Latin America Thematic Network on Bioenergy - LAMNET

3rd Project Workshop - Brazil

Timing: 2nd December 2002 – 4th December 2002

Location (3-4 Dec): National Confederation of Industry – CNI
Brazilian Banking Sector North (SBN) – Square 1 – Block C
Edificio Roberto Simonsen
70040-903 Brasilia – DF, Brazil

WORKSHOP PROCEEDINGS

This workshop was **organised by WIP-Munich**, Germany, **in collaboration with ETA-Florence**, Italy, **and the Brazilian National Reference Centre on Biomass - CENBIO** within the framework of the LAMNET project funded by the European Commission, DG Research.

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Coordination: WIP, Germany
Coordinator/ focal contact point:
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Updated information on this workshop is available at www.wip-munich.de, www.etaflorence.it and at www.bioenergy-lamnet.org.

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MONDAY 2nd DECEMBER 2002

Technical Tour: 07:00 – 16:00

This technical tour organised in the framework of the 3rd LAMNET project workshop visits the Copersucar Technology Center – CTC, one of the most advanced centers in the world focussed on the development of agricultural and industrial technology for the sugar cane industry. The CTC is located in Piracicaba/SP around 200 km west of São Paulo.

Programme of the Technical Tour:

07:00: Departure by bus from Radisson Faria Lima Hotel
Address: Hotel Radisson Faria Lima, Av. Cidade Jardim 625

09:00: Arrival at CTC and beginning of the tour

Introductory presentation of CTC activities by Manoel Regis L. V. Leal, Head of the Industrial Technology department

Presentation on recent research and development efforts in the ethanol production sector by Jaime Finguerut, Industrial Technology department

Guided tour to the research and technological development facilities of the Copersucar Technology Center by Manoel Regis L. V. Leal and Tadeu Andrade, CTC Technology Manager.

13:00: Lunch at CTC

14:00: Return to São Paulo by bus

Transfer to Brasilia from Congonhas Airport

TUESDAY 3rd DECEMBER 2002

Inauguration Session: Welcome, Bioenergy Strategies and Policies
Moderators: José Moreira, CENBIO and Rainer Janssen, WIP

Afternoon Session: Biofuels and Sustainable Electricity Generation in Latin America
Moderators: Suani T. Coelho, CENBIO

WEDNESDAY 4th DECEMBER 2002

Morning Session: Ethanol Based Fuel Cell Technologies

Moderator: Newton Pimenta Neves Jr., National Reference Center for Hydrogen Energy – CENEH, Brazil

09:00 – 09:30	Introductory Lecture: Principle and Applications of Fuel Cells Wolf Vielstich, University of São Paulo (USP), Brazil	62
09:30 – 10:00	The production of hydrogen from ethanol for fuel cells Monica Saraiva Panik, Ballard Power Systems, Germany	67
10:00 – 10:30	Coffee Break	
10:30 – 11:00	Research on the reforming of ethanol Peter Hübner, Fraunhofer Institut für Solare Energiesysteme – ISE, Germany	69
11:00 – 11:30	Direct electro-chemical oxidation of ethanol for the application in fuel cells Teresa Iwasita, University of São Paulo (USP) – Institute of Chemistry, Brazil	76
11:30 – 12:30	Panel Discussion: Challenges and opportunities of ethanol based fuel cells Moderator: Peter Hübner, ISE, Germany Panellists: Newton Pimenta Neves Jr., Wolf Vielstich, Monica Saraiva Panik,	84
12:30 – 13:30	Lunch Break	

Afternoon Session: Innovative Bioenergy Technologies

Moderators: Osvaldo S. Martins, CENBIO

13:30 – 14:00	Decentralised energy self-sufficient supply and disposal systems Susanne Kimmich, Institut für Solare Energieversorgungstechnik e.V. (ISET), Germany	86
14:00 – 14:30	Technological and economical analysis of innovative bioenergy systems Giuliano Grassi, European Biomass Industry Association - EUBIA	95
14:30 – 15:00	Republic of South Africa: Renewable Energy Strategy Denis Tomlinson, Illovo Sugar, South Africa	97
15:00 – 15:30	Coffee Break	
15:30 – 16:00	Pellets derived from biomass residues – a new market perspective Francesco Cariello, ETA-Florence, Italy	98
16:00 – 16:20	Opportunities for biofuel driven micro-turbines Rainer Janssen, WIP, Germany	99
16:20 – 17:20	Discussion Round: Summary of the workshop and outlook Moderator: Rainer Janssen, WIP, Germany	

THURSDAY 5th DECEMBER 2002

Seminar on Climate Change – Brazil 2002

This seminar focuses on the activities of Working Group III (Mitigation of Climate Change) of the Intergovernmental Panel on Climate Change – IPCC. In order to make results and findings of the IPCC's Assessment reports on emissions, methodologies and technology transfer available to a broader Brazilian public a series of seminars is organised by the Brazilian institutions CENBIO, CentroClima and BRASUS within the framework of a specific national dissemination project.

Date and venue of the 3rd LAMNET workshop in Brasilia have been chosen in a way that all LAMNET members are given the chance to participate in this seminar on Climate Change and benefit from complementary themes and activities.

08:30 – 09:00 Registration

09:00 – 09:30 Opening

Fábio Feldmann, Executive Secretary Brazilian Forum on Climate Change

Armando de Queiroz Monteiro Neto, President CNI

José Roberto Moreira, President CENBIO

Suzanne Maia, President BRASUS

Emílio Lèbre La Rovere, Executive Coordinator CentroClima – COPPE/UFRJ

Annick Osthoff, IPCC Working Group III

Hon. Robert H. Meys, Ambassador of The Netherlands

09:30 – 10:10 The international context of climate change
Gylvan Meira Filho, Secretariat for Policies and Science and Technology Programs

10:10 – 10:50 IPCC special working group on Emission Senarios
Emílio Lèbre La Rovere, IPCC Principal Author

11:10 – 11:50 IPCC special working group on Transfer of Technology
Sérgio C. Trindade, President SE2T International, Coordinating Author of IPCC

11:50 – 12:30 IPCC Working Group III – Mitigation of Climate Change
José Roberto Moreira, President of Council - CENBIO, Coordinating Author of IPCC

Afternoon Session: Presentation of the national IPCC dissemination project working groups on Agroforestry, Industry and Municipalities

14:30 – 15:10 Report on the activities of the project working group on agroforestry
Maria de Lourdes O. Freitas, IMAH

15:10 – 15:40 Report on the activities of the project working group on industry
Paulo Serna, Rio LIGHT

15:40 – 16:10 Report on the activities of the project working group on municipalities
Isaura Fraga, FGV

16:30 – 17:00 The national context of Climate Change
Fábio Feldmann, Brazilian Forum on Climate Change

3rd LAMNET Workshop – Brazil 2002

Technical Tour: Copersucar Technology Center

Contact: Manoel Regis L. V. Leal
Head of Industrial Technology Division
CTC – Copersucar Technology Center
Fazenda Santo Antonio, Bairro Santo Antonio
CEP 13 400-970 – Piracicaba/SP
Brazil

The '**Cooperativa de Produtores de Cana, Açúcar e Álcool do Estado de São Paulo**' - **COPERSUCAR** (Cooperative of Cane, Sugar and Ethanol Producers of the State of São Paulo) is a private association whose basic objective is the competitive development of the agro-businesses of its associates, covering the following activities:

- Commercialising, with exclusivity, the sugar and ethanol production of its associates.
- Running and operating the logistics complex of the products commercialised.
- Developing, adapting, transferring and aiding the incorporation of new sugar cane production and transformation technologies for and by its associates.
- Opening new markets and businesses and developing new products in the sugar cane agro-businesses of interest to its associates.

Created on July 1st, 1959, Copersucar currently has 91 associates, including 32 sugar and alcohol production units. With the exception of three agroindustrial units located in the states of Minas Gerais and Parana, all the associates are located in the state of Sao Paulo.

Copersucar holds the exclusive responsibility for the commercialisation of the entire sugar and ethanol production of the associates, which requires diversified activities in the various market segments industrial, commercial, logistics and port handling operations which complement the associates productive activities are distributed among the companies which make up the Copersucar Group.

In the season 2001/2002 the cane production capacity of Copersucar amounted to 54 million tons (about 20% of the total Brazilian production) which was almost equally used for the production of ethanol (2.4 billion liters) and sugar (3.5 million tons). Figure 1 shows the fraction of sugar produced for export and for domestic consumption as well as the ethanol export figure and the relative production of hydrated and anhydrous ethanol.

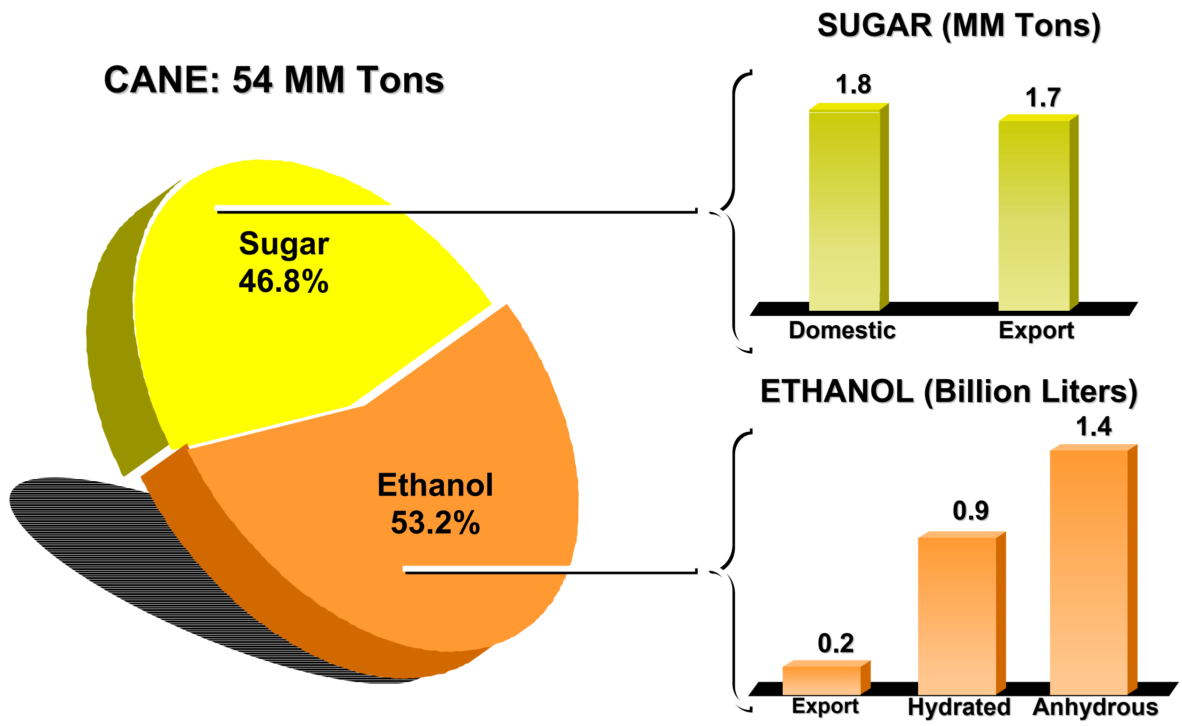

Figure 1: Copersucar production in the season 2001/2002

Technological research has played a very fundamental role among Copersucar´s objectives since the end of the 1960´s, when the program to improve the varieties of sugarcane was created. In 1979, the associates created the **Copersucar Technology Center – CTC**, which is today one of the most advanced technological research centers in the cane, sugar and ethanol producing sector in the world.

Based in Piracicaba, São Paulo State, CTC is responsible for the development and implementation of new technologies. It provides technical assistance and develops new products and businesses for the Co-operative and its associates. With its ISO 9002 certification, the Center is also responsible for the quality of the commercialised products.

To carry out all these functions, the CTC has analytical and development laboratories, three experimental stations and a research field. In terms of human resources, there are over 500 employees, graduates of the most eminent universities in Brazil and abroad. The annual budget is around US$ 15 million, and is raised through both contributions from Copersucar associates and the revenues from services rendered and from royalties.

The **activities of CTC** include:

- Development of new varieties of cane
- Technology for agricultural production
- Technology for transformation of sugar cane: production of sugar and ethanol
- New products such as biodegradable plastic
- Research into technology development in association with local and foreign universities

The **main results** of recent years' CTC activities can be summarised as follows:

- Increase in agricultural and industrial yields break down
- 31 varieties of cane, denominated "SP", have been certified and account for 50% of the sugarcane planted in Brazil
- Pilot scale production of biodegradable plastic
- Technology to utilize cane results for generation of electricity
- Economical utilization of sub-products and rationalization of sugarcane transportation
- ISO 9002 Certification for Copersucar analytical laboratory

Figure 2: Copersucar Technology Center in Piracicaba/SP, Brazil

Few economic sectors generate such relevant social, economic and environmental benefits for Brazil as the sugar and ethanol agrobusiness. The sugar and ethanol production generates 100 thousand jobs, with 80 thousand in the agricultural sector and the rest in the industrialization of sugar and ethanol. In addition, Copersucar itself and associated companies offer 1900 jobs and another 900 jobs in outsourced activities.

One third of the raw material used by Copersucar comes from rural producers. In the state of São Paulo there are 11.000 small producers with farm areas smaller than 150 hectares. Furthermore, social assistance program for the workers of sugarcane agro-industry exist, which are supported by the producers. These resources are spent in health, education, nutrition, recreation and social purposes and represent 1,5% of the mills and distilleries net revenue, thereby complementing official government programs.

