 PJ	8 110 PJ	12 165 PJ
	30 tTS/ha	6 083 PJ	12 165 PJ	18 248 PJ
Oceania	10 tTS/ha	907 PJ	1 814 PJ	2 721 PJ
	20 tTS/ha	1 814 PJ	3 628 PJ	5 442 PJ
	30 tTS/ha	2 721 PJ	5 442 PJ	8 163 PJ

Lower combustion energy value is 18 MJ per kg TS; 1 PJ equals  $10^{15}$  J

Table 4b. Scenarios of area utilization of arable land at the world and particular continents for energy crop production expressed in MTOE

	Area used for energy production	10% of arable land	20% of arable land	30% of arable land
	Yield pr. ha			
<b>World</b>	10 tTS/ha	564 MTOE	1 128 MTOE	1 693 MTOE
	20 tTS/ha	1 128 MTOE	2 257 MTOE	3 385 MTOE
	30 tTS/ha	1 693 MTOE	3 385 MTOE	5 077 MTOE
Africa	10 tTS/ha	74 MTOE	147 MTOE	223 MTOE
	20 tTS/ha	149 MTOE	297 MTOE	446 MTOE
	30 tTS/ha	223 MTOE	446 MTOE	669 MTOE
Asia	10 tTS/ha	206 MTOE	411 MTOE	617 MTOE
	20 tTS/ha	411 MTOE	822 MTOE	1 234 MTOE
	30 tTS/ha	619 MTOE	1 234 MTOE	1 850 MTOE
Europe	10 tTS/ha	115 MTOE	231 MTOE	346 MTOE
	20 tTS/ha	231 MTOE	462 MTOE	692 MTOE
	30 tTS/ha	346 MTOE	692 MTOE	1 039 MTOE
North & Central America	10 tTS/ha	103 MTOE	207 MTOE	310 MTOE
	20 tTS/ha	207 MTOE	414 MTOE	620 MTOE
	30 tTS/ha	310 MTOE	620 MTOE	930 MTOE
South America	10 tTS/ha	45 MTOE	91 MTOE	136 MTOE
	20 tTS/ha	91 MTOE	181 MTOE	272 MTOE
	30 tTS/ha	136 MTOE	272 MTOE	407 MTOE
Oceania	10 tTS/ha	20 MTOE	41 MTOE	61 MTOE
	20 tTS/ha	41 MTOE	81 MTOE	122 MTOE
	30 tTS/ha	61 MTOE	122 MTOE	182 MTOE

MTOE: 1 million ton oil equivalent ~ 44.8 PJ

J.B. Holm-Nielsen, P.O. Popiel & M. Madsen, Department of Bioenergy, SDU, Denmark (2005)

In the coming 10 -20 years it will not be unrealistic to see an increasing utilisation of crops for energy and industrial purposes. Scenarios of 10 -20 -30 pct. of arable land shifting from food and feed towards energy farming will gradually occur. Another large European country, Ukraine is rapidly developing in the same direction like the EU countries. In such a large, fertile agricultural country it is stipulated that introduction of renewable energy sources will grow as fast as in many EU countries. In the table below it is depicted that biomass will cover nearly 50 pct. of the renewable energy resources in the long term future. Energy cropping will even increase this potential when energy crops are integrated in large scale biorefinery systems in Ukraine.

Table 5. Renewable energy sources (RES) in Ukraine; Calculations and predictions until 2030 [2]

Type	Technical potential		Heat and electricity production from RES							
			2001		2010		2020		2030	
	Mln t coal eqv	%	Mln t coal eqv	%	Mln t coal eqv	%	Mln t coal eqv	%	Mln t coal eqv	%
Wind energy	15	23.8	0.01	0.2	0.22	3.2	1.0	7.0	2.15	10
Photovoltaic	2.0	3.2	N/A	N/A	0.001	0.02	0.01	0.1	0.03	0.1
Small hydro	3.0	4.8	0.17	3.1	0.15	2.2	0.48	3.4	0.65	3.0
Big hydro	7.0	11.1	4.36	78.7	4.8	68.6	5.6	39	6.53	30.2
Solar heating	4.0	6.4	0.002	0.04	0.12	1.7	0.7	4.9	1.28	5.9
<b>Biomass</b>	<b>20</b>	<b>31.7</b>	<b>0.99</b>	<b>17.9</b>	<b>1.66</b>	<b>23.8</b>	<b>6.3</b>	<b>43.9</b>	<b>10.13</b>	<b>46.9</b>
Geothermal	12	19	0.004	0.1	0.034	0.5	0.247	1.7	0.83	3.8
Total	63	100	5.54	100	6.99	100	14.34	100	21.6	100

