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Welcome Address – Global Renewable Energy Potential

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Abstract

The intensive use of renewable energy is one of the options to stabilize CO_2 atmospheric concentration at levels of 350 to 550ppm. A recent evaluation of the global potential of primary renewable energy carried out by IPCC sets a value of at least 2800EJ, which is more than the most energy intensive SRES scenario forecasts as the energy requirement for the year 2100.

Nevertheless, what is really important to quantify is the amount of secondary renewable energy since the use of renewable sources may involves conversion efficiencies from primary to secondary energy different from the ones of conventional energy sources. In a very recent study, Lightfoot and Green, using almost the same land areas listed by IPCC, concluded the amount of secondary energy from renewables is far less than from the same amount of conventional sources primary energy. The result is so small that the authors claim against the IPCC statement that available technologies if largely deployed can stabilize CO_2 concentration at low level.

In reality, IPCC does not provide a complete account of the secondary energy from renewables, but the text claims that using several available options to mitigate climate change, and renewables is only one of them, it is possible to stabilize CO_2 concentration at low level.

In this paper, we evaluate in detail biomass primary and secondary energy using sugarcane crop as a proxy, since it is one of the highest energy content form of biomass. The conclusion is that primary energy for biomass has been under evaluated by that authors and by IPCC, and the under evaluation is even larger for secondary energy since sugarcane allows co-production of electricity and liquid fuel.

With the new potential amount of secondary biomass energy (788 EJ/year) it is possible to show that even using the pessimistic conversion efficiency of the authors for solar energy, all together renewable sources of energy can yield above 1000 EJ/year. With the conversion efficiency of solar primary energy in electricity assumed by IPCC (15%) using all sources of renewables it is possible to fulfil the energy requirement of all SRES scenarios for the year 2100.

Another important part of this paper is the addition of a larger extension of land for solar energy production that is presented in IPCC but neglected by the authors when presenting criticism to IPCC’s conclusion. Assuming that 10% of “other lands” category as defined by FAO can be used to install photovoltaics it is possible to produce all the secondary energy forecasted in SRES scenarios independent of what the two conversion factor value is accepted.

As a final conclusion, this paper agrees that available technologies for renewables are sufficient to stabilize CO_2 atmospheric value at low level and endorses IPCC conclusion.

1. Introduction

This paper deals with two interconnected issues. One is the maximum amount of biomass energy that can be produced at global level and used as a primary energy source and how much can be obtained as a secondary energy (essentially electricity and liquid fuel). The second issue is a reply to a criticism presented to the IPCC/TAR result that claims that new energy technologies must be developed if we want to stabilize CO_2 concentration level at the atmosphere around 350-550ppm (Lightfoot and Green, 2002). The IPCC/TAR concludes that there are already a set of technologies that can stabilize CO_2 concentrations at below 350 ppm, being renewables one of the options.

More precisely the following statements are extracted from Lightfoot and Green, 2002:

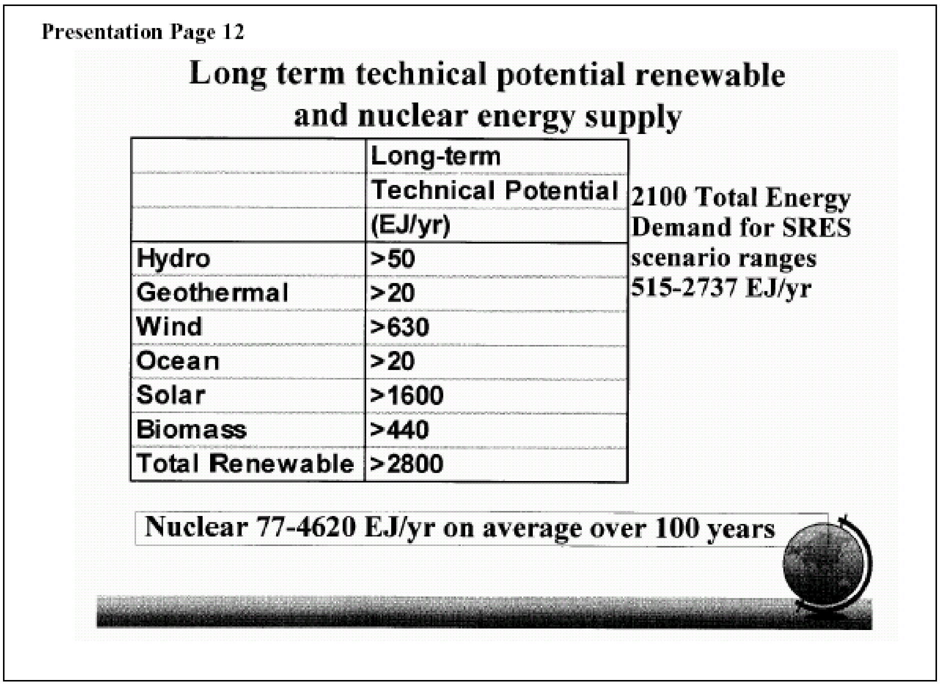
"To stabilize the level of carbon dioxide in the atmosphere at 550 ppmv in 2100 requires that 37-38 TW (1,188 EJ/yr) of the 1,453 EJ/yr of world energy demand be carbon-emissions-free primary energy. To fill the 830 EJ/yr (26 TW) gap between 1,188 EJ/yr and the maximum contribution of 467 EJ/yr of renewable energies requires new carbon-emissions-free energy technologies not now in existence."

"The results of our research do not support the statement on page 8 of Climate Change 2001: Mitigation that, **"…known technological options could achieve a broad range of atmospheric carbon dioxide stabilization levels, such as 550 ppmv, 450 ppmv or below over the next 100 years or more...".**

Renewable energies make a small, but important, **contribution to world energy supply**. **Solar and wind electricity** contribute as stand alone operations in small niche applications."

"Hydroelectricity is the most valuable of the renewable energies but is relatively small compared to world energy consumption. Geothermal electricity will continue to be small unless heat from the centre of the earth can be tapped on a large scale."