The economic benefits of the sugar and ethanol agrobusiness include tax payments by the operational units of around R$ 160 million. This figure increases to R$ 250 million if sales taxes on fuel ethanol, the responsibility of the fuel distributors, are taken into account. Moreover, due to the substitution of 40,000 barrels of gasoline per day by fuel ethanol around US$ 300 million per year on petroleum imports are saved.

Finally, the following **environmental benefits** of the Brazilian simultaneous production of sugar and ethanol from sugar cane need to be emphasised:

- Because of the ethanol program, Brazil was the first country to totally eliminate the use of tetraethyl lead in gasoline
- Lower levels of carbon monoxide (CO) emissions and hydrocarbons and nitrogen oxides less aggressive and less reactive in the atmosphere
- Copersucar, through the use of ethanol and bagasse, avoids the release of 2,7 million tons of carbon annually (in the form of CO_2) in Brazil. This corresponds to 5% of all fossil fuels CO_2 emissions in the country
- So, Brazil and Copersucar have been the pioneers in adopting measures for reducing effectively the greenhouse gas emissions in the energetic sector

Annex: General Information on the **Brazilian Ethanol Programme**:

- Created in 1975, due to the impact of the first oil crisis
- 3,0 million vehicles running exclusively on hydrous ethanol
- All the gasoline used in the country contains 25% of anhydrous ethanol
- Brazil produces nearly 310 million tons of sugarcane annually, 50% of that production is used for ethanol
- The ethanol consumption in Brazil is about 12 billion liters per year, of which 11 billion liters are used as fuel: Anhydrous – 54%, Hydrous – 46%
- Sugar cane cultures covers an area of about 5 million hectares (2% of the total Brazilian agricultural area)

Additional information is provided in the Power Point Presentation Viewgraphs available at the LAMNET project web site **www.bioenergy-lamnet.org/events/events.html**.

Inauguration Session: Welcome, Bioenergy Strategies and Policies

3rd LAMNET Workshop – Brazil 2002

Welcome Address – Global Renewable Energy Potential

Prof. José Moreira
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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:

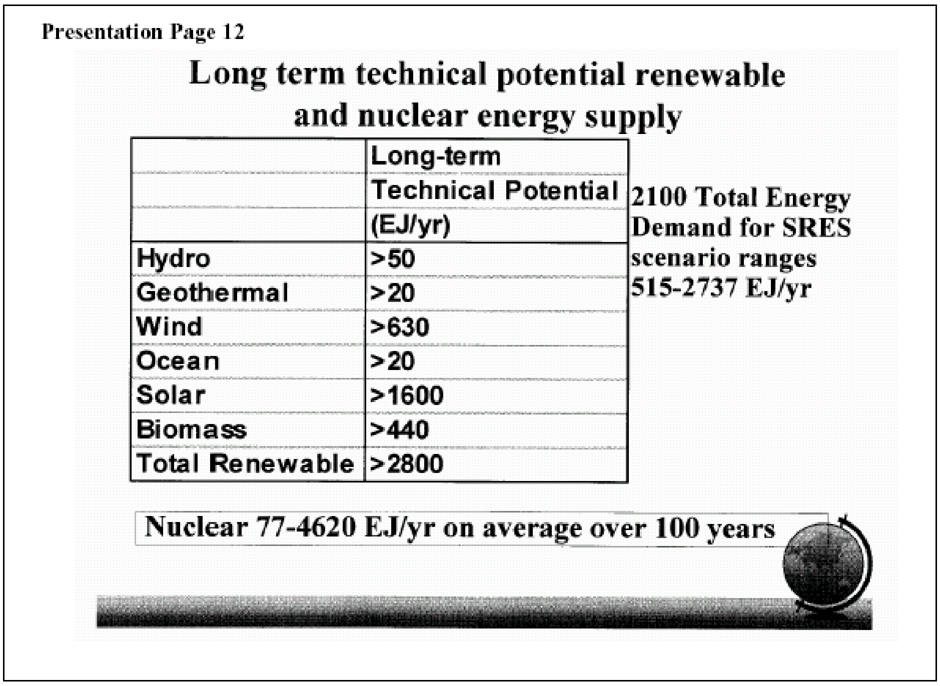
“To stabilize the level of carbon dioxide in the atmosphere at 550 ppmv in 2100 requires that 37-38 TW (1,188 EJ/yr) of the 1,453 EJ/yr of world energy demand be carbon-emissions-free primary energy. To fill the 830 EJ/yr (26 TW) gap between 1,188 EJ/yr and the maximum contribution of 467 EJ/yr of renewable 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.



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

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.

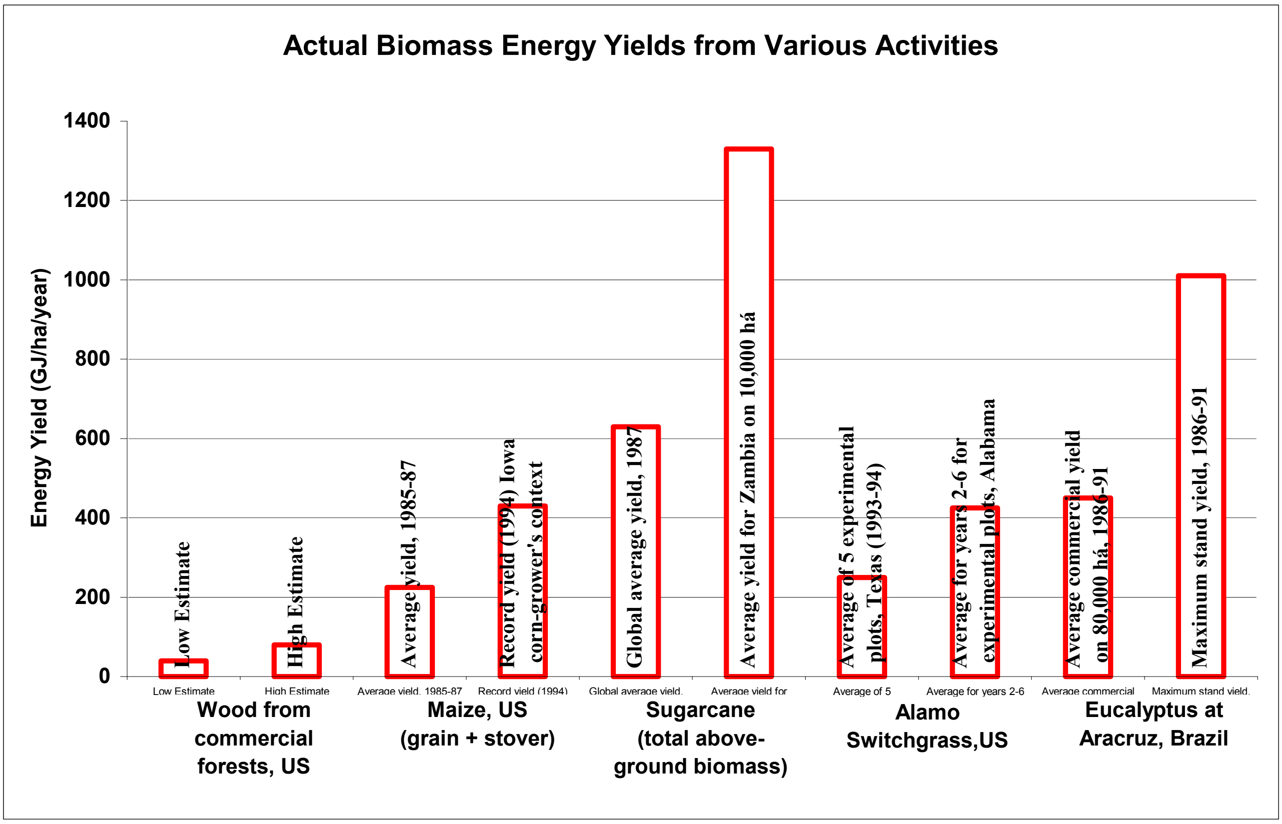

Figure 2: Actual biomass energy yields from various activities (Source: IPCC/SAR/Chapter19)

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 Secondary energy (EJ/yr				40% More Yield 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.

Energy Sources	Primary energy (EJ/yr)			Best performance/2002 Steam turbine Secondary energy (EJ/yr)			
	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 x 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 Our estimate of representative renewable secondary energy, Table 11 EJ/yr	C Conversion factors for renewable secondary energy to primary energy from Table 12	D Our estimate of representative renewable primary energy available B x C EJ/yr	E 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.**

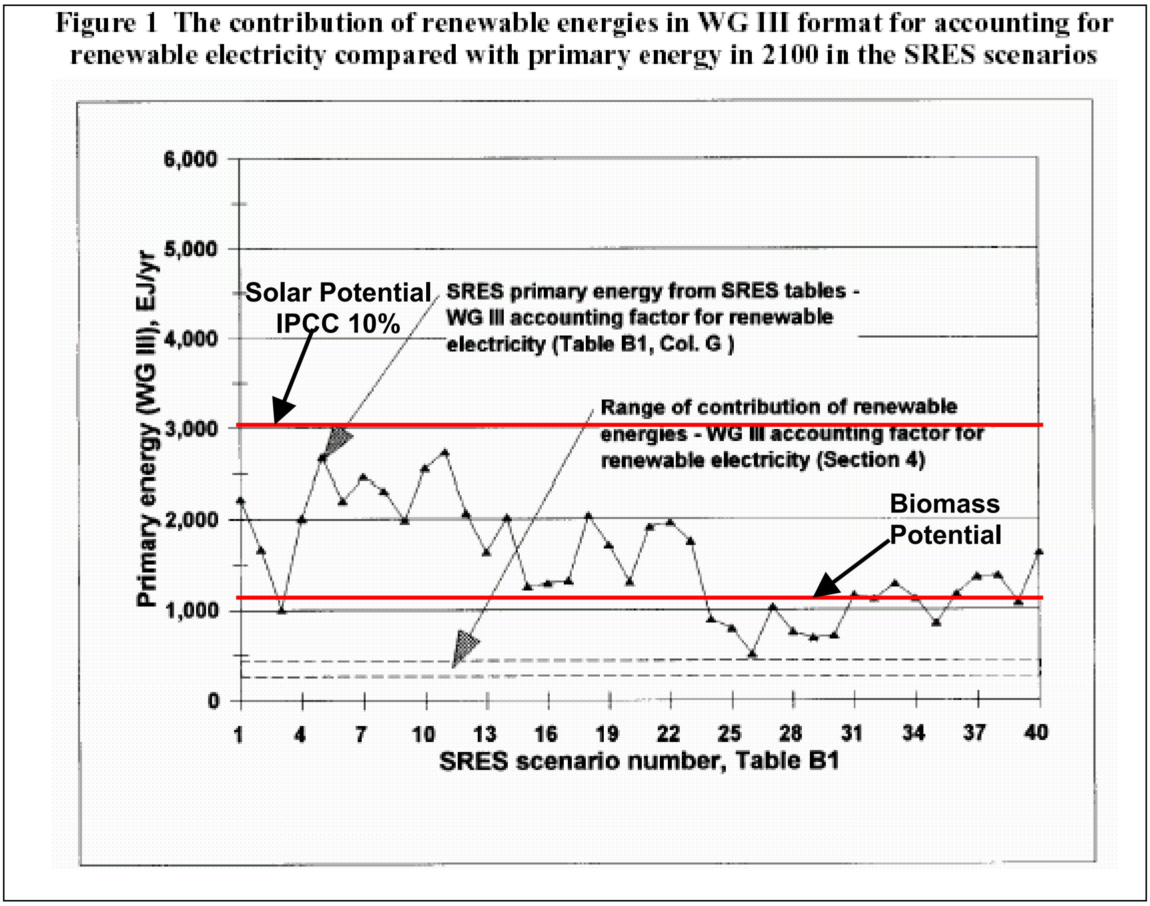

Figure 3: Contribution of renewable energies to the future energy supply.

	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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Additional information is provided in the Power Point Presentation Viewgraphs available at the LAMNET project web site **www.bioenergy-lamnet.org/events/events.html**.

3rd LAMNET Workshop – Brazil 2002

Inauguration Address – Energy Policy on Bioenergy

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Brazilian R&D Targets in the Bioenergy Sector

1) Biofuels

Alcohol/sugarcane ethanol

- To improve energy production efficiency and volume
- To optimise the mix with gasoline and diesel

Biopetroleum from biomass

Biodiesel from vegetable oils such as dendê, mamona, soja and babaçu

- With transesterification via ethanol
- Direct vegetable oil application for micro generation with diesel engines

2) Electricity Generation

Direct burning of sugarcane residues

- To improve efficiency
- To use new residues

Biomass Gasification

- To use in gas turbines and fuel cells

Ethanol as fuel for fuel cells and gas turbine power plants

Incentives to introduce renewable energy in the power market

1) Off-grid Projects

Financial support from CCC (Fuel Consumption Account)

Total budget: US$ 200 million to cover the overcost of power generation in isolated systems

Economic value of displaced diesel can benefit renewable project budget

Vegetable oil, biodiesel, gasification, direct burning

2) On-grid Projects

PROINFA (Incentive to Alternative Sources of Energy Programme)

- Total investment: US$ 8.1 billion
- Connection to the grid of biomass, small hydro plants and wind energy

CDE (Energetic Development Account)

- To cover the gap between the economic and the competitive value for biomass, small hydro plants and wind energy

PROINFA Legislation

PROINFA is one of the mechanisms created by Law 10438 in order to provide incentives for the development of non-conventional renewable energy projects. The two previously existing incentive programmes for the development of small hydro plants and wind power projects, PCH-COM and Proeólica, respectively, have been replaced by PROINFA.