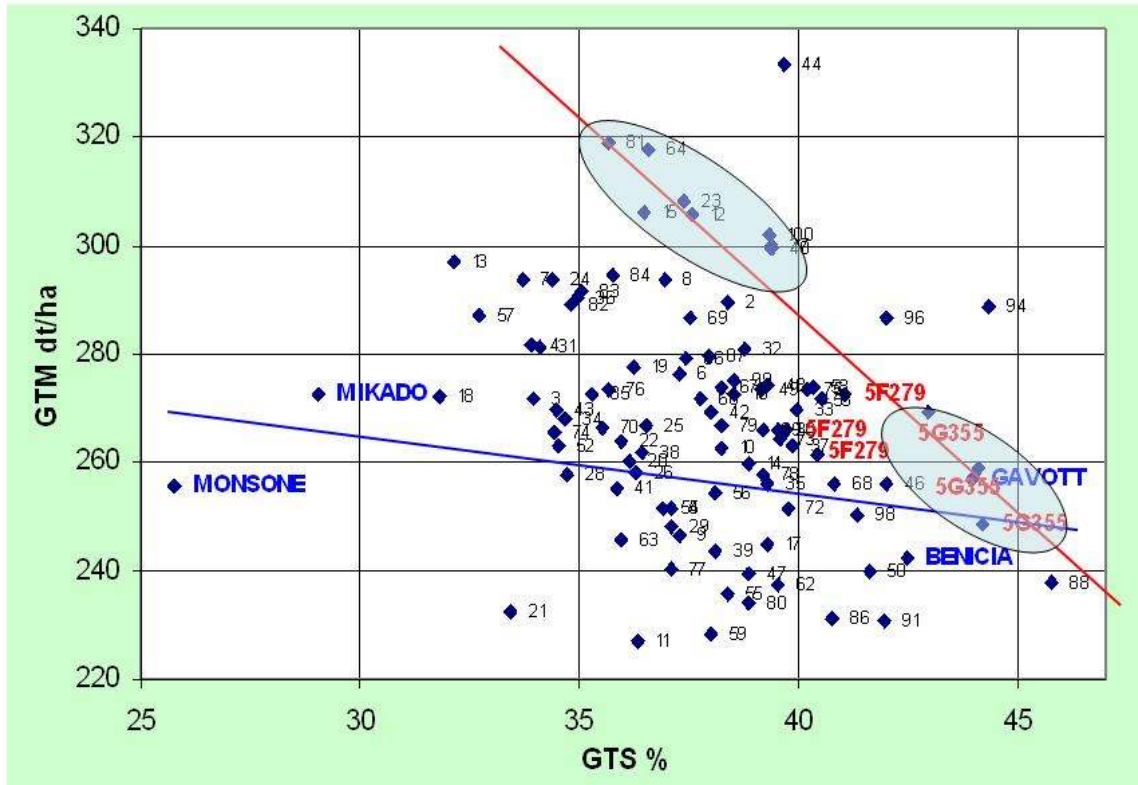
1 TOE =1.43 t coal eqv.; N/A: Not Available

### Case example of plant breeding gene pool potentials exemplified by maize/corn crop varieties.

The gen-pools are not yet developed for dedicated biomass production. For decades crop breeding was dedicated for specific tasks of optimal production yields for starch, vegetable oil, sugar, proteins and not for the total crop yield, including the interesting lignocelluloses complexes in stems and leaves and the entire crop biomass. A future perspective for biomass carbon capture includes the whole crop, with as effective and/or robust conversion into photosynthesis products, at as good rates as will be possible, due to various growing and climate conditions. Potentials are not yet very well developed in the plant breeding and cropping sectors of agriculture.

Below is a plant breeding company example of new maize varieties. The breeding incentives for energy maize varieties include **a.** short-day genes, **b.** tolerance towards cold growing conditions in late varieties, **c.** nutrient/water efficiency. Commercial energy maize varieties, as an example, will be on the market in 2007. The figure below shows how to grow not 15-20 t of TS/ha, but with an increasing trend towards 30 t of TS/ha in the future (figure 1, 2).

LP92\_ Wesel  
 90 BC1S1-lines from (5G355<sup>2</sup> x Mex) x Flinttester + 10 Standards



Source: Dr. Ernst Kesten, KWS Saatgut AG, Einbeck, (D)

Figure 1. Case example of plant breeding gene pool potentials for maize crop [4]

Harvest of energy maize



Source: Dr. Ernst Kesten, KWS Saatgut AG, Einbeck (D)

Figure 2. Harvesting of maize crops [4]

## **Future perspectives for biomass utilisation in the energy and industrial sectors.**

At present the energy supply from biomass is around 45 +/- 10 EJ per year. Main uses consist on traditional way e.g. firing for cooking and heating. The modern technologies (e.g. production of liquid biofuels or electricity and heat – CHP) are approximated at 7EJ a year [6].