Figure 1 is taken from a presentation 'Technological and Biological Mitigation Potentials and Opportunities' on the major findings from the IPCC WG III contribution to the Third Assessment Report. It synthesizes most of the findings carried out in IPCC/TAR (IPCC/TAR, 2001) about alternative sources of energy evaluation and these findings are used in this article as the results being criticized by Lightfoot and Green.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Long term technical potential renewable and nuclear energy supply

	Long-term Technical Potential (EJ/yr)
Hydro	>50
Geothermal	>20
Wind	>630
Ocean	>20
Solar	>1600
Biomass	>440
Total Renewable	>2800

2100 Total Energy Demand for SRES scenario ranges 515-2737 EJ/yr

Nuclear 77-4620 EJ/yr on average over 100 years

Figure 1: Long term technical potential: Renewable and nuclear energy supply

2. Evaluation of the biomass energy potential

Table B1 is extracted from Lightfoot and Green and lists data used for several authors to compile the global renewable energy potential. The table is fully presented here since we will use solar and wind data later in this paper. In this section we will discuss biomass energy data only. At the footnotes, also part of the Table B1, there are a some comments in italics added to specifically start our disagreement with Lightfoot and Green.

Table B1 A comparison of WG III data with that from other sources

	Solar	Horizontal flat collector plate			2-axis tr.
A	B	C Lightfoot Green W/m^2	D Eliasson W/m^2	E WG III Col. 2 W/m^2	F WG III Col. 3 W/m^2
1	Solar input, W/m^2, horizontal flat plate (C,D,E), 2-axis tracking (F)	249	228	175	312
		km^2/EJ	km^2/EJ	km^2/EJ	km^2/EJ
2	Area/EJ of Solar input, calculated from Line 1, km^2/EJ	127	139	181	102
3	Area/EJ of Solar input, calculated from Line 4A, km^2/EJ (C & D only)	147	143	-	-
4	Area/EJ of PV electricity delivered: 15% efficient PV cells, land/collector ratio = 2.12, 2, and 2 for Cols C, D, and E respectively	2,078	1,905	2,413	-
4A	Area/EJ of PV elect. delivered, 15% eff. PV cells land/coll. = 5 (F)	-	-	-	3,400
4B	Area/EJ of solar input, calculated from Cols 9 & 10, Table 3.33b	-	-	250	79
4C	Area/EJ of PV electricity delivered: 15% efficient PV cells, land/collector ratio = 2 and 5 (E, F)	-	-	3,333	2,633
5	Area/EJ of hydrogen delivered from electrolysis of water, (C)	2,970	-	-	-
6	Area/EJ of electricity delivered, solar thermal power generation (D)	-	2,540	-	-
	Wind				
7	Average wind velocity, m/sec (10 metres above ground)	5.6 – 6.0	6	5.1	-
8	Area per EJ of electricity delivered	20,000	25,079	16,670	-
9	Area per EJ of electricity delivered	-	-	See p39	-
	Biomass				
10	woody biomass	-	-	33,333	
11	short rotation trees - max.	46,000	47,642	-	
12	short rotation trees – min.	19,000	28,802	-	
13	methanol - max.	120,000	-	66,666	
14	methanol - min.	50,000	-	66,666	
15	Ethanol from sugar cane	32,000	-	-	
16	Sorghum - max.	-	46,882	-	
17	Sorghum - min.	-	20,076	-	

Table B1: Comparison of WG III data with that from other sources (Lightfoot and Green, 2002).

In the following the biomass related data reported by Lightfoot and Green in Table B1 are critically discussed.

Line 10:

E WG III: 33,333 km^2/EJ is calculated from note (a) under Table 3.31 on page 244, i.e., **Assumed 15 odt/ha/yr and 20 GJ/odt**. The references to biomass are "fibre", "lignocellulosics", "woody biomass", which are all consistent and could be covered by the term "woody biomass".

The figures used either in IPCC/TAR (IPCC/TAR, 2001) or Lightfoot and Green, 2002 are very modest compared with the above ground yield of several sources of biomass, in particular the ones grown in tropical countries

It is important to note that the best records are for sugarcane grown in a 10,000 ha in Zambia with 1,350 GJ/ha/year, for sugarcane global average with 650 GJ/ha/yr, for the best Eucalyptus plantation at Aracruz, in Brazil with 1000 GJ/ha/yr, and for average Eucalyptus plantation in Aracruz, Brazil, as 450 GJ/ha/yr (see Figure 2).

It is important to note that the total amounts of primary energy transported to the mills and used in Table 1, when analyzing sugarcane energy potential are 462(210+252)GJ/ha/yr for sugarcane bagasse plus sugar[1], and 210 GJ/ha/yr for the residues[2], performing a total of 672 GJ/ha/yr. This figure is conservative since we analyze in Table 1 real results from an efficient sugar mill, with an ethanol yield of 8,000 l/ha/yr, while Brazilian average yield is around 6,000 l/ha/yr (According with FAO (FAO, 2002) Brazilian average productivity was 6% lower than global average in the year 2000).

With the real figures from Table 1 present land requirement for processed primary energy is 24,400 km^2/EJ, better than the results quoted in table B1 for woody (33,300km^2) and for alcohol from sugarcane (32,000 km^2). Adding the content of 60% of the residues it is possible to obtain 19,200 km^2/EJ/yr. The best yield considered in Table 1 assumes 40% more biomass, consequently the overall primary energy is 941 GJ/ha/yr, yielding 13,700 km^2/EJ[3]. This last number that is compatible with the yield obtained in countries with the highest marks (FAO, 2002), and with the past experience in Brazil, where yield has increased significantly with the growing commercial interest in energy production. It is worthwhile to comment that the 941 GJ/ha/yr is only 45% above world average yield (650 GJ/ha/yr) and 67% of the maximum yield already achieved (see Figure 2)

Line 11:

C Lightfoot & Green: Maximum area is 46,000 km^2/EJ from McGill Centre for Climate and Global Change Research (C2GCR) report 92-6.