PROINFA – Phase 1 (until December 2006)

Insertion in the grid of 3,300 MW of renewable sources

- Wind: 1,100 MW; 2.89 TWh/yr
- SHP: 1,100 MW; 5.78 TWh/yr
- Biomass: 1,100 MW; 6.75 TWh/yr

PROINFA – Phase 2 (2006 - 2019)

Insertion in the grid of 15% of annual market growth until reaching 10% of total consumption

- Wind: 6,518 MW; 17.13 TWh/yr
- SHP: 6,518 MW; 34.26 TWh/yr
- Biomass: 6,518 MW; 39.97 TWh/yr

Additional information is provided in the Power Point Presentation Viewgraphs available at the LAMNET project web site **www.bioenergy-lamnet.org/events/events.html**.

3rd LAMNET Workshop – Brazil 2002

LAMNET - A Global Network on Bioenergy – Strategies and Results

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Objectives

Good management of resources, alleviating poverty and improving the socio-economic conditions of living are key objectives for research and development efforts in emerging countries and the EU partnership with emerging countries. In order to promote the sustainable use of biomass in Latin America and other emerging countries it is the general objective of this project to establish a network of Knowledge Centres (Universities and R&D Institutes) and SMEs from Latin America and other emerging countries and the European Union. For this purpose a number of members with excellent expertise in the field of biomass are selected and effective co-operation between members is assured.

Activities

The main objective of this global network on bioenergy is to establish a trans-national forum for the promotion of sustainable use of biomass in Latin America and other emerging countries. This global network of 48 institutions (Knowledge Centres and SMEs) from 24 countries worldwide is set up to face urgent needs for improved and regionally adapted bioenergy applications.

The focus of the project will thereby be the identification of technological objectives and the development of policy options to boost promotion of decentralised biomass production and biomass based energy generation. Concerning the large-scale promotion of bioenergy and the realisation of significant benefits from the deployment of modern, efficient and sustainable bioenergy systems in Latin America and other emerging countries the following key Thematic Priorities have been identified and will be addressed during the implementation of this project.

- Analysis of the energy policy framework
- Quantitative and qualitative assessment of demand
- Assessment of present and future resources for the use of biomass
- Analysis of available technologies and systems
- Development of policy options for the promotion of bioenergy
- Implementation of policy options for the promotion of bioenergy

Results

This project will provide recommendations for the development and implementation of policy options for the promotion of the sustainable use of biomass in Latin America and other emerging countries. This objective will be realised through the establishment of a network of Knowledge Centres (Universities and R&D Institutes) and SMEs from Latin America, other emerging countries and the EU comprising a large number of members with excellent expertise in the field of biomass.
The efficient dissemination of the results of this project is realised through the publication of a periodical newsletter and the establishment of a project web site (www.bioenergy-lamnet.org). Additionally, a shared data-base is established on a regional scale to allow for enhanced comparability and accessibility of the project results. Several workshops and seminars will be organised during the project. These events will be organised under participation of members of the Thematic Network and interested persons or organisations from Latin America and other emerging countries.

Management

The co-ordination of the global network on bioenergy is carried out by WIP in partnership with ETA and EUBIA, while the Latin American organisations CENBIO/Brazil and UNAM/Mexico act as co-ordination support points on the South- and Central American continent.

Additional information is provided in the Power Point Presentation Viewgraphs available at the LAMNET project web site **www.bioenergy-lamnet.org/events/events.html**.

3rd LAMNET Workshop – Brazil 2002

Sustainable energy supply for Germany – Results of the Enquete Commission of the German Parliament

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Summary of the report of the “Enquete Commission on Sustainable Energy Supply Against the Background of Globalisation and Liberalisation” by Harry Lehmann, Director of ISUSI and Chairman Eurosolar

Short summary of the Final Report

The consensus view is that Germany’s current energy supply system is not sustainable. The Commission confirms that a sustainable energy supply, based on renewable energy resources and efficient energy technologies is technically feasible and economically beneficial. A sustainable energy supply represents an opportunity for Germany. Sustainable development is a technical, economic, social and institutional challenge and a political response to globalisation. Liberalisation is a supporting measure to achieving sustainable development.

Sustainable development requires observing the barriers imposed by nature. This leads to a hierarchy of sustainable development objectives that are not consistent with the factual priority still granted to economic objectives today: Any irreversible damage to natural life support systems must be prevented because intact natural resources are the prerequisite to economic and social development.

Objectives of a sustainable energy system

The production and consumption patterns that currently predominate worldwide create major environmental problems. The release of substances into the environment due to non-closed material cycles, the high energy consumption associated with these production and consumption patterns, the resulting emissions and the nuclear risks, as well as the vast areas of land used, are not compatible with the concept of sustainable development.

In its First Report, the Commission stated that the current consensus was that the model of “sustainable development” encompassed three dimensions: the conservative use and preservation of natural life support systems, as well as the social and economic development. Bearing this in mind, the Commission wanted to define ecological, social and economic objectives that should be largely compatible with each other.

The majority of the Commission’s members felt that it is possible to identify natural barriers for ecosystems and the atmosphere – barriers that as a matter of principle impose limits on human activities. The term “natural barrier” is used metaphorically to indicate that nature imposes limits on man-made interventions in natural cycles, and that going beyond these limits is associated with unacceptable risks for the individual and society at large. However, these “natural barriers” are not rigid boundaries; they can be identified in terms of ranges, rather than clearly defined limit. This leads to a hierarchy of sustainable development objectives that are not consistent with the factual priority still granted to economic objectives today: Any irreversible damage to natural life support systems must be prevented because intact natural resources are the prerequisite to economic and social development. For this reason, the Commission first defines the requirements to be met by a sustainable energy supply system from an ecological perspective. This leads to the emergence of a corridor of objectives, within which it is then possible to define social and economic objectives.

- **Ecological objectives**: The global reduction of energy-related greenhouse gases is the core of energy and transport policies designed to achieve sustainable development. The goal must be to stabilise the global climate. The concentrations of harmful substances must be reduced below the so-called critical loads in all regions worldwide. By the year 2050, the quality of water resources should not drop below water quality grade II as defined in Germany. The net use of land for residential settlement and transport purposes and for the extraction of raw materials should be reduced to zero by the year 2050. The global energy supply system must be designed in such a way that they will no longer generate any highly radioactive waste in future. The risk of extremely serious accidents occurring in energy generation facilities must be minimised as quickly as possible

- **Social objectives**: All citizens must be given free and reliable access to services in the energy sector. The percentage share of money spent by private households on energy costs should not be allowed to increase. The energy supply system must be subject to democratic decision-making structures. The lives and health of employees in the energy sector must be protected and the interests of workers should be safeguarded. Increased training in renewable energy systems is required.

- **Economic objectives**: Energy productivity is expected to increase by a factor of 2.5 between 1990 and 2020, and by a factor of 4 by the year 2050. Energy efficiency activities will also reduce the external costs of the energy supply system. A long-term and sustainable approach is required to energy. Reliability is vital, therefore combined heat and power and renewables must be promoted. Renewables have to be promoted in Germany to offer a “First-mover advantage”. Improve competitiveness and reliability of supply and reduce dependence on imports esp. oil. It will be necessary to find solutions that decouple transport services from fuel consumption. Stabilise the total mileage in the fields of motor vehicle road transport and in aviation by the year 2010. Limit the increase in the volume of road freight traffic and air traffic.

The development in Germany: Potentials and scenarios

In order to be able to design strategies aimed at developing a sustainable organisation in the future energy industry, it is necessary to develop concepts regarding the possible effects – up to the year 2050 – of a continuation of current trends and future trends to be expected in the development of demographic, social, technological, economic and political variables. Three groups of scenarios were used to study the concrete implementation of a GHG reduction target of 80%, which is necessary to stabilise the global climate.

The first group of scenarios (UWE) is primarily focused on reducing emissions in the conversion sector, including the separation and storage of CO2 in repositories. The “RES/EEU Initiative” group of scenarios assumes that nuclear power will be phased out completely by the year 2030 and that, by the year 2050, fossil fuels will be phased out as much as is required to attain the global warming management targets. By way of compensation, efforts to increase energy efficiency and to use renewable energy sources will be substantially stepped up. According to the targets, at least 50 per cent of the primary energy consumption should be covered by renewable energy sources by the year 2050. In addition, a variant of this scenario – called “Full Solar Supply” – was modelled in which energy supply is ensured exclusively by renewable energy sources by the year 2050. In response to the events on 11 September, a third variant was examined to find out whether the use of nuclear power could be phased out within a very short period of time.

At the suggestion of the minority of the CDU/CSU and the FDP, the Commission defined a third group that permits an increase in the use of nuclear energy in order to attain the reduction target of 80 per cent, which in the final analysis will lead to the construction of between 50 and 70 new nuclear power stations. The scenarios were calculated independently by two institutions.

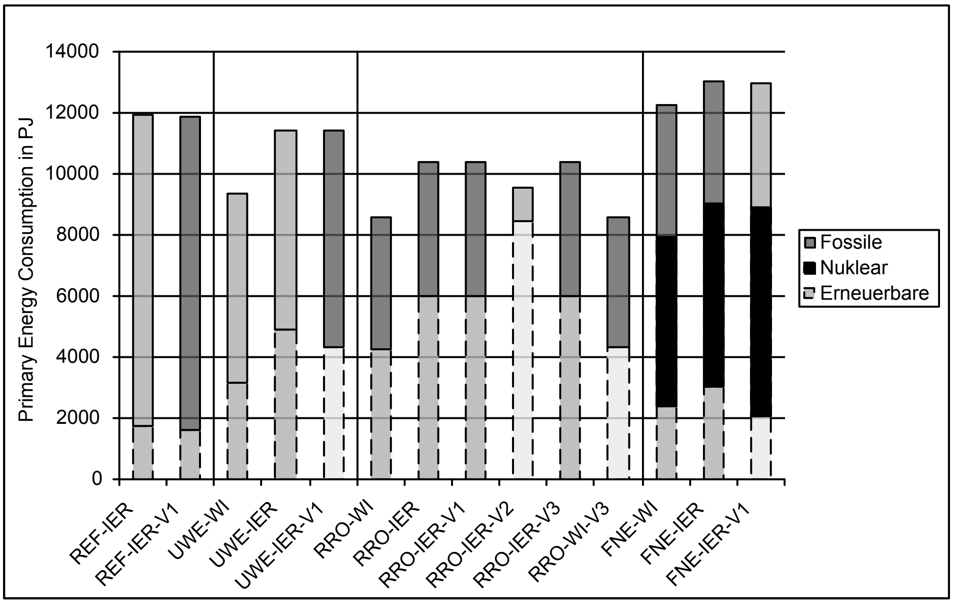

Chart 1-1: Primary Energy Consumption by the Year 2050, According to the various scenarios

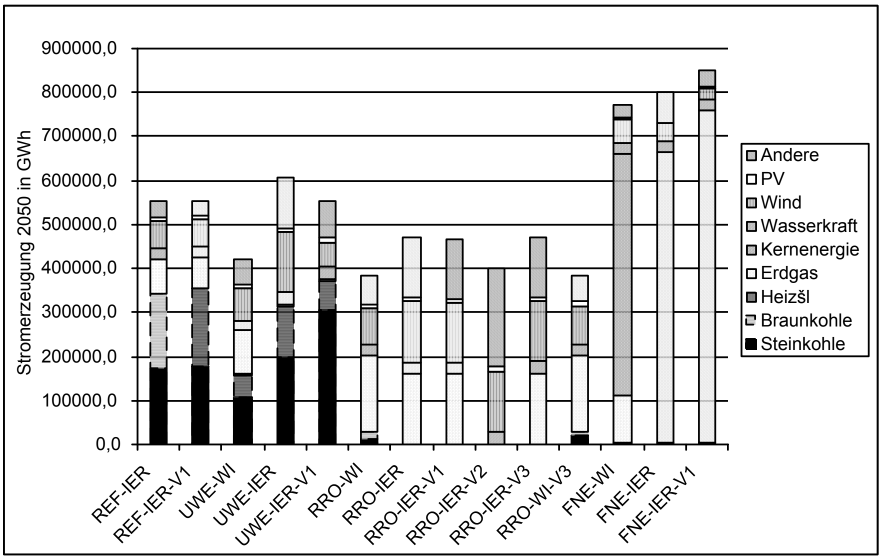

Chart 1-2: Net Electricity Supply by the Year 2050

Chart 1-2 shows the power plant portfolios by the year 2050 as predicted by the simulations. Table 1–1 provides a summary of the scenario results.

The results of an analysis of the various development paths can be summarised as follows:

- It is possible to phase out nuclear power.
- A major role for hard coal and lignite is only sustainable if a technological and cost-effective solution is found for the separation and permanent storage of CO_2.
- In some scenarios, natural gas has an important bridging function to facilitate the final transition toward CO_2-free energy sources.
- It is possible to cover the total energy demand by means of solar energy.
- The scenarios of the RES/EEU Initiative (RRO) is a development path that permits other development options, also beyond the time horizon under review in the report.