The potential to upgrade biomass for biofuels is evident, and can be converted in conventional used technologies, as example fermentation processes for fuels to the transportation sector. At the same time the developments are well on the track for new harvest and conversion technologies. Biofuels and fuel cells can reduce CO<sub>2</sub> emissions significantly from the transportation sector, as we have seen in stationary systems such as biomass for heat and electricity production systems [7].

Ethanol obtained from biomass is one of the most promising sustainable transportation fuels. This compound can be produced from any simple sugar or starchy material. However, big effort is enforced on improvement of the bioethanol production from lignocellulosic materials (forestry and straw from agriculture, the whole crops) which are the richest and renewable compounds for people. Unfortunately, the polymers are not accessible for microorganisms, therefore the material must be prior degraded to basic monomers. Different pre-treatment methods are under investigation in laboratories around the world such as acid hydrolysis, steam explosion or wet-oxidation among others [9].

Developments and implementation of improved growing systems for the purpose of biomass production for biorefinery utilisation will get more and more into focus due to increasing demands for biofuels and a variety of biorefinery products. The commitments for making this kind of shift in the way of widespread using sustainable resources in much larger scales have grown and will grow in this and the coming decade, mainly due to increasing needs of growth in living conditions in big countries like China and India, and all over the world and because fossil fuels will be completely inadequate in the medium to long term.

However, the challenge will be to make the paradigm shift in a sustainable manner.