D Eliasson: Table 4-5, page 61, Maximum area for plantations, hybrid poplar (short rotation trees) are listed as net energy output in GJ/ha of 223.7 - 13.8 = 209.9 GJ/ha in 1990, which is 47,642_km^2/EJ. The net energy output increases to 347.2 GJ/ha in 2010 and the area drops to 28,802 km^2/EJ. No reason is given for the increase in output, but it may relate to improved methods and tree stock.

E WG III has no equivalent to hybrid poplar (short rotation trees).

Line 12:

C Lightfoot & Green: Minimum area is 19,000 km^2/EJ.

D Eliasson: Minimum area is 28,802 km^2/EJ in 2010.

E WG III has no equivalent to hybrid poplar (short rotation trees).

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[1] The value listed in Table 1 (A1) is for ethanol energy. Ethanol is obtained from sugars that are the primary energy source in the process. See note 3 below.
[2] The value quoted in Table 1 (A2) is the energy contend of 60% of the residues.
[3] This value only considers the energy contend of residues transported to the mills.

Line 13:

C Lightfoot & Green: Methanol**: minimum area is 120,000 km^2/EJ. This is more than twice the area to grow solid biomass because it takes more than one half of the energy in the wood to convert the wood to a liquid fuel, i.e., methanol**.

D Eliasson has no equivalent.

E WG III: Area = 66,666 km^2/EJ based on the following comment which appears on page 245 (Col. 2, line 10) - "Research into methanol from woody biomass continues with successful conversion of around 50% of the energy content of the biomass at a cost estimate of around US$0.90/litre." For purposes of this table, the assumption is exactly 50%. In the body of our report we have adjusted the 50% by multiplying by 0.7 to compensate for the energy to plant, grow and harvest the biomass. The final result is 35% efficiency of conversion, or 94 EJ/yr of liquids from 268 EJ/yr of solid biomass.

From the highlighted sentence above it is very clear the authors ignore the possibility of co-production of alcohol and electricity. This is a very important consideration. It is applicable to few energy crops only. May not be applicable to methanol from woody materials. We will return to this point when commenting line 15.

Line 14:

C Lightfoot & Green: Minimum area is 50,000 km^2/EJ.

D Eliasson has no equivalent.

E WG III: Minimum area is 66,666 km^2/EJ.

Line 15:

C Lightfoot & Green: area of land in suitable climate to grow sugar cane, 32,000 km^2/EJ.

D No equivalent.

E No equivalent.

Returning to the co-production issue alcohol from sugarcane is obtained from the primary energy content of sugars, through the use of mechanical energy for juice extraction, heat for juice heating, and heat for ethanol separation from water. All the mechanical, electric, and heat requirements are obtained from sugarcane bagasse that is, presently burned in boilers for steam production and may be gasified in the near future to drive gas and steam turbines cogeneration plants, The amount of bagasse is more than enough to fulfil all energy requirements for ethanol production and the surplus is sold to the grid in many countries. With the use of residues the amount of electricity will increase more than proportional to the amount of biomass, since it is not necessary to increase process steam production at all in the mills. This factor allows a significant increase in the conversion efficiency of primary energy to secondary energies, as can be seen in Table 1 (D4) where overall process efficiency is higher than 50%.

Line 16:

C No equivalent.

D Eliasson: Table 4-5, page 61, Maximum area for plantations, sorghum is listed as net energy output in GJ/ha of 232.8 - 19.5 = 213.3 GJ/ha in 1990, which is 46,882 km^2/EJ. The net energy output increases to 498.1 GJ/ha in 2010 and the area drops to 28,802_km^2/EJ. No reason is given for the increase in output, but it may relate to improved methods and seed stock.

E No equivalent.

Line 17:

C No equivalent.

D Minimum area for sorghum in 2010 is 20,076 km^2/EJ.

E No equivalent.

From comments about Lines 16 and 17 it is evident that co-production is not accounted. For sweet sorghum co-production of electricity and ethanol is feasible.