			REF-IER	UWE-WI	UWE-IER	RRO-WI	RRO-IER	RRO-IER Var. 2*	RRO-IER Var. 3	RRO-WI Var. 3	FNE-WI	FNE-IER
End-point energy	Total	PJ	8.208	5.918	6.656	5.156	5.910	5.531	5.909	5.183	6.140	7.229
		GJ/cap	121	100	87	82	87	76	87	91	76	107
	Transport	PJ	2.299	1.247	1.975	1.122	1.669	1.894	1.667	1.122	1.409	2.115
	Households		2.221	1.632	1.732	1.352	1.654	1.474	1.653	1.368	1.651	1.814
	CTS		1.389	1.075	1.169	950	1.057	1.065	1.057	952	1.093	1.275
	Manufacturing		2.299	1.964	1.779	1.732	1.530	1.099	1.532	1.742	1.987	2.026
End-point energy by source of energy	Renewables	PJ	334	796	1.220	1.142	1.437	2.136	1.424	1.204	690	1.065
		EEC share	4%	13%	18%	22%	24%	39%	24%	23%	11%	15%
	Other	PJ	152	718	34	252	78	675	81	44	906	7
		EEC share	2%	12%	1%	5%	1%	12%	1%	1%	15%	0%
	Total renewables	PJ	486	1.514	1.254	1.394	1.515	2.811	1.504	1.247	1.596	1.072
		EEC share	6%	26%	19%	27%	26%	51%	25%	24%	26%	15%
	Fossil	PJ	5.539	2.277	2.644	1.864	1.989	300	1.988	1.864	2.465	2.634
		EEV share	67%	38%	40%	36%	34%	5%	34%	36%	40%	36%
	Electricity	PJ	1.816	1.542	1.935	1.368	1.563	1.495	1.564	1.368	1.793	2.628
		EEC share	22%	26%	29%	27%	26%	27%	26%	26%	29%	36%
	Heat	PJ	368	427	823	286	843	925	853	286	240	761
		EEC share	4%	7%	12%	6%	14%	17%	14%	6%	4%	11%
Primary energy	Total	PJ	11.937	9.348	11.400	8.552	10.397	9.547	10.396	8.599	12.266	13.048
		EEC share	176	138	168	126	153	141	153	127	181	192
	Renewable	PJ	1.765	3.130	4.896	4.266	5.998	8.420	5.993	4.318	2.381	3.041
		EEC share	15%	33%	43%	50%	58%	88%	58%	50%	19%	23%
	Fossil	PJ	10.172	6.218	6.504	4.285	4.398	1.127	4.404	4.281	4.321	4.009
		EEC share	85%	67%	57%	50%	42%	12%	42%	50%	35%	31%
	Nuclear	PJ	0	0	0	0	0	0	0	0	5.563	5.997
		EEC share	0%	0%	0%	0%	0%	0%	0%	0%	45%	46%
System costs	Cumulative cost difference vs. reference (€ 19,182.6 billion)		€/cap	3.333	5.134	2.966	9.106	25.383	9.954		2.077	-4.928
	Cumulative cost difference vs. reference discounted to 1998 (€ 9,280.1 billion)		€/cap	527	1.158	596	2.094	6.136	2.560		227	-1.345
	Cost difference vs. reference in 2050 (€ 5,201.6 billion)		€/cap for 2050	298	323	170	605	1.225	616		175	-144
	Cost difference vs. reference in 2050 discounted to 1998 (€ 676.7 billion)		€/cap für 2050	39	42	22	79	159	80		23	-19
External costs	Cost difference vs. reference in 2050 (€ 5,074.8 billion)		€/cap for 2050	-1.848	-2.338	-2.201	-2.649	-2.700	-2.647		14.717	17.515
	Cost difference vs. reference in 2050 discounted to 1998 (€ 660.2 billion)		€/cap for 2050	-240	-304	-286	-345	-351	-344		1.915	2.279

Total percentages may be greater than 100 per cent due to rounding errors.
* For reasons inherent in the model, renewables cannot cover full demand. The balance relative to 100 % in the primary energy share is due to the use of energy sources for non-energy purposes.

Table 1-1: Overview of the Results of the Various Scenarios

It is technically and economically feasible from today's perspective to reduce greenhouse gas emissions by 80 per cent by the year 2050 (relative to the 1990 level). All the technology paths examined in the target scenarios make it possible to achieve the ambitious greenhouse gas reduction targets. The results predicted in the scenarios can only be achieved if the technological developments assumed in the models are supported and promoted by the necessary framework conditions and energy policies. Structural changes such as the transition from an energy supplying industry to a solar energy services industry, or even higher conceivable rates of improvement in resource efficiency (e.g. by a factor of 10) were either not taken into consideration at all in the scenarios, or only to a very limited extent.

It was possible to identify three robust trends that are common to all scenarios:

- **Energy efficiency** All scenarios the predict increases in efficiency go beyond the trend. Major energy conservation potentials are found in buildings so energy saving measures in this area is vital, but all sectors will have to make their contribution.
- **Renewable energy sources** All the scenarios including the (fossil) Conversion Efficiency scenario involve a much greater use of renewable energy sources than the reference scenario (see chart 1-3). The mix of renewables will be determined by need for reliability.
- **Secondary energy sources** In all scenarios, hydrogen is introduced as a new secondary energy source by the year 2050 at the latest. Considerable efforts will have to be made to develop a sustainable energy supply system in general and to achieve the global warming management targets in particular Early decisions are therefore required.

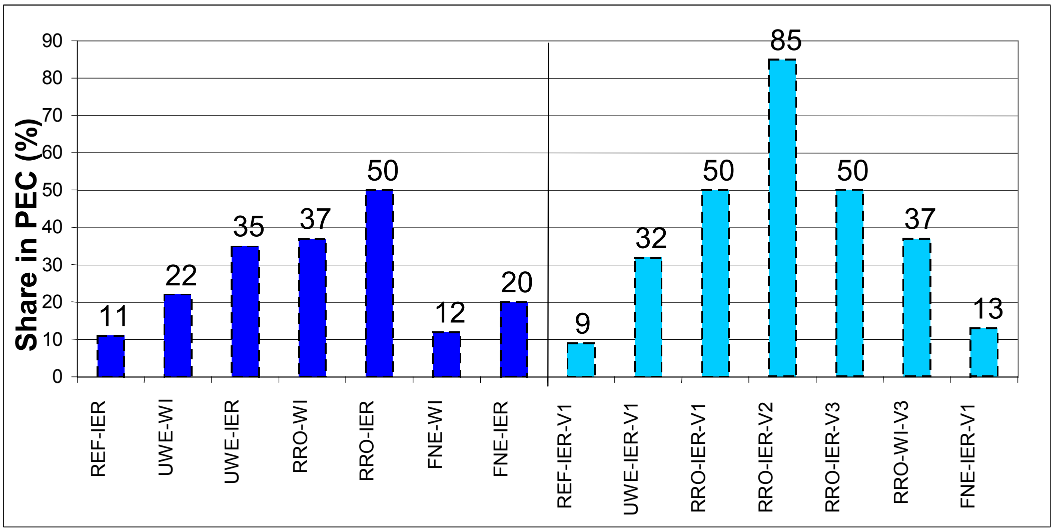

Chart 1-3: Share of Renewable Energy Sources in Total Primary Energy Consumption

Note: In the "Full Solar Supply" scenario, an analysis of the remaining shares shows that these can also be covered by renewable resources.

Scenarios vary widely in terms of their sustainability

The scenarios vary as far as the implementation of the principles of sustainable energy supply is concerned. While all scenarios achieve the reduction of emissions by 80 per cent, most of them have shortcomings in other areas, such as carbon storage, nuclear power and land use.

Only a development path that is oriented toward the RES/EEU Initiative scenario can be qualified as sustainable.

Greenhouse gas reduction costs are tolerable for Germany

Costs are a major criterion, but uncertainties exist. Costs are in the range of 10% of GDP depending on the scenario. This is roughly equivalent to energy costs today.

Conclusions:

The Commission confirms that a sustainable energy supply, based on renewable energy resources and efficient energy technologies is technically feasible and economically beneficial.

Some goals of sustainable energy supply to be pursued up to the year 2020

- To improve the macroeconomic energy productivity by 3 per cent p.a. in the next 20 years,
- To reduce national greenhouse gas emissions by 40 per cent by the year 2020,
- To increase electricity generation from renewable energy sources by a factor of 4 by the year 2020 and to increase the use of renewable primary energy sources by a factor of 3.5 by the year 2020,
- To increase electricity generation from CHP by a factor of 2 by the year 2010, and by a factor of 3 by the year 2020,
- To decrease the average specific end-point energy consumption of recently modernised older buildings to 50 kWh/m^2 by the year 2020,
- To decrease the fleet consumption of new passenger cars to between 3.5 and 4 litres per 100 km by the year 2020,

- Providing more funding for activities that will help tap the potential for efficient energy supply and use (as a first step, so-called "no-regret" measures), and the use of renewable energy sources should be systematically increased.
- Stepping up efforts to transfer capital, technology and know-how from the industrialised nations for the energy sector and to engage in fair energy-related co-operation with developing countries, newly industrialised countries, and countries in transition.

Political strategies and instruments for the development of a sustainable energy system

Policies aimed at implementing a sustainable energy supply system are subject to conflicting requirements imposed by environmental protection and global warming management, economic efficiency and social needs.

The Commission proposed a policy mix that is suitable for initiating the structural changes needed to develop a sustainable energy supply system.

- **Future development of liberalisation.** The process of liberalisation should be backed by regulations that facilitate and safeguard competition.
- **Sustainable energy management.** Clearly quantified targets, for assessing the implementation of global warming management measures are required. A 40% reduction in CO2 levels by 2020, 50% by 2030, and an 80% reduction by 2050 (compared to 1990). The decentralisation of energy supply structures is also considered vital. Stronger temporary incentives should be provided in order to achieve a breakthrough in the fields of energy efficiency and solar energy. Increase energy efficiency on the demand side. Develop eco taxes. Implement a system of tradable emission permits. Establish an Energy Efficiency Fund. Introduce an integrated research, demonstration and further education programme on "Efficient and Cost-Effective Electricity Use". Promote the retrofitting of existing buildings with thermal insulation materials and to introduce efficient space heating and water heating technologies. A variety of regional energy generation sources should be fostered. A research and education initiative should be launched, centred on energy efficiency aspects and renewable energy sources.
- **Transport.** "Sustainable Mobility" should be the subject of further research.
- **European policies** Create energy markets with transparent and equal framework conditions and systematically to remove obstacles that impede the substitution of efficient technologies for energy. EU legislation should be amended to include the promotion of efficient and renewable energy. EURATOM should be terminated. The EU enlargement states should be supported in energy terms and nuclear power phased out in those states.
- **International policies** The industrialised nations should develop a special partnership with developing countries, newly industrialised countries and countries in transition; the industrialised countries should set an example and play a pioneering role in the design and development of future energy supply systems. National efforts should be supported by a transfer of funds, technology and know-how to other countries. This will also help develop export markets. An initiative should be launched to export renewable energy and efficiency technologies to developing and newly industrialised countries. Renewables and efficient technologies should also play a greater role in the framework of development co-operation and project funding programmes. Co-operation with today's and future energy-supplying countries and regions will play an important role. Due to the global energy markets, the world has become highly interdependent. As a result, political instabilities in energy-supplying countries and regions can have major economic and political repercussions on a global scale. The primary concern is the consequences of price turbulences for the increasingly integrated world energy markets. The promotion of co-operation to preserve economic and political stability and to foster a sustainable development in the energy-supplying regions, as well as helping countries cope with the economic and political consequences of a global transition to more efficient and renewable energy supply systems give rise to a new foreign-policy dimension in energy policy.