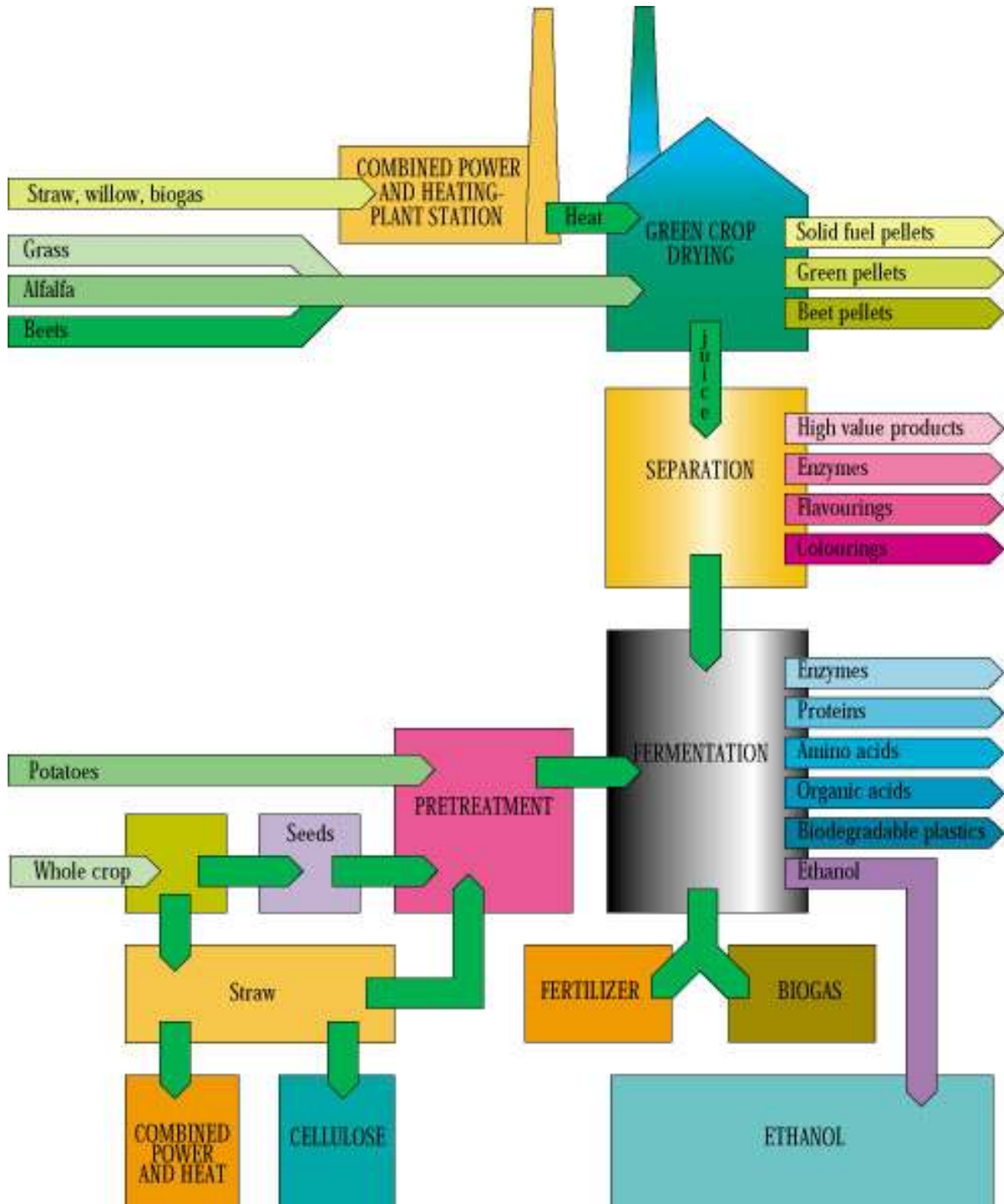
### **What is a Biorefinery?**

According to [8] one can distinguish two types of biorefinery. Brazil, the United States, China, Southern Asia or Australia is principally “biomass-producing-country” type. Useful products are being produced from biomass such as grains, sugarcane or potatoes. Whereas, in European countries or in Japan - where due to lack of space, the significant problem with storage of huge quantity of organic waste occur – the biorefinery is often based on “waste-material-utilization” type [8]. The production of valuable bioproducts, until now, is mainly connected with organic waste handling problems.

The basic conceptual idea of Biorefinery is illustrated by the flow sheet below (figure 3), from the survey conducted by the research group – The Biomass Institute, SUC, (DK) back in the early 90'ties and after that realized in the full scale: The green juice – amino acid , Lysin plant, Agroferm Ltd., Esbjerg. Other ideas are realized as joint biogas plants in Denmark like Ribe, Linko, Lemvig, Blaabjerg and Thorsoe and Hashoej biogas plants, to mention only some examples.

In this decade, interesting ideas are under development in new concepts like energy crop biorefineries for gaseous and/or liquid biofuels. A new integration is under R D & D realisation, for conversion of lignocelluloses products like straw, wood chips and whole crop silage for conversion

into biofuels, biogas and new products. All initial products will be used for either bioethanol for the transportation sector and biogas for combined heat and electricity production or the natural gas grid and biofertilizers for recycling to the arable land.



Source: Pauli Kiel et. al. Biomass Institute, SUC, 1994

Figure 3. Ethanol in the Green Biorefinery [5]

## World energy scenarios – goals for future

Table 6 presents possible energy obtained from agriculture. In table 7 two world primary energy consumption scenarios are depicted.

Table 6. Energy scenarios

No.			Source
1.	Non collected straw (50%)	75 000 PJ/year	Sanders J.: <i>Biorefinery, the bridge between Agriculture and Chemistry</i> .
2.	Collected waste processing (50%)	45 000 PJ/year	Wageningen University and Researchcenter. Workshop: Energy crops & Bioenergy.
3.	Forest/pastures (50%)	150 000 PJ/year	
4.	10% of arable land – World Wide (20 t TS / ha)	50 549 PJ	Holm-Nielsen J.B., Madsen M., Popiel P.O.: <i>Predicted energy crop potentials for biogas/bioenergy. Worldwide – regions – EU25</i> .
5.	20% of arable land – World Wide (20 t TS / ha)	101 097 PJ	
6.	30% of arable land – World Wide (20 t TS / ha)	151 646 PJ	AAUE/SDU. Workshop: Energy crops & Bioenergy.
Sum: 1+2+3+5		371 097 PJ	

Table 7. World primary energy consumption for 2050

	Predicted value	Source
Total energy required 2050	1 000 000 PJ/year	Sanders J.: <i>Biorefinery, the bridge between Agriculture and Chemistry</i> . Workshop: Energy crops & Bioenergy.
Total energy demand 2050	1 300 000 PJ/year	Shell's World Energy Scenario

20% of arable land dedicated for energy production (20tTS/ha) would give us around 10% of total world energy required in 2050. Adding: 7.5% from non collected straw, 4.5% from collected waste processing, and 15% from forest or pasture would result in almost 40% of the whole energy needed in 2050. However, Shell predicts that energy demand in 45 years will increase even to 1300EJ/year. On the other hand, it forecasts that energy from renewable would be more than 50% of the total energy.

## Summary

Biorefineries are thoroughly integrated thinking and utilization of biomasses of any kind for new products, for industrial and energy use at sustainable conditions and terms. A terminology as biomass for food, feed, fibers, fuels, and future industrial applications is going to be realized and implemented at increasing speed in this and the coming decade. A full paradigm shift has started in this decade going from fossil fuel dependencies towards biomass and accompanying renewable energy recourse based economies.

Optimal utilization of biomass converted to valuable industrial and energy products, as high valuable replacements for fossil fuel products are highly prioritized at the agenda. At year 2050 it will be possible to meet the world energy demand with 75-90 percent of all energy by full integrated utilization of Bioenergy, Wind, Hydro and Solar energy sources. Bioenergy can fulfill in between 30-50 percent of the entire world energy needs and demands. The world is getting greener and more sustainable if we are doing a more progressive and faster effort, bearing a more balanced future in mind, environmentally as well as economically speaking internationally.

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