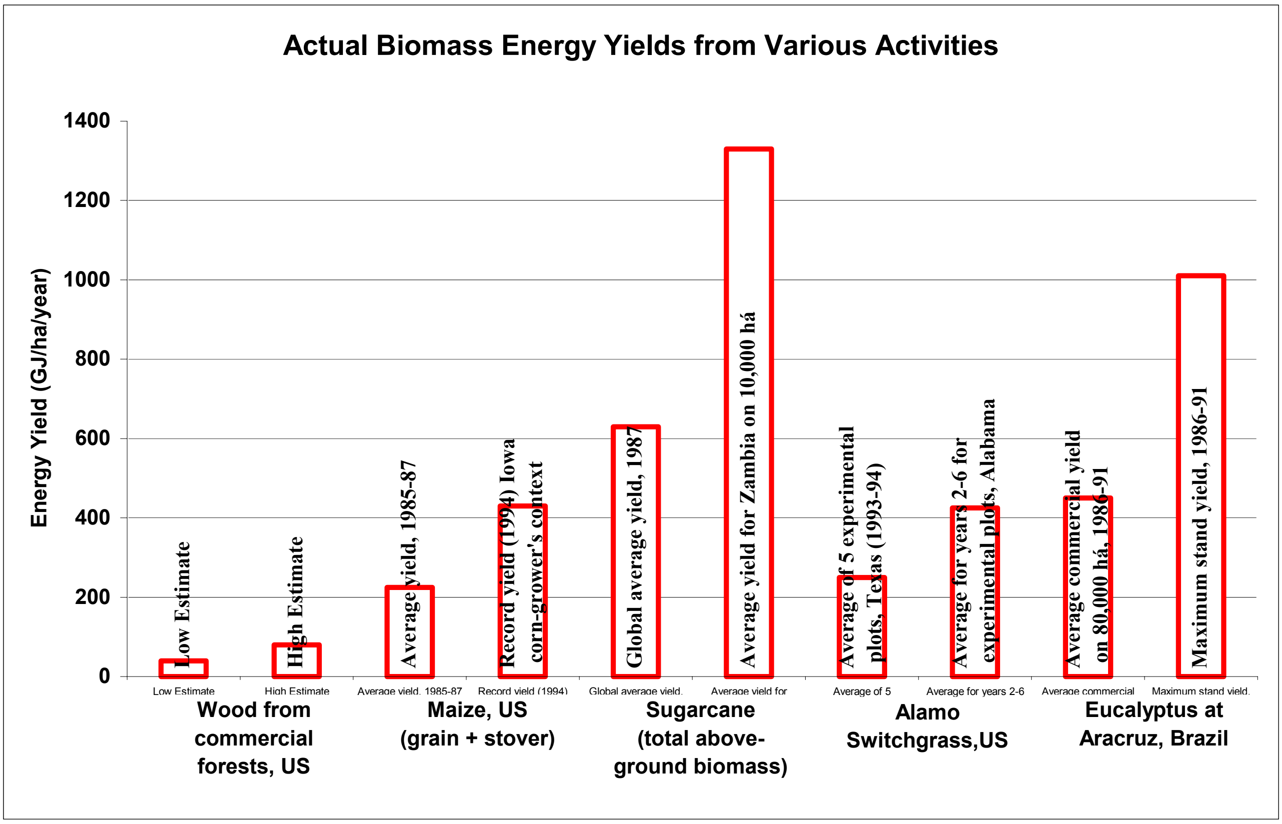

Figure 2: Actual biomass energy yields from various activities (Source: IPCC/SAR/Chapter19)

Based on the above reported information from Lightfoot and Green and in complimentary information already added above we will focus our comments on biomass energy with the purpose to show that Lightfoot and Green's energy analysis is far from being completed and that some of their conclusions are not correct. That authors' paper and criticism has other faults when dealing with solar energy but we will concentrate here only on one energy source. Solar energy is discussed in section 4 of this paper.

Lightfoot and Green claim that the number of plants would be huge and unlikely to be built, using as reference the large pulp mills installed in the world. Such mills consume 6,000 tons of wood per day. If we look at the sugarcane sector in Brazil the largest mills handle 5,000,000 tonnes of sugarcane per season (200 days/year). This means 25,000 tonnes per day!

One of these mills is producing 80 liters of ethanol and 100 kWh of electricity per tonne of sugarcane processed. This is equivalent to 80 x 5,000,000 x 23MJ + 100 x 5,000,000 x 3.6MJ of secondary energy (fuel and electricity). Based on such results we present Table 1, which shows primary and secondary energy production of the mill as well as several future operational scenarios. Some of the scenarios have a large chance of becoming reality in few years. The one using biomass gasification may take 10 years.

Energy Sources	Primary energy (EJ/yr)			Best performance/2002 Steam turbine			
				Secondary energy (EJ/yr)			
	A			B			
	Current Practice	With 60% barbojo	Total	Current practice	With 60% barbojo	Total	Efficiency (%)
	1	2	3	1	2	3	4
Electricity	0.0105[4]	0.0063[5]	0.0168	0.0018	0.0016	0.0034	20.24
Self-consumption			0	0.00025	0	0.00025	
Surplus			0	0.00155	0.0016	0.00315	
Alcohol	0.0092[6]	0	0.0092	0.0092	0	0.0092	100
Total	0.0197	0.0063	0.026	0.011	0.0016	0.0126	48.46
Total for sale				0.01075	0.0016	0.01235	47.5

Energy Sources	Primary energy (EJ/yr)			Best performance/2002 BIG/GT				40% More Yield	
								Secondary energy (EJ/yr)	
				Secondary energy (EJ/yr					
	A			C				D	
	Current Practice	With 60% barbojo	Total	Current practice	With 60% barbojo	Total	Efficiency (%)	Total	Efficiency (%)
	1	2	3	1	2	3	4	3	4
Electricity	0.0105	0.0063	0.0168	0.00315	0.00252	0.00567	33.75	0.007938	33.75
Self-consumption			0	0.00025	0	0.00025		0.00035	
Surplus			0	0.0029	0.00252	0.00542		0.007588	
Alcohol	0.0092	0	0.0092	0.0092	0	0.0092	100	0.01288	100
Total	0.0197	0.0063	0.026	0.01235	0.00252	0.01487	57.19	0.020818	57.19
Total for sale				0.0121	0.0025	0.01462	56.23	0.020468	56.23

Table 1: Primary and secondary energy evaluation from the largest sugar/alcohol mill in operation in São Paulo, Brazil (Part 1)

The current figures are 0.009 and 0.0018 EJ of alcohol and electricity (B1), respectively 0.0054 Mboeq/yr and 0.496 TWh/yr (B*1). In 1990, 38EJ of electricity was consumed at global level and this would require 21,000 of such biomass conversion facility. This number is huge, but let us remember that each of these sugarcane units also provides 1.998 Mboeq/yr (400 million l of ethanol/yr) and 21,000 similar units would produce 41,958 Mboeq/yr (8.4 trillion liters of alcohol per year or 115 million barrels of oil equivalent per day). Remembering that world oil consumption was 70 million barrels per day in 2000 we conclude that this set of 21,000 sugar/alcohol mill could do a lot more than just produce the electricity demand of 1990!!.

Such results presenting more secondary energy as alcohol than as electricity is because electricity generation from sugarcane mills is very much below the present technology capability, due to the lack of interest in this energy source in Brazil.

[4] This is the amount of electricity obtained from sugarcane bagasse (270 kg per ton of cane with 50% moisture contend. LHV=7.85 MJ/kg, assuming 2% ash and 1% waste sugar). Assumes a theoretical conversion of 100% for biomass energy to electricity.

[5] This amount of electricity is obtained from a share of sugarcane residues, which presently are mostly burned in the field before harvesting. This practice is being banned through legislation in Brazil, and is not used in Cuba since long ago. LHV is obtained from the same formula used for bagasse but with 20% moisture contend, 2% ash, and 1% waste sugar.

[6] This is the present practice energy contend in alcohol. The alcohol is obtained from the primary sugars available in sugarcane. Typical Total Reducible Sugar is 145 kg/t
cane and a conversion efficiency sugar to ethanol of 73.8% is obtained.