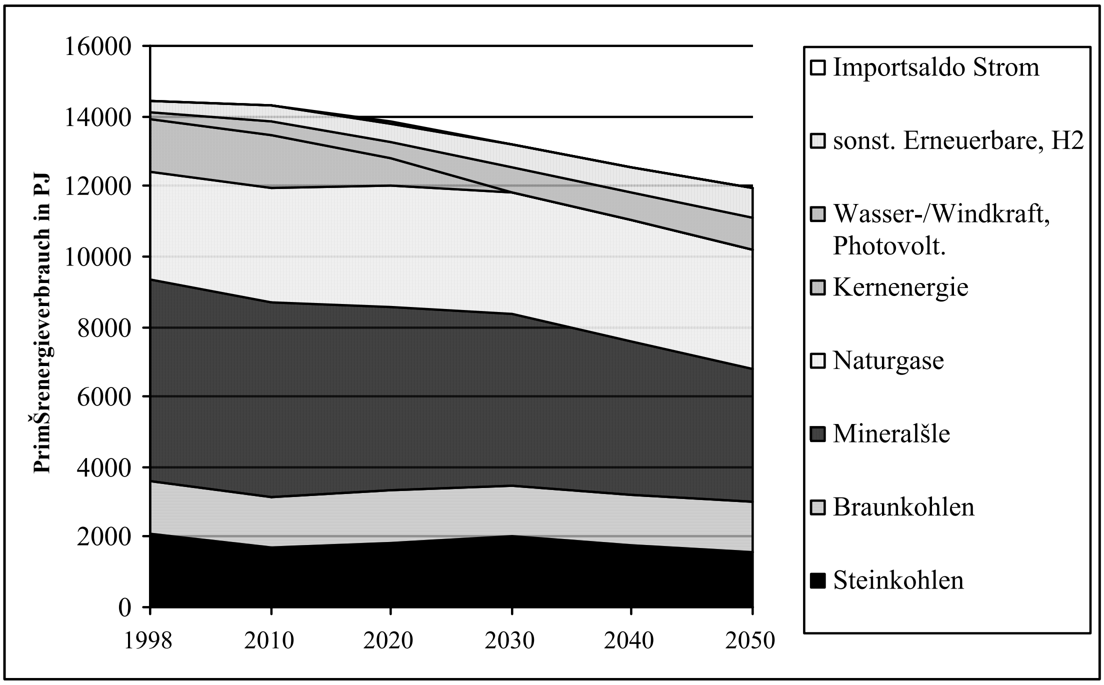

Chart 1-4 REF-IER primary energy demand in PJ (Reference Scenario)

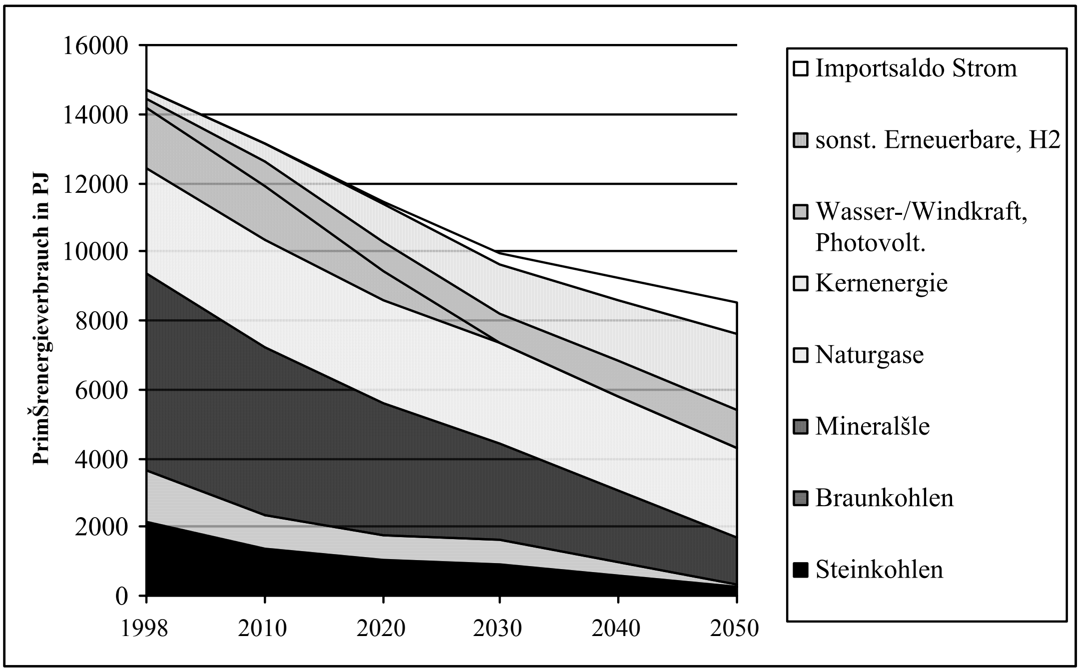

Chart 1-5 RRO-WI primary energy demand in PJ (Scenario of the RES/EEU Initiative)

3rd LAMNET Workshop – Brazil 2002

Sugarcane as a Perfect Biomass for Energy

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Liquid Biofuels in Brazil

ABSTRACT: This paper seeks to show the evolution of both the production and use of ethanol in Brazil, characterizing its importance among the liquid fuels in the country. At the same time, it qualifies the competitiveness of ethanol in Brazil under the current conditions, presenting the positive externalities of the renewable product and scenario-based demand projections. At the end, it seeks to characterize the fundamental works on the consolidation of ethanol as an international commodity.

It was only in the 20th century when liquid energy was effectively used in vehicles, where ethanol, as a fuel, was the basis for the studies of the German inventor Nicolaus August Otto at the end of 19th century. The production and use of ethanol in Brazil was all based on the competitive culture raw material sugar cane, the main product of which in the beginning of the 20th century was sugar, and ethanol was already a balance factor for the overage of that raw material in face of the limitation of the Brazilian internal market. This strategy yielded good results for the development of today´s modem Brazilian renewable ethanol as a fuel and gave high competitiveness level for the sugarcane of the agribusiness sector.

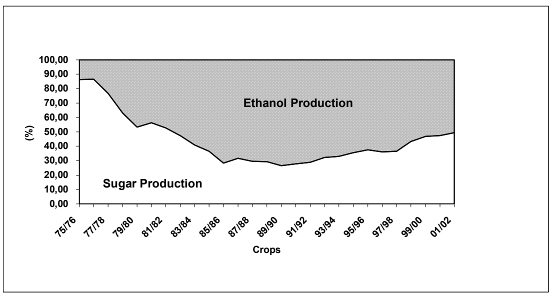

Figure 1: Sugarcane: Sugar and Ethanol Production in Brazil

The short history of the liquid energy in Brazil (one century), renewable ethanol in this case, had two clear development phases: a) The use of anhydrous alcohol as a gasoline additive (since 1920) for the various kinds of vehicles (now 60% of the total); b) The use of hydrated alcohol as the sole fuel in dedicated vehicles (now 40% of the total).

Today, Brazil has around 19 million vehicles running with Otto Cycle engines (gasoline and ethanol), where, roughly, 16 million are "gasohol" and 3 million are ethanol driven cars.

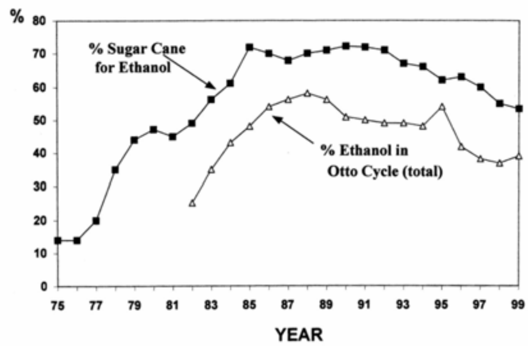

Figure 2: Ethanol and Gasoline Utilization

As it is possible to see, the importance of ethanol in the consumption of fuels in Brazil is highly relevant. Today it represents 40% of the Otto Cycle, after having reached nearly 60%.

Anyway, Brazil is a continental country where highways are extremely important, that is, gasoline (with ethanol), ethanol and diesel have a great impact on the national development. The advantages as a gasoline additive when compared with MTBE are clear:

a) Approximately twice as much oxygen; b) Greater latent vaporization heat; c) Better octane rating; d) Less air required for combustion; e) Lower reactivity in the atmosphere; f) Lower toxicity; g) Biodegradability in water and soils; h) No highly offensive odor; i) Produced from renewable raw materials; j) It consumes (by substituting for gasoline) a lot less CO_2 than it gives out (in the case of Brazil, uptake 20% from all CO_2 emitted by the fuel cell products).

The evolution of both the production and consumption of alcohol in Brazil shows the times of transition from the present reality:

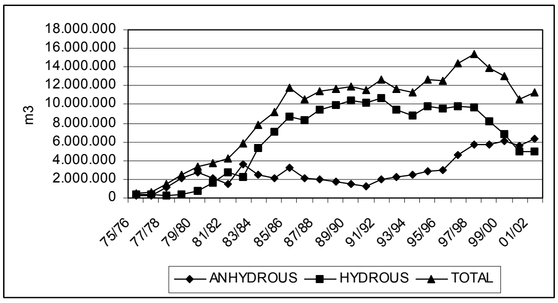

Figure 3: Ethanol Production in Brazil

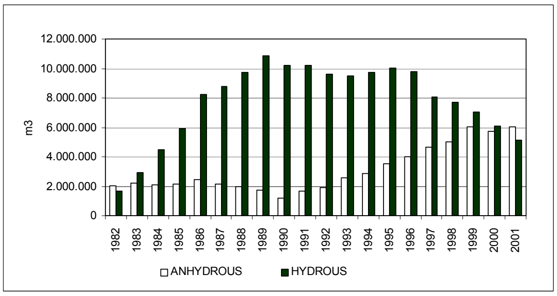

Figure 4: Fuel Ethanol Consumption in Brazil

There are two explanations for the consumption curves: while the anhydrous ethanol consumption increases in the face of the increase in both gasoline car sales and the percentage of anhydrous ethanol content of gasoline, the demand for hydrous ethanol falls in the face of the scrapping of the ethanol fleet.

As to the ethanol fleet, sales have been experiencing growth since 2001, regardless of the lack of policies to support it.

It is important to point out the main efforts in the USA (Illinois) and Europe (Sweden), which are also shared in Brazil, in testing fleets for the use of ethanol directly in diesel (with additive) or in biodiesel (seed oil transesterified with ethanol). The sugar cultures currently rule the ethanol production market worldwide.

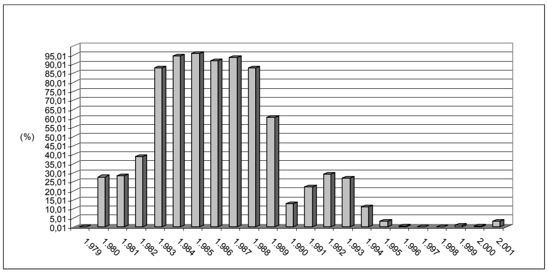

Figure 5: Brazil – Ethanol Cars and Light Commercial Cars: Sells in the Internal Market

Table 1: World Ethanol Production(1) by Feedstock

Feedstock	%
Sugar Crops	59
Grain	32

Note: (1) 31 bln liters in 2001
Source: Berg, C, The Outlook for the World Sugar and Molasses Market, Power Crops for the Americas, Miami, April/2002

The maintenance, expansion of or the resource for this trend in the future will depend on the competitiveness degree of the raw materials, the availability and potential of the lands for production, and the global and national public policies implemented.

This is an extremely relevant point for the future of the biomass as a liquid fuel. The competitors, in this case, would be gasoline and diesel. In the case of gasoline, its current international price (N.Y. base) is US$ 32 per barrel at the Brazilian refinery; the current cost of anhydrous alcohol at the Brazilian producer is also US$ 32 per barrel:

Table 2: Ethanol´s Competitiveness - Brazil

US$ 1 = R$ 2,50	Anhydr. Ethanol	
Producer – Sale Price (R$/l)	0,60	
Producer – Cost Price (R$/l)	0,50	
(US$/l)	0,24	0,20
(US$/b)	38,00	32,00
Base Relation (ethanol/gasoline)	1..00	
Gasoline Price (International Price) (US$/b)	32.00	
Gasoline Sales´ Price in Brazil (US$ / b)	64.00	

In the Brazilian case, the efficiency gains and cost reductions achieved since 1975 (in large scale), between 2 and 3% per year (average), are related to the well-known "learning curve":

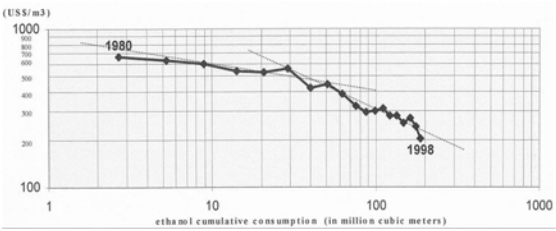

Figure 6: Ethanol Cost "Learning Curve"

The expectations for the future are promising. On the one hand, because the countries' maturation on the planet heating issue and the importance of the transportation sector in this matter (>50%); on the other hand, due to the investments in R&D&D, which are making ethanol and biodiesel viable. In the Brazilian case, there are two scenarios in discussion for the case of ethanol:

a) Continuity, that is, with sales of ethanol driven cars near zero:

Table 3: Scenario 1: Fuel Ethanol Consumption without Ethanol Car Sales (bi l)

Crops	Anhydr.	Hydrous	Total
98/99	5,69	7,33	13,02
99/00	5,93	6,98	12,91
00/01	5,43	5,86	11,29
01/02	5,40	5,23	10,63
02/03	6,58	4,72	11,30
05/06	7,83	2,93	10,76
10/11	9,82	0,77	10,59

b) With ethanol car sales of around 15%, including, in this case, new technologies like the FFV (flexible fuel vehicles) for ethanol (100% ethanol or 100% gasoline or the desired percentage):

Table 4: Scenario 2: Fuel Ethanol Consumption with Ethanol (± 15%) or FFV Car Sales (bi l)

Crops	Anhydr.	Hydrous	Total
98/99	5,69	7,33	13,02
99/00	5,93	6,98	12,91
00/01	5,43	5,86	11,29
01/02	5,40	5,23	10,63
02/03	6,58	4,72	11,30
05/06	7,,49	4,53	12,02
10/11	8,93	6,02	14,95

The analysis of the differences between the scenarios points to over 4 billion liters in 2010, which is relevant.

The differentiated policies for alcohol are justified by the positive externalities of the product when it is compared with the fossil competitor.

There are various positive externalities of ethanol in Brazil. Two very objective examples are the number of jobs created by the kind of vehicle produced (gasohol or ethanol ones) and the CO_2 uptake by the "sugar cane system" in Brazil:

Table 5: Employments in the Production of the Vehicle and of Fuel Men-Year per Thousand Vehicles

Men Year Generated	Ethanol Vehicles	"C" Gasol. Vehicle	"A" Gasol.Vehicle
Vehicle Production	51,3	51,3	51,3
Fuel Production in 15 years of Average Life	1.482,0	369,9	18,8
Total Employments	1.533,36	421,2	70,1
Ratio of Employments per Type of Vehicle	21,87 (1)	6,01	1 (2)

(1) Considering that an alcohol driven vehicle consumes, on average, 2.600 liters of hydrated alcohol p/y, during average work life of 15 years, and that the production of one million liters of alcohol p/y, generates 38 direct employments on average in Brazil.
(2) Considering that a gasoline driven vehicle spends 20% less fuel than a similar alcohol vehicle, and that the production of one million liters of gasoline p/y generates 0.6 direct employments in the country. (Petrobrás had 41,173 employees in 1997, extracting 1 million barrels/day of petroleum and refining 1.45 million).

Souce: UNICA/ANFAVEA/Matriz Energética/Petrobrás

Table 6: Net CO_2 Balance in Brazil (1996)

	10^6tc (equiv)/year
• Fossil fuel utilization in the agri-industry	+ 1.28
• Methane emissions (sugarcane burning)	+ 0.06
• N_2O emissions	+ 0.24
• Ethanol substitution for gasoline	- 9.13
• Bagasse substitution for fuel oil (food and chemical industry)	- 5.20
• Net contribution (carbon uptake)	- 12.74

Source: Macedo, Isaias (1997)

Table 5 showed that what would be 1 job per vehicle (if Brazil had gasoline driven cars) means actually 6 jobs (because Brazil uses gasohol), and that there are 22 jobs/car when alcohol is the fuel.

Table 6 shows a CO_2 uptake that is equivalent to more than 20% of all of the CO_2 emitted by oil derivatives in Brazil.

The automobile issue in Brazil, as well as in other countries, indeed deserves global analyses.

In the case of Brazil, it was learned that, for a future in which hydrogen (and ethanol!) cars will prevail, flexibility is the magic word in the transition, not to mention the success of E 100 cars (having alcohol as the sole fuel).

The following points will be fundamental to the intended evolution:

1) Variation of the anhydrous ethanol level in gasoline

In Brazil, the band that defines by law the level of anhydrous ethanol in gasoline ranges between 19 and 26%. This is an important supply and demand balancing mechanism that allows a flexible production.

2) Flexible fuel vehicles that work with any gasoline (E22) and hydrous ethanol mixtures

- Serving the consumer, who will be able to choose the fuel having a lower price or better performance;
- Technology already known (± 1.8 million vehicles in the USA);
- For the technology currently used in Brazil (stoichiometric mixture and 3-way catalyst), it would be an intelligent commitment solution between ethanol and gasoline (compression rate ~ of ethanol).

3) Stakeholders

The automobile assembling industries, autopart manufacturers, technology institutes and governmental agencies should combine their efforts to introduce solutions that meet the interests of consumers while defending the interests of the country and preserving the environment. It recommends government coordination.

4) R&D&D

Investment in R&D&D in the production and use areas.

5) International Mechanisms

Having international mechanisms to turn bio-fuels into commodities, with futures contracts in Stock Exchanges, with price and volume reference.

Additional information is provided in the Power Point Presentation Viewgraphs available at the LAMNET project web site:

www.bioenergy-lamnet.org/events/events.html.

3rd LAMNET Workshop – Brazil 2002

Densification of Biomass Vegetable Residues

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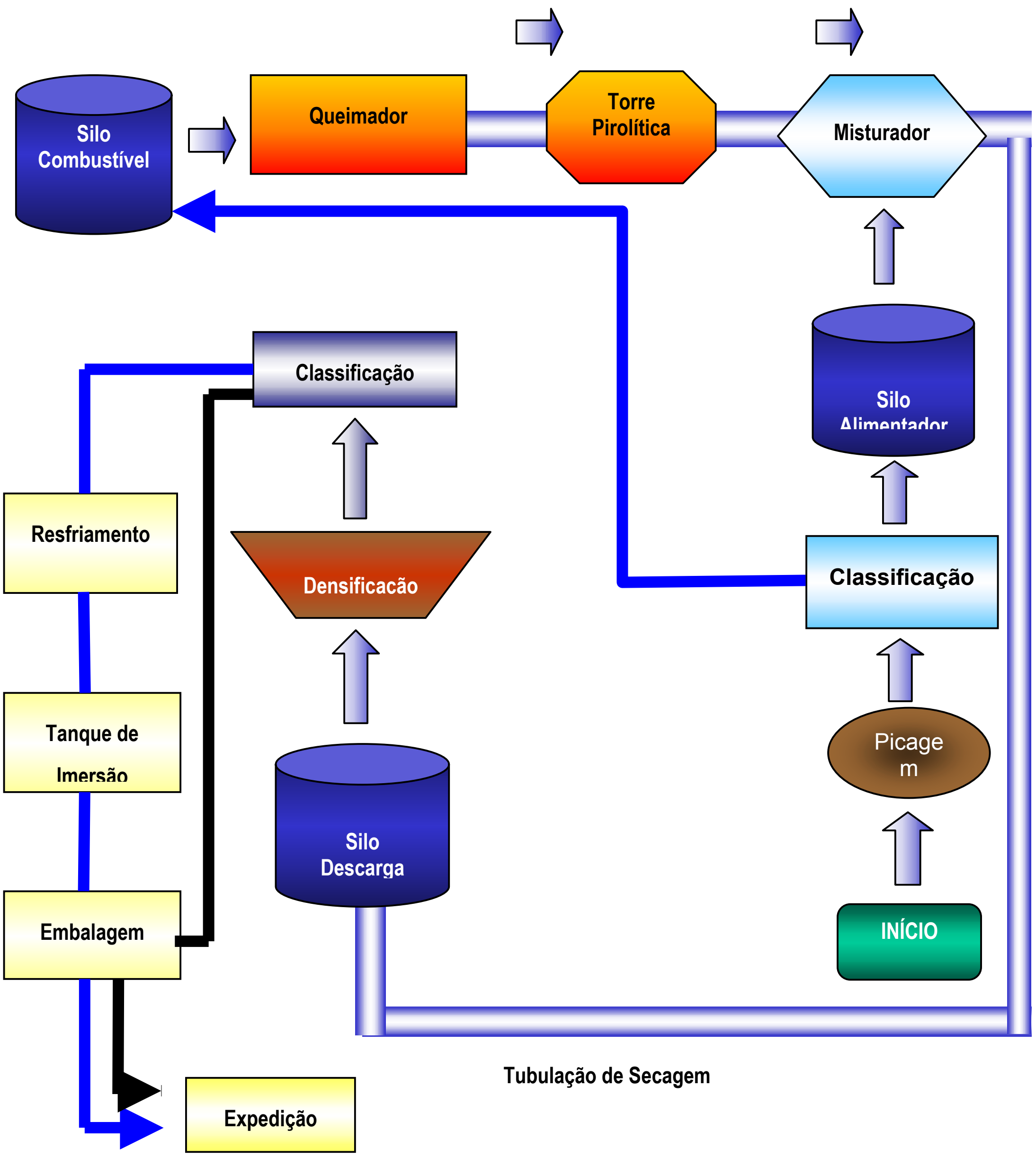
Flow Diagram of the Bio Energy Densification Process

Additional information is provided in the Power Point Presentation Viewgraphs available at the LAMNET project web site **www.bioenergy-lamnet.org/events/events.html**.



3rd LAMNET Workshop – Brazil 2002

Discussion Round: Impact of the World Summit on Sustainable Development in Johannesburg on the Future of Bioenergy

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The moderator Prof. José Moreira, CENBIO, led the audience of about 50 people through this round table discussion, introduced the speakers and co-ordinated the questions and discussions.

The round table discussion started with introductory statements by the panellists:

Prof. Suani T. Coelho, Executive Assistant – Secretary of State for the Environment, Brazil

Prof. Coelho presented a brief overview on the Impact of the World Summit on Sustainable Development (WSSD) in Johannesburg, August 28th to September 4th, on the Future of Bioenergy. As Executive Assistant of the Secretary of State for the Environment of São Paulo State she had been member of the Brazilian delegation at the summit.

The focus of the World Summit with participants from more than 170 countries was an assessment of the status of Agenda 21 implementation as well as the Millenium Goals 'eradication of social exclusion', 'poverty alleviation' and 'environmental sustainability'. With respect to energy policies there are only 3 possible approaches to reach these goals: new technologies, energy efficiency and renewable sources.

The main issues discussed at the WSSD with respect to energy policies were the sustainability of large hydro projects, traditional biomass utilisation (mainly fuelwood) and nuclear energy. Considerable disagreement existed concerning the set-up of ambitious targets and timeframes as well as the cost-effectiveness of renewable technologies.

Two main energy initiatives were proposed at the World Summit being the Brazilian Energy Initiative *to increase the global share of renewable energy to 10% by 2010* (supported by Latin American and Caribbean countries) and an initiative presented by the European Union which aimed to *Diversify energy supply by developing cleaner, more efficient and innovative fossil fuel technologies, and by increasing the global share of renewable energy sources to at least 15% of global total primary energy supply by 2010.* The latter proposal included large hydro and traditional biomass and therefore was a very modest proposal practically to be seen as a business as usual approach. Both initiatives were not adopted by the summit due to strong opposition by the US, Japan, Korea, Australia, Russia as well as the OPEC countries and the final approved text reads as follows:

Diversify energy supply by developing advanced, cleaner, more efficient, affordable and cost-effective energy technologies, including fossil fuel technologies and renewable energy technologies, hydro included, and their transfer to developing countries on concessional terms as mutually agreed. With a sense of urgency, substantially increase the global share of renewable energy sources with the objective of increasing its contribution to total energy supply, recognising the role of national and voluntary regional targets as well as initiatives, where they exist, and ensuring that energy policies are supportive to developing countries' efforts to eradicate poverty, and regularly evaluate available data to review progress to this end.

The shortcomings of this text in the view of renewable energy supporters were the inclusion of nuclear technologies and large hydro without environmental constraints and the exclusion of quantified targets and timeframes.

On the other hand '*the substantial increase of the global share of renewable energy sources*' '*with a sense of urgency*' marks a progressive point of no return realised through the continuous pressure by environmentalists, the press and private companies. Additionally, regional initiatives by Latin American and European countries will in future strengthen the role of renewables and the World Summit has provided new impulses to the Kyoto commitment and it has broadened the discussion on sustainability.

The impact of WSSD on renewable energies can be summarized as follows:

- a **new target-oriented approach**: bottom-up and voluntary, building upon national and regional targets and goals, including a review process;
- integration of **renewables and energy efficiency** within national or regional sustainable development strategies;
- improved access to **financial resources and services**;
- promotion and follow-up on **WSSD energy partnerships**;
- enhanced **international co-operation**, through innovative modalities to implement adequate public policies to promote renewable energy;
- **role** of incentives, public-private partnerships, Clean Development Mechanism (CDM); and the
- **economic viability** of renewables.

Dr. Wolfgang Palz, Member of the World Council of Renewable Energies, Germany

Dr. Palz reported on recent initiatives in the European Union in the field of bioenergy. The European Commission has adopted an action plan and two proposals for Directives to foster the use of alternative fuels for transport, starting with the regulatory and fiscal promotion of biofuels. The Commission considers that the use of fuels (such as ethanol) derived from agricultural resources (i.e. biofuels) is the technology with the greatest potential in the short to medium term. The action plan outlines a strategy to achieve a 20% substitution of diesel and gasoline fuels by alternative fuels in the road sector by 2020.

Additionally, the German Government discusses a 100% tax exemption for alternative fuels which is currently being checked by the Competition Directorate General of the European Commission and in Germany an influential group has formed, consisting of the global players DaimlerChrysler and Volkswagen as well as the German Association of Farmers, engaged in the promotion of biofuels. Furthermore, strong cooperation links are being established with Brazil in order to benefit from its long-term experience in the field of bioethanol production.

Finally, the German Chancellor Schröder has anticipated the organisation of a World Conference on Renewable Energies in Berlin in 2003 as a follow-up of the measures initiated at the WSSD.

Hon. Rivacoba, Ambassador of Cuba in Brazil

Hon. Rivacoba stated that it is of utmost importance to keep in mind all aspects of the broad concept of sustainable development including the distribution of wealth, the condition of life and the international economic relationships. The Millenium Development Goals which formed the heart of the WSSD can be summarised as follows:

- ensure environmental sustainability
- eradication of extreme hunger and poverty
- reach a minimum primary education with equal opportunities
- reduce child mortality, specially of AIDS and malaria
- improve life conditions of the more needed ones
- increase access to potable water

- develop a global partnership to development that includes non-discriminatory international systems of trade and finance, suitable to the special needs of developing countries, alleviating their debts, providing jobs and access to medicines and new technologies

Hon. Rivacoba stressed the opportunity which modern sugar cane technologies can offer to countries such as Cuba in order to reduce their dependence on imported oil and to guarantee the national security of energy supply. Therefore, international cooperation aiming at technological support and business relationships with countries like Brazil are very important for sustainable development in Cuba.