	Primary energy (EJ/yr)			Best performance/2002 Steam turbine Secondary energy (EJ/yr)			
Energy Sources	A*			B*			
	1	2	3	1	2	3	4
				TWh/yr	TWh/yr	TWh/yr	
				Mboe/day	Mboe/day	Mboe/day	
Electricity				Mboe/yr	Mboe/yr	Mboe/yr	
Self-consumption	Current	60% barbojo	Total	Current	60% barbojo	Total	(%)
Surplus	1	2	3	1	2	3	4
Alcohol	0.0105	0.0063	0.0168	0.499	0.443	0.942	20.24
Total			0	0.069	0.000	0.069	
Total for sale			0	0.429	0.443	0.873	
Alcohol	0.0092	0	0.0092	0.005	0.000	0.005	100.00
Total	0.0197	0.0063	0.026	2.731	0.652	3.382	48.46
Total for sale				2.662	0.652	3.313	47.50

Energy Sources	Primary energy (EJ/yr)			Best performance/2002 BIG/GT Secondary energy (EJ/yr				40% More Yield Secondary energy (EJ/yr)	
	A*			C*				D*	
	1	2	3	1	2	3	4	3	4
				TWh/yr	TWh/yr	TWh/yr	Efficiency	TWh/yr	Efficiency
				Mboe/day	Mboe/day	Mboe/day		Mboe/day	
				Mboe/yr	Mboe/yr	Mboe/yr		Mboe/yr	
	Current	60% barbojo	Total	Current	60% barbojo	Total	(%)	Total	(%)
	1	2	3	1	2	3	4	3	4
Electricity	0.0105	0.0063	0.0168	0.873	0.698	1.571	33.8	2.1988	33.8
Self-consumption			0	0.069	0.000	0.069		0.0970	
Surplus			0	0.803	0.698	1.501		2.1019	
Alcohol	0.0092	0	0.0092	0.005	0.000	0.005	100.0	0.0077	100.0
Total	0.0197	0.0063	0.026	3.281	1.026	4.307	57.2	6.0295	57.2
Total for sale				3.211	1.026	4.238	56.2	5.9325	56.2

Table 1: Primary and secondary energy evaluation from the largest sugar/alcohol mill in operation in São Paulo, Brazil (Part 2)

Using the sugarcane residues, which are usually burned before harvesting, but due to present legislation that requires gradual vanishing of this practice, more electricity will be generated soon. Assuming all residues will be green-harvested and 60% of them transported to mills, electricity generation will increase to 0.0034 EJ/yr (B3). This means that we would need 11,000 of such units to deliver the 38 EJ of electricity consumed in 1990.

With biomass gasification and gas turbines the availability of electricity will be 0.00567 EJ/yr, (C3) (or 1.57 TWh/yr (C*3)) using bagasse and 60% of the residues, or 3.15 times bigger than present generation. Another consideration is that a productivity of 100 ton/ha is quite poor for a long term global energy program. There are countries were average productivity is 130 ton/ha/year (FAO, 2002). For a significant biomass energy program we can assume a future yield of 140 ton/ha/year. The combination of better technology for electricity generation and better yields means that one large sugar/alcohol plant should be able to produce 0.007938 EJ/yr of electricity (D3) (or 2.2 TWh/yr (D*3)) and 1.4 times more ethanol than the present figure (D3 and D*3).

Under this assumption instead of 11,000 units it would be enough to install 4,800 mills to produce the electricity consumed at the global level in 1990. Again, let us remind that due to co-production these 4,800 units would deliver 62 EJ/yr of alcohol (13,400 Mboeq/yr) which means a daily production of 37 million barrels of oil equivalent per day (53% of oil used in 1990) (see Table 2).

Looking at the present situation there are 200 sugar/alcohol plants in the state of São Paulo, Brazil. Not all are of this size but the average is 1/5 of the largest ones. The state of São Paulo has an area of 270,000 km^2 and a population of 40 million people. It is the most developed state in Brazil responsible for 40% of industrial production, has very large agricultural activity, has cattle-ranching areas and has 1% of its lands flooded with water for hydroelectricity generation. This means that, based on the state of São Paulo experience, it would be no problem from the point of view of surface land to accommodate 40 of these large units in the state. This means an average density of 1 unit per 6,750 km^2. At this rate we would need to distribute the units over a land area of 32.4 million km^2 to accommodate all the 4,800 units, which exceeds the available agricultural areas by 30%. This requires either a 30% increase in the density or an assumption that water irrigation and somewhat long transportation would be required for 30% of the productive units. We prefer the first alternative (see Table 2).

SECONDARY ENERGY CATEGORY	**PRIMARY ENERGY (EJ/yr)**	**SECONDARY ENERGY (EJ/yr)**	**TOTAL LAND AREA USED FOR CROPS**
ELECTRICITY	**113**	**38**	
LIQUID FUEL	**62**	**62**	
TOTAL	**175**	**100**	**1.71×10^6 km^2**

Table 2: Amount of secondary energy produced from sugar/alcohol mills distributed over world agricultural land area at a density of 1 every 5,208km^2 (Total number of renewable energy producing units is 4,800)

If we are talking about a demand level of 300 EJ of electricity by the year 2100 then we would need to distribute 37,800 units over an area of 255 million km^2, which is 10 times the potential agricultural area of the world, from which only 12 million km^2 shall be used for food production by the year 2050, when global population is expected to peak. Obviously, 255 million km^2 are not available and the only solution is to significantly increase the unit density. To accommodate all the 37,800 sugar mills in the 25 million km^2 of agricultural land their density would be 1 unit per 661 km^2, from which 357 km^2 would be used for the sugarcane crop. The crops would occupy 54% of all world agricultural area, which is the upper limit considered in the IPCC/TAR. At this level of electricity production the 37,800 units would co-produce 487 EJ/yr of alcohol (D3) (or 105,700 Mboeq/yr and 289.5 Mboeq/day(D*3), which is 4.1 times the world consumption in 1990) (see Table 3).

Just in case these 300 EJ of renewable electricity and the 487 EJ renewable liquid fuel estimated above are not enough to cover the world secondary energy supply by 2100, as anticipated in the most energy intensive SRES scenarios in combination with the pessimistic transformation efficiency of primary to secondary as quoted in Lightfoot and Green, 2002, even more energy from biomass can be obtained. For a maximum demand of 1100 EJ (30 TW) of renewable secondary energy it would be necessary to expand by 40% the number of sugar mills from 38,000 to 53,000. This means that the unit density should be 1 unit each 472 km^2, with the energy crop occupying 18.9 million km^2, which represents 75% of all agricultural area and conflicting with land for food crops.

SECONDARY ENERGY CATEGORY	PRIMARY ENERGY (EJ/yr)	SECONDARY ENERGY (EJ/yr)	TOTAL LAND AREA USED FOR CROPS
ELECTRICITY	890	300	
LIQUID FUEL	488	488	
TOTAL	1378	788	$13.5X\ 10^6$ km^2

Table 3: Amount of secondary energy produced from sugar/alcohol mills distributed over world agricultural land area at a density of 1 every 661 km^2 (Total number of renewable energy units is 37,800)

3. Conclusions from new data

The conclusion is that using sugarcane crop as the source of biomass at the highest achievable energy production level is around 800 EJ of secondary energy. This is not big enough to guarantee the 2700 EJ of primary energy forecasted by the most energy intensive scenarios of SRES. Nevertheless, it is necessary to recognize that with 37,800 units it is possible to produce 300 EJ of electricity (83,200 TWh/yr) and 487 EJ of liquid fuel (105,700 Mboeq/yr or 290 Mboeq/day).

A good metric to estimate if 37,800 units is a huge number for renewable energy producing stations is to compare with the total number of hydro dams. At global level, the overall number of dams is, presently, 45,000, of which 40% are used for electricity production. And global hydroelectricity represents 2,500 TWh/yr today. This means that, in average, each hydroelectric plant produces 0.125 TWh/yr. Why not have 37,800 biomass-based units producing 2.2 TWh/yr each and providing 7 times the present global electricity demand, plus 4.1 times present global oil demand, instead of the 19% electricity provided by the 20,000 hydroelectric plants?

We recognize that 37,800 units is really a huge figure, but the amount of secondary energy is also unthinkable:

300 EJ/yr of electricity (or 83,200 TWh/yr)

487 EJ/yr of liquid fuel (290 million barrel/day)

Also, if we would like to produce such an amount of electricity using nuclear plants with 1,000 MW each (operating factor of 70%, 6.1 TWh/yr) we would need 13,640 nuclear plants in operation at the year 2100 or the installation of a new plant every 2,5 days from now on.

Regarding the statement of Lightfoot and Green that it would be very difficult to use this energy since it will be produced in regions different from those where the consumption will occur it is necessary to consider the following:

As listed in the document by Lightfoot and Green, 40% of the usable land would be in Latin American and the Caribbean. Thus, 40% of the plants would be installed there (15,120 units) with a production of 33,300 TWh/yr and 116 million barrels of liquid fuel per day. Transportation of the liquid fuel should not be a problem. Today we already transport 40 million barrels of oil per day. Transportation of electricity may be an issue. Probably, all electricity consumption of Latin American and Caribbean would be less than 10,000 TWh/yr even at 2100. The large surplus (23,000 TWh/yr) could not be transferred to other continents. One possible solution is to concentrate major energy intensive activities in the region.

Finally, all this exercise is for an extreme situation where all world energy by 2100 would have to be supplied through biomass.

As stated in IPCC/TAR we confirm that it will be possible to achieve low CO_2 atmospheric concentration using several technological options. We also agree that no single solution will be able to solve the problem. IPCC/TAR presents a series of technological solutions, being essentially:

1. Energy efficiency improvement
2. Renewable energy
3. Shift to low-C fossil fuels
4. Biological C sequestration
5. Physical C sequestration

And, in the category “Renewable Energy” we shall rely on several possibilities, mainly Solar PV, Wind and Biomass.

4 Solar and Wind Energy Potential

Let us discuss the overall renewable energy potential in light of the better results identified in sections 2 and 3. As a starting point we use Table H1 data extracted from Lightfoot and Green.

Table H1 Comparison of primary and secondary renewable energies available

	A	B	C	D	E
		Our estimate of representative renewable secondary energy, Table 11 EJ/yr	Conversion factors for renewable secondary energy to primary energy from Table 12	Our estimate of representative renewable primary energy available B x C EJ/yr	WG III estimate of renewable primary energy available EJ/yr
1	Hydro	19.3	1.18	22.8	50
2	Geothermal	1.5	6.2	9.3	20
3	Wind	72	3.33	240	630
4	Ocean	-	-	-	20
5	Solar	178	13.3	2,367	1,600
6	Sub-total: electricity	271	-	2,639	
7	Solid biomass	-	-	268	440
8	Liquid biomass	94	2.85	-	-
9	Totals	365	-	2,907	2,800

Table H1: Comparison of primary and secondary renewable energies available (Lightfoot and Green)

In Table H1, column B shows the representative amount of renewable secondary energy and column C displays the conversion factors identified by Lightfoot and Green. Column D shows the amount of renewable primary energy represented by the secondary energy in Column B. Column E is the amount of primary energy estimated by WG III in their presentation to CoP6, and displayed in the Introduction Section of this paper.

According to the table, about 60% of the available renewable primary energy is solar energy, which has a recovery rate for solar electricity per unit of land from sunlight of about 7% to 8%, on average. This is why the secondary renewable energy of 365 EJ/yr in Column B is only 13% of primary renewable energy of 2,907 EJ/yr in Column D.

The primary energy for the range of secondary renewable energies identified by Lightfoot and Green is 251 EJ/yr to 467 EJ/yr or 1,945 EJ/yr to 3,481 EJ/yr respectively, with the representative average value of 2,907 EJ/yr. Thus, the primary energies estimated by WG III and ourselves are in the same order of magnitude.