Harry Lehmann, Former Member of the German Enquete Commission on Energy, Germany

Mr. Harry Lehmann presented a different view on the strong opposition to quantified targets and timeframes for renewable energies by countries such as the US, Japan, Korea, Australia, Russia and the OPEC. He claimed that this lack of consensus will provide opportunities to those countries dedicated to the promotion of renewable energies whereas in the case of a broad consensus 'the slowest ship would make the pace'. Today, there is no doubt about the supporters and opponents of a stronger role of renewable energies and partnerships can be formed along these lines. As renewable energies are among the key technologies for the 21st century a head-start may well soon turn into considerable business opportunities.

Nevertheless, Mr. Lehmann pointed out several dangers with respect to the present approach towards renewables. Today, the focus is placed on cheap and easy-to-handle technologies whereas in the year 2020 the world will most probably need all renewable technologies in order to cover the growing energy demand. Moreover, a shift towards very large projects (e.g. CDM/JI projects) is currently underway whereas often smaller projects are more likely to guarantee truly sustainable development.

Mr. Lehmann concluded that today effective networks as well as strong regional, national and international initiatives and cooperation schemes have to be formed which are dedicated to the substantial increase of the global share of renewable energy sources.

Dr. Giuliano Grassi, Secretary General of the European Biomass Industry Association

Dr. Grassi highlighted the opportunities offered by modern bioenergy technologies for sustainable development such as the integrated production of food, animal feed and energy.

This integrated bioenergy complexes, based on the exploitation of sweet sorghum for the production of bioethanol and other energy/industrial commodities, offers a sustainable path for the production of bioethanol, which is considered a strategic fuel for the transport sector. Such complexes may be implemented in China and other regions on a large scale. The economic viability of these bioenergy complexes has been demonstrated and past studies have shown the high yields of sweet sorghum in terms of grains, sugar and bagasse in different climatic belts.

These bioenergy complexes will provide numerous diversified jobs to village inhabitants. The outputs of the various products (i.e. grains, liquid sugar, electricity, heat, bioethanol, charcoal, MHV gas, CO2-dry ice, pellets) will exceed the needs of the local village and sales of these commodities will serve as significant income surplus.

Finally, it has been estimated that these bioenergy complexes require investment costs of approximately 1500 $ per person. This rather small amount of money can change the life of villagers and significantly contribute to the achievement of the Millenium Goals towards Sustainable Development.

Tuesday Afternoon Session: Biofuels and Sustainable Electricity Generation in Latin America

3rd LAMNET Workshop – Brazil 2002

Innovative Fuels and Biomass Resources

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Future alternative fuels should offer the possibilities to be used as the current fuels within the existing infrastructure, to contribute to the reduction of greenhouse gases, to promote the development of new technologies of the recent combustion systems and energy generation (i.e. fuel cells), to be affordable, sustainable and they should be renewable. Moreover, they have to ensure a safe supply within the regional and global markets.

Biomass can be considered as the best option and it has the largest potential, which meets these requirements and could insure fuel supply in the future. Plant oils, bio diesel, biogas and ethanol have been successfully introduced and are already in use. Innovative synthetic fuels are related to aspects and the new developments in conversion technologies of lignocellulosic to fuels: Gasification, pyrolysis and upgrading to gasoline, diesel and hydrogen, methanol, DME as well as the possibilities of their generation from biomass.

Fuels derived from biomass are not only potentially renewable, but they are also sufficiently similar in origin to fossil fuels in order to provide direct substitution opportunities. They can be converted into a wide variety of energy carriers (biogas, biodiesel, ethanol, methanol, DME, diesel, gasoline, hydrogen) as of recent fossil fuels through conversion technologies, and thus have the potential to be significant new sources of energy for the 21st century (Fig. 1).

The input/output energy balance ratio may reach up to 1:25. The CO_2 mitigation potential of energy crops as energy sources is considerably large. Data related to global conversion of solar energy to biomass are summarised in table 1 and the possible contribution of biomass in future global energy supply is given in table 2.

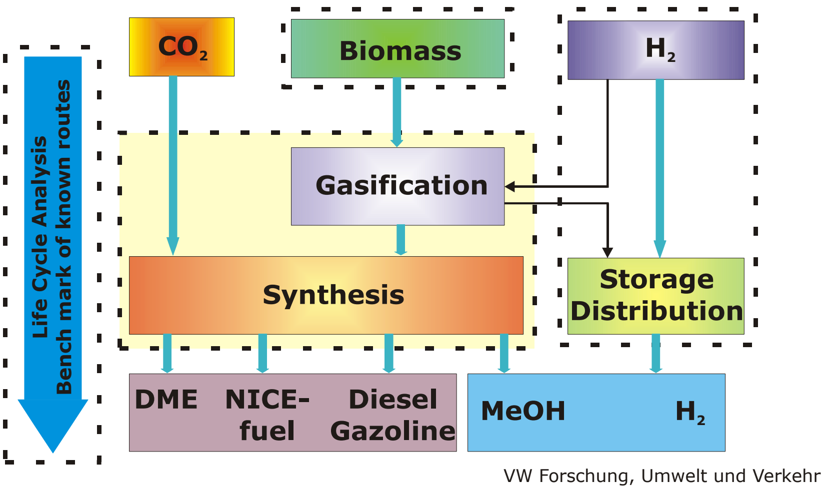

Figure 1: Pathways to Renewable Fuels (from plant to tank)

1000 kWh is 3.6 GJ and 1 ha is 10 000 m², so the total annual energy is	36 000 GJ
One third of this delivered during the growing period	12 000 GJ
20% of which reaches the growing leaves	2 400 GJ
After a further loss of about 20% by reflection	2 000 GJ
50% of this is photosynthetically active radiation	1 000 GJ
30% of which is converted into stored energy	300 GJ
But 40% is consumed in sustaining the plant, leaving	180 GJ
Corresponds to	10 t ha^{-1} y^{-1} GJ

Table 1: Conversion of Solar Energy (Annual Energy Delivered by Solar Radiation is 1000 kWh m^{-2} y^{-1}. ha^{-1})

Scenario	**Year of Scenario**		
	2025	2050	2100
IEA (1998)	60*	--	--
IIASA/WEC (1998)	82**59***	153** 97***	316** 245***
Shell (1996)	85	200-220	--
IPCC (1996)	72	280	320
Greenpeace (1993)	114	181	--
Johansson *et al* (1993)	145	206	--
WEC (1993)	59	94-157	132-215
Dessus *et al* (1992)	135	--	--
Lashof and Tirpak (1991)	130	215	--

** 2020 (Total primary energy supply)*
*** Scenario A3 (High growth – biomass and nuclear)*
**** Scenario C1 (ecologically driven - large renewables, no nuclear)* **Source: Hall (1999)**

Table 2: The role of modernized biomass in the future global energy use (Present biomass energy use is about 55 EJ/year)

Biomass can be considered as a source for carbon and hydrogen (table 3). The possible outcome of oil from biomass depends on the productivity of energy plants and up to 9000 l oil through modern conversion technologies from one hectare could be achieved (table 4).

Fuel	*Ratio of atoms*			*% by weight*		
	C	H	O	C	H	O
Coal	1	1	<0.1	85	6	9
Oil	1	2	0	85	15	0
Methane	1	4	0	75	25	0
Wood	1	1.5	0.7	49	6	45

Table 3: Proportions of carbon, hydrogen and oxygen in fuels

Biomass Yield (t ha^{-1}. y^{-1}. kg^{-1})	Energy content *(MJ . kg^{-1})*	*eta Conversion Efficiency*	*Fuel Yield (t. ha^{-1}. y^{-1})*	*Fuel Yield (l. ha^{-1}. y^{-1})*
10	*17,5*	*0,48*	*1,9*	*2448 (3000)*
20	*17,5*	*0,48*	*3,8*	*4895 (6000)*
30	*17,5*	*0,48*	*5,7*	*7343 (9000)*

Table 4: Fuel yields from biomass

More than 100 plant species have been identified for different region of the world to serve as biomass sources for biofuels. A summery of energy plant species which could be grown under various climatic conditions have been documented in the tables 5-7.

Table 5: Representative energy plant species for different climate (temperate climate)

- Cordgrass (*Spartina spp.)*
- Fibre sorghum *(Sorghum bicolor)*
- Giant knotweed (*Polygonum sachalinensis)*
- Hemp (*Cannabis sativa)*
- Kenaf (*Hibiscus cannabinus)*
- Linseed (*Linum usitatissimum)*
- Miscanthus *(Miscanthus x giganteus)*
- Poplar *(Populus spp.)*
- Rape *(Brassica napus)*
- Reed Canary Grass (Phalaris arundinacea*.)*
- Rosin weed *(Silphium perfoliatum)*
- Safflower (*Carthamus tinctorius)*
- Soy bean (*Glycine max)*
- Sugar beet (*Beta vulgaris)*
- Sunflower (*Helianthus annuus)*
- Switchgrass *(Panicum virgatum)*
- Topinambur *(Helianthus tuberosus)*
- Willow *(Salix spp.)*

Table 6: Representative energy plant species for different climate (aride and semiaride climate)

- Argan tree (*Argania spinosa)*
- Broom (Ginestra) *(Spartium junceum)*
- Cardoon (*Cynara cardunculus)*
- Date palm (*Phoenix dactylifera)*
- Eucalyptus (*Eucalyptus spp.)*
- Giant reed (*Arundo donax)*
- Groundnut *(Arachis hypogaea)*
- Jojoba *(Simmondsia chinensis)*
- Olive (Olea europaea*.)*
- Poplar *(Populus spp.)*
- Rape (*Brassica napus)*
- Safflower (*Carthamus tinctorius)*
- Salicornia (*Salicornia bigelovii)*
- Sesbania (*Sesbania spp.)*
- Soybean *(Glycine max)*
- Sweet sorghum *(Sorghum bicolor)*

Table 7: Representative energy plant species for different climate (aride and semiaride climate)

- Aleman Grass (*Echinochloa polystachya)*
- Babassu palm *(Orbignya oleifera)*
- Bamboo (*Bambusa spp.)*
- Banana (*Musa x paradisiaca)*
- Black locust (*Robinia pseudoacacia)*
- Brown beetle gras (*Leptochloa fusca)*
- Cassava *(Manihot esculenta)*
- Castor oil plant *(Ricinus communis)*
- Coconut palm (*Cocos nucifera)*
- Eucalyptus *(Eucalyptus spp.)*
- Jatropha (*Jatropha curcas.)*
- Jute *(Crocorus spp.)*
- Leucaena (*Leucaena leucoceohala)*
- Neem tree (*Azadirachta indica)*
- Oil palm (*Elaeis guineensis)*
- Papaya (*Carica papaya.)*
- Rubber tree *(Acacia senegal)*
- Sisal *(Agave sisalana)*
- Sorghum *(Sorghum bicolor)*
- Soybean *(Glycine max)*
- *Sugar cane (Saccharum officinarum)*

Figure 2 shows the energy plantation of the Federal Agricultural Research Centre (FAL) which represents the "Oilfields of the 21st century.

Figure 2: A VW car fuelled with "SunFuel" from biomass on the energy plantation of FAL.

Summery and Perspectives

- Annual primary biomass production: 220 billion DM, 4,500 EJ = 10 times of world primary energy consumption.
- Biomass used for food: 800 millions DM = 0.4% of primary biomass production.
- Annual food production corresponds to 140% of the needs of world population.
- Biomass currently supplies 14% of the worldwide energy consumption. The level varies from 90% in countries such Nepal, 45% in India, 28% in China and Brazil with conversion efficiency of less than 10%. The potential of improving is efficiency through novel technologies is very high.
- Large areas of surplus of agricultural in USA, EU, East Europe and former soviet countries and could become significant biomass producing areas (> 200 millions ha).
- Microalgae have the potential to achieve a greater level of photosynthetic efficiency than most other forms of plant life. If laboratory production can be effectively scaled up to commercial quantities levels of up to 200 mt/ha/yr may be obtained.
- The efficiency of photosynthetic is less than 1%. An increase in this efficiency (through genetic engineering) would have spectacular effects in biomass productivity: successful transformation of C_4-mechanism (from maize) to C_3-crops (rice). New achievement in accelerating cell division opens opportunities to speed up the growing seasons, resulting in several harvests per year and an overall increase in biomass.
- Developments in car technologies is leading to significant reduction in fuel consumption, i.e. less areas will be needed for more cars.

Conclusion

Of all options, biomass represents the largest and most sustainable alternative to substitute fossil transport fuels as "Win-Win" strategy.

Reference

El Bassam, N. (1998) Energy plant species: Their use and impact on environment and development. James&James Science Publishers, UK.

Additional information is provided in the Power Point Presentation Viewgraphs available at the LAMNET project web site **www.bioenergy-lamnet.org/events/events.html**.