Using data from Table H1, and the new information presented in section 2 and 3 for biomass we elaborated Table 4.

Energy Source	A	B	C	D	E	F	G	H	I
	Lightfoot et al.	THIS PAPER 4800 units	THIS PAPER 37,800 units	Lightfoot et al.	THIS PAPER	Lightfoot et al.	IPCC TAR	THIS PAPER 4800 units	THIS PAPER 37,800 units
	Secondary Energy	*Secondary* Energy	Secondary Energy	Conversion Factor	Conversion Factor	Primary Energy	Primary Energy	Primary Energy	Primary Energy
	EJ/yr	EJ/yr	EJ/yr			EJ/yr	EJ/yr	EJ/yr	EJ/yr
						F=A*D		H=B*E	I=C*E
Land Area (Mkm^2)	12.8	1.71	13.5			12.8	12.8	1.71	13.5
Solid Biomass						268	400	175	1378
Liquid Biomass	94	38	300	2,85	1*			113	890
Electricity		62	488		2.97			62	488
Total	94	100	788						

Table 4: Comparison of biomass energy potential from several authors and this paper

* This value refers to alcohol as primary energy since the figures quoted at the liquid biomass line for this Paper figures are already alcohol. In reality, ethanol is obtainable from sugars and the primary energy shall be better listed for sugars. The conversion efficiency from total reducible sugars to ethanol is 73.8%.

Almost all quantifications in Table 4, except one scenario ('This Paper 4,800 units'), assume an available land area of 12.8 million km^2, which is the result quoted in IPCC/TAR as the extension of agricultural area not used for food crop by 2050, the year where the global population shall reach its highest record. The quantification under the label 'This Paper 37,800 units' assumes a slightly higher land availability of 13.5 million km^2. The quantification under the label 'This Paper 4800 units' uses only 1.71 million km^2.

The major conclusions when comparing the results for areas of approx. 13 million km^2 are:

- IPCC/TAR/Chapter 3 did not quote explicitly the amount of secondary energy that can be obtained from the 400 EJ/yr biomass primary energy. Nevertheless, there are comments in the text where conversion efficiency around 25 to 30 % can be inferred, when transforming biomass into electricity.
- Regarding Primary Energy production the lowest value is from Lightfoot and Green with 268 EJ/yr, the intermediate one is the IPCC/TAR with 400 EJ/yr, and the highest one is from 'This Paper 37,800 units' with 1,378 EJ/yr.
- All scenarios except the ones labelled 'This Paper' do not consider co-production of secondary energy when transforming biomass primary energy. Co-production is a very efficient way to convert primary into secondary energy forms, but it can not be performed for all biomass sources. It is very appropriate for sugarcane, sweet sorghum, and ethanol/methanol production from woody materials. Nevertheless, such technology is presently practiced only for sugarcane. With co-production it is possible to increase conversion efficiency. In the scenario 'This Paper', the conversion factor is 1.75 (see column E, in combination with results listed in column

H and I) for the particular relative amounts of liquid fuel and electricity energy obtainable with the technologies used.

- The amount of secondary energy presented by the different evaluations using similar land areas (approx. 13 million km^2) is completely different due to differences in the primary energy and the conversion efficiencies assumed. Lightfoot and Green find 94 EJ as liquid biomass energy, while 'This Paper' finds 788 EJ/yr from which 300 EJ/yr is as electricity and 488 EJ/yr as liquid biomass fuel. These variations by up to a factor 8 are due to differences in primary energy (Factor of 4.88, already normalizing for the same land area) and a factor of 1.71 from the different conversion factors.
- The amount of secondary energy in 'This Paper 37,800 units' is equivalent to 83,200 TWh/yr of electricity production plus 291 million barrels of oil equivalent per day. This shall be compared with year 2000 energy production of 12,500 TWh and 70 million barrel of oil per day.
- The scenario 'This Paper 4,800 units' has been added since it represents a density of sugarcane units similar to what is operational today in the state of São Paulo, Brazil. Its result shows that it is possible to obtain more secondary energy (100 EJ/yr) using 1.75 million km^2, than has been identified in Lightfoot and Green using 12.8 million km^2 (94 EJ/yr). Also, the amount of electricity produced in this scenario is enough to supply the world electricity demand in 1990. Regarding liquid fuel its level of production is 37 million barrels of oil equivalent per day or half the 1990 consumption.

It is important to note that such high levels of biomass-based secondary energy may not be enough to fulfil the world demand by 2100. Examining columns D and E of Table H1, we see the total primary energy available is estimated at about 2,800 EJ/yr, and the secondary energy available at only 280 EJ/yr (column B).

Figure 3 prepared by Lightfoot and Green (Lightfoot and Green, 2002a), including figures for 40 energy scenarios from IPCC/TAR/Chapter 2 and SRES, shows the same conclusion. The much smaller value found for all renewable secondary energy sources (288 EJ/yr listed in Table H1, column B) is a consequence of the lower conversion factors for all energy sources used by Lightfoot and Green compared with IPCC/TAR and 'This Paper'.

The possible range of primary energy from renewables is displayed in Figure 3. Even assuming Lightfoot and Green's conversion factors for the transformation of primary wind and solar energy to secondary forms, including the significant increase in biomass secondary energy reported in sections 2 and 3, the total secondary renewable energy source in Table H1 (cell B9) should read 1018 EJ/yr (271 from hydro, wind & solar+747 from biomass). By using the IPCC/TAR conversion factor for solar energy this amount of energy would double and the same result from Table H1 (cell B9) would be 1196 EJ/yr (178 more from solar + 1018).

In Figure 2 this new level of biomass primary energy is displayed. This last figure should be enough to fulfil global energy requirements by 2100 for all SRES scenarios.

5. Conclusion

Even with the demonstration that it is possible to supply all the secondary energy requirement for the year 2100 we want to add a few more considerations, since the construction of 37,800 units for biomass energy production may be considered as an upper limit, achievable only if other possibilities do not exist.

It is important to remember that areas used for wind and solar energy production at the IPCC/TAR/Chapter 3 are a small fraction of what is already known as potentially feasible for the future. Potential wind land area is 30 million km^2, from which IPCC/TAR used only 4%, while solar land area is only 1% of what is defined as "other land" by FAO. By the way, IPCC/TAR makes 2 assumptions for solar energy production: one using 1% and the other 10% of "other land".

Unfortunately, the upper value is not considered in Table H1. Restricting discussion to the 1% value is very unfair, since it represents an area of only 390, 000 km^2. This area is a very small land area to solve the energy requirement of the world. Just for comparison, hydroelectricity production, responsible for fulfilling 5% of present world energy demand flooded more than 400,000 km^2 and, according to Lightfoot and Green hydroelectricity is considered the most valuable of the renewable energies (see section 1). Under these premises there should be no concern from the authors if by using 3.9 million km^2 we could supply all the world energy requirement in 2100.

Using 10% of the land area it should be possible to generate 1,780 EJ/yr of secondary energy even with Lightfoot and Green's conversion factor, or 3,580 EJ/yr using IPCC/TAR/Chapter 3 conversion factor (see Figure 3). Considering either one of these figures it is possible to cover the world secondary energy demand in the year 2100 for all SRES scenarios, independent of the availability of other renewable energy sources that we have demonstrate are also significant (see Table 5).

The main conclusion from this paper is that Lightfoot and Green statement that renewables can not limit CO_2 stabilization at levels as low as 350 ppm and as such we must develop new energy alternatives to fossil fuels is incorrect. It is incorrect because:

- **Biomass can provide a significant share of the secondary energy needed**
- **Solar energy alone can provide all the needed secondary energy.**

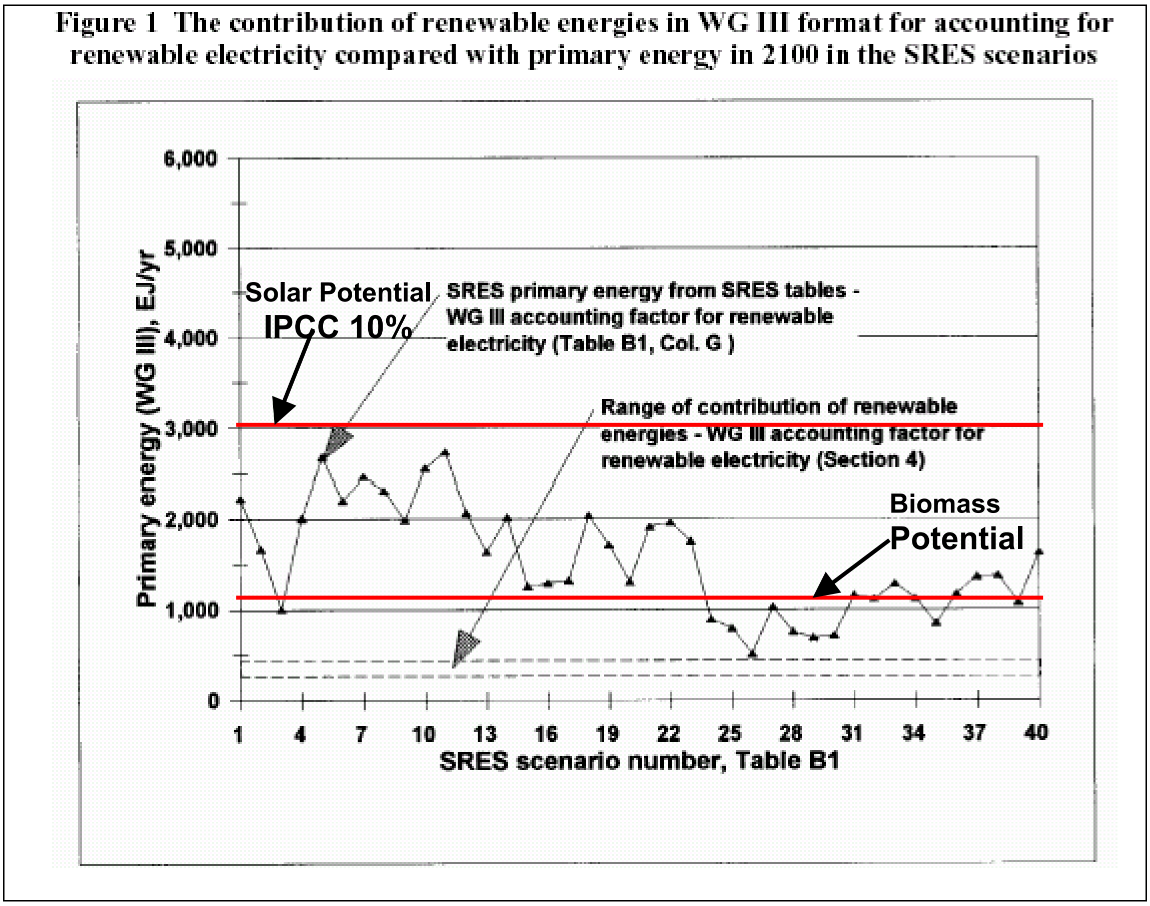

Figure 3: Contribution of renewable energies to the future energy supply.

	A WG III method of accounting for renewable electricity as primary energy	B Same as A With biomass energy from this paper	C Same as A With solar energy from WG III (10% area)
Range of world energy demand in 2100 (EJ/yr)	514 – 2,737	514 – 2,737	514 – 2,737
Range of contribution of renewable energies to world energy demand (EJ/yr)	251 - 467	845 - 1051	4,245 – 4,451
contribution of renewable energies to world energy demand (%)	9.2 – 81.4	30.7 – 38.4	155.1 – 162.6
Average primary energy of 40 SRES scenarios in 2100 (EJ/yr)	1,542	1,542	1,542
Average contribution of renewable energies (%)	16 - 30	16 - 30	16 -

Table 5: Summary of the contribution of renewable energies to world energy demand in 2100

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