3rd LAMNET Workshop – Brazil 2002

Ethanol Potential in Costa Rica

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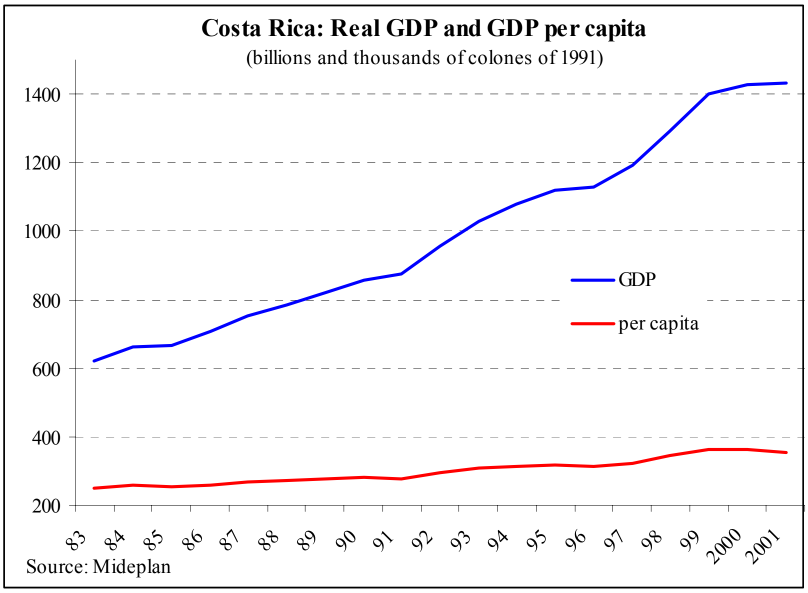
Section 1: Some economic and social figures: from the crisis to a new economy based in exports and tourism[7]

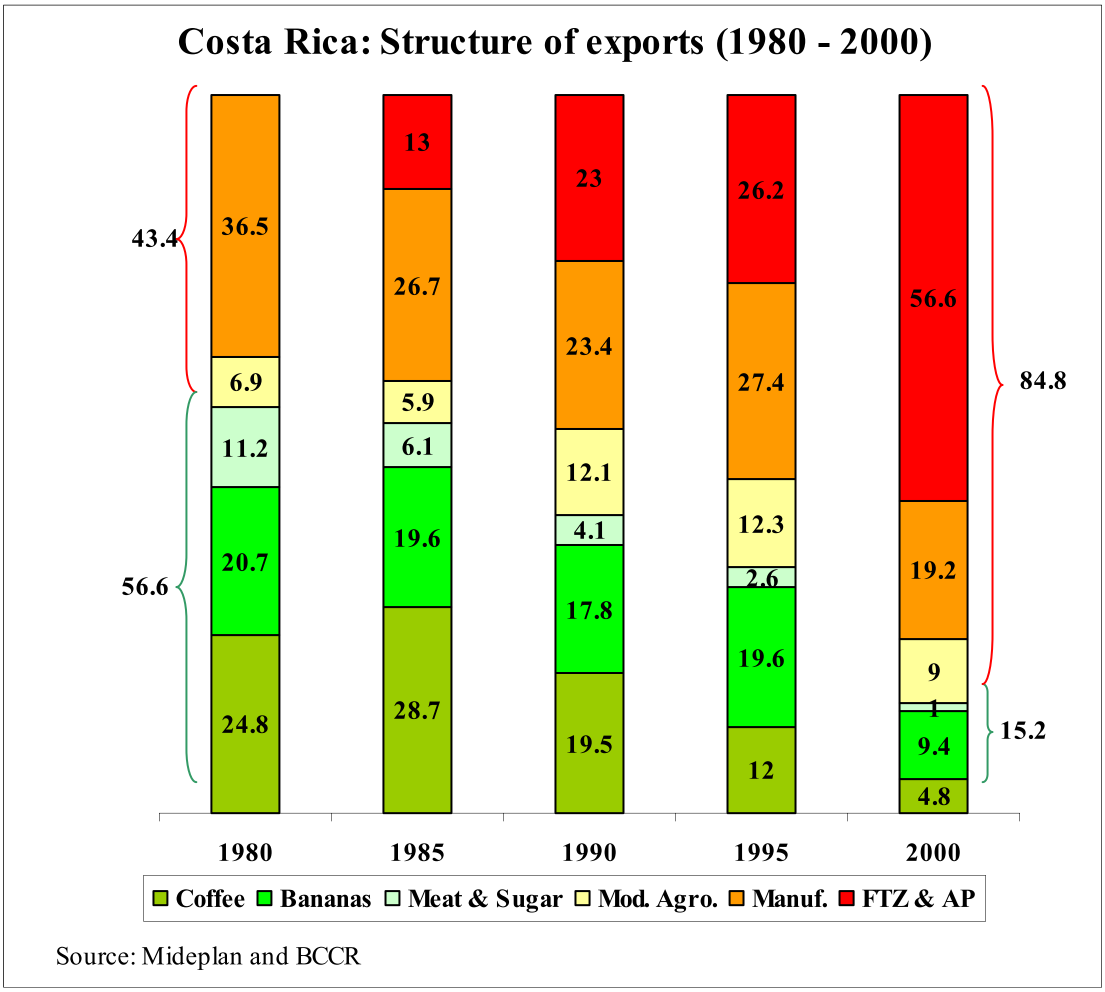
Since the beginning of the seventies, the Costa Rican economy has been strongly affected by external shocks by the international oil market. An small economy, basically driven in the external sector by basic tropical commodities like coffee and bananas, was and will always be affected by global energy crises. During the eighties and the nineties, the economy has been diversifying into more industry based free zone facilities, tourism and non-traditional agricultural products. All these diversification of the economy has implied important changes in energy uses and demands.

In spite of the severity of the crisis at the beginning of the eighties, stabilization was particularly successful, as it took only two years to control most of the basic macroeconomic and social disequilibria. A combination of factors made possible such a rapid recovery, ranging from a very able management of stabilization policies by the government – both in economic and political terms – to a significant amount of foreign aid, that came to support Costa Rica's efforts at a time Central America was going through a critical period. Most impressive, however, was the fact that Costa Rica's stabilization process in the post-crisis years, as well as the process of structural adjustment that followed, while generally in line with the strictures of fiscal and external responsibility imposed by both crisis and adjustment, did not follow the typically recessive and regressive recipes then en vogue.



[7] This section is based in the report Costa Rica within the 'New Economy: The Role of Education, Training and Innovation Systems, de Garnier, Leonardo 2002.

But it was not just that the economy was growing again, that employment, incomes, investment and consumption were growing again, but that this was happening through a complex, not always consistent and, sometimes, even contradictory process of structural adjustment, through which Costa Rica's economic and social structure, as well as its institutional setting, were gradually being transformed. This transformation was particularly evident in the structure of Costa Rica's exports, which had been historically concentrated in a few traditional agricultural products. As the next graph shows, coffee, bananas, meat and sugar represented, as late as 1980, almost 57% of Costa Rica's exports, while 36% were manufacturing exports, mostly to the Central American Common Market and which, being highly dependent on heavy tariff protection, could hardly survive international competition. In just two decades, this changed radically: by 2000, Costa Rica's traditional exports would only account for 15% of its exports.



This radical change in the structure of exports did not come as the result of a reduction in the volume or total value of traditional exports, but rather through the emergence of new exporting activities that have grown at a very rapid pace during the last two decades and, especially after the mid nineties. The problem with traditional exports remains – as in the past – one of relative prices: in fact, the amount of coffee Costa Rica exported between 1980 and 2000, doubled; but, as coffee prices almost halved in the same period, the total value of coffee exports remained basically the same in 2000 as in 1980, so that their relative importance went from 25% to a mere 5% of total exports. With bananas the situation was better: while the volume of exports also doubled during these two decades, banana prices remained relatively stable, so that total value of banana exports increased from US$207 million in 1980 to $549 million by 2000. Still, their participation was halved during that period: from 20.7% to 9.4%. The rest of Costa Rica's traditional exports – meat and sugar – went from 11% to 1% of total exports.

There were other significant changes: diversification of agricultural exports (like flowers and ornamental plants, fruits, and more exotic products like heart of palm, macadamia, asparagus, and so on); contraction of traditional manufacturing activities – whose weight in total exports went from over 36% to less than 20% - and, especially, the emergence and consolidation of new industrial activities, that came to represent about 57% of Costa Rica's total exports, that is, the same proportion that, twenty years earlier, depended on traditional agricultural exports.

But changes were not limited to Costa Rica's exporting activities. There were also significant changes in the services sector: in commerce, where traditional *pulperias* and local stores were confronted by the appearance of huge supermarkets and shopping malls; in professional services (medical, consulting, engineering, educational and so on); and, especially, in banking and financial services. Last but not least, tourism became one of Costa Rica's most important sources of income and indirect employment. These changes were clearly reflected in the changing structure of Costa Rica's labor market. People working in agricultural related activities, for one, went from 35% to 20% of the economically active population during the last quarter of the 20th century, which is rather significant for a country that, by the 1950s, was basically a rural nation, with 60% of its workers dedicated to agricultural activities.

Costa Rica: employment by sector (structure)

	1950	1976	1990	2000
Agriculture and related activities	59	35	26	20
Industrial and manufacturing activities	8	15	18	15
Construction	4	6	6	7
Basic Services	4	6	5	7
Commerce, restaurants, hotels	8	16	16	20
Financial institutions			3	5
Personal and social services	16	22	25	26
Source: MIDEPLAN (Ofiplan for 1950)	100	100	100	100

Significant as they are, however, these structural transformations have occurred in parallel with the ongoing operation of many of Costa Rica's more traditional activities. Today, Costa Rica is a much more complex society, but also one with much stronger contrasts and contradictions. Some parts of its economic and social structure, as well as some of its institutions – public and private – have changed dramatically in the last couple of decades, while others remain practically untouched.

Energy sector in Costa Rica

The transportation sector was the most important user of fuel based energy, followed by industry, residential and others. Mayor fuels used in transport are diesel and gasoline. The demand for transportation increased not only for goods (train system failed and it was close down beginning of the nineties) but also, passengers using private cars. The amount of new cars grows rapidly, just as the process of urbanization of the country.

As a result of the democratization processes in Central America and the increasing role of trade in the economy, demand for international transportation is also growing, leading to a collapse of the infrastructure build from the fifties until the eighties. The new demands for transport and air quality is increasingly putting pressure on the mayor oil refinery state company (RECOPE).

Also, the demand for environmental quality is growing. New governments are doing efforts to set rules and regulations for the petrol industry as well as the electricity sector. Even though mayor state owned sectors where privatized at the beginning of the nineties, electricity and oil oriented industry is still public oriented sector. Some space for small investors in areas like exploration and co-generation was allowed at the beginning of the nineties, but mayor reforms were block-out by civil society groups (See Vargas, 2001).

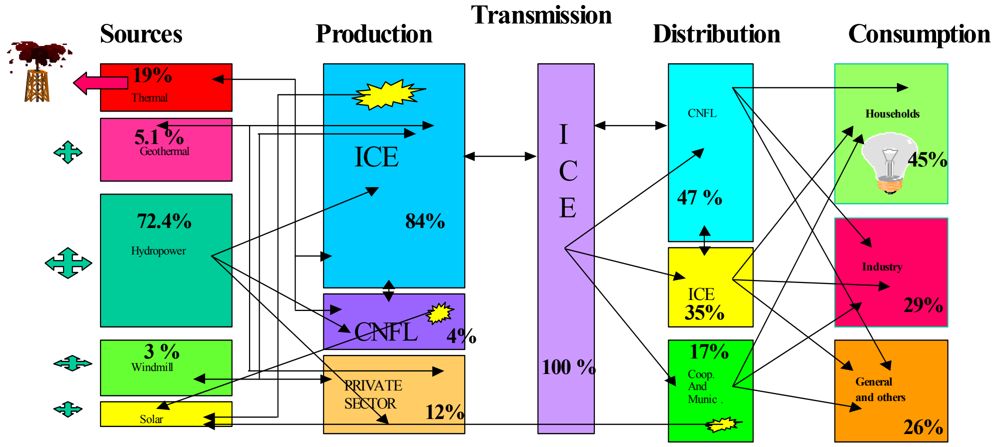
Contrary to what has been seen in other developing countries in Latin America, the Costa Rican public electricity sector has shown quite good results in all the main indicators traditionally used to measure performance. In 1949, when the National Institute for Electricity was founded, the installed capacity was 36,637 kW. At that time there were many problems related to the maintenance of the networks and the inefficiency of private local monopolies. Only major cities were electrified and some technical problems such as blackouts and quality of the power were common. In order to solve these problems, the development of infrastructure for the network and additional capacity became the priority of the new company (ICE) during its first decade.

This process of increasing the capacity was developed by means of different mechanisms, especially the use of external funding for the support and implementation of interconnection of the country with the new hydropower supply-oriented system. Since then, hydropower has been the most important source of electricity (ICE, 1996).

For example, in 1999, 19.1% of all the energy consumed in Costa Rica came from the electricity sector. Of this energy, 82% is produced by hydroelectric sources.[8] Another aspect is that the electric interconnection levels for 1999, covered approximately 96% of the population. This implies a strong share of equity and access to energy for the multiple needs of production and consumption throughout the country. This has been a result of a *clear public policy to electrify Costa Rica*, which had a coverage of under 41% in the early 1950s (DSE, 1996). Generally speaking, in spite of the existence of a heterogeneous production structure, the main source or primary input for electricity production in Costa Rica is water. In 1999, the total generation was 6198 GW. Of that, 82% of the generation came from water resources, 13% was geothermal, 3% thermal, and 2% came from windmill generators.

Although Costa Rica is smaller in size and population than some of the other countries, the size of the electricity sector is larger and the amount of water and geothermal resources is higher than the rest. Also, the country is the first in including non-conventional energy sources, such as wind in the electricity system. A general chain of electricity production for Costa Rica is presented in the Figure below to illustrate the degree of development of the sector and characteristics at this moment. The sources of electricity have been concentrated in hydropower and thermal projects; more recently geothermal and windmill projects have been included.

Figure 2.5. Costa Rican Electricity Chain in 1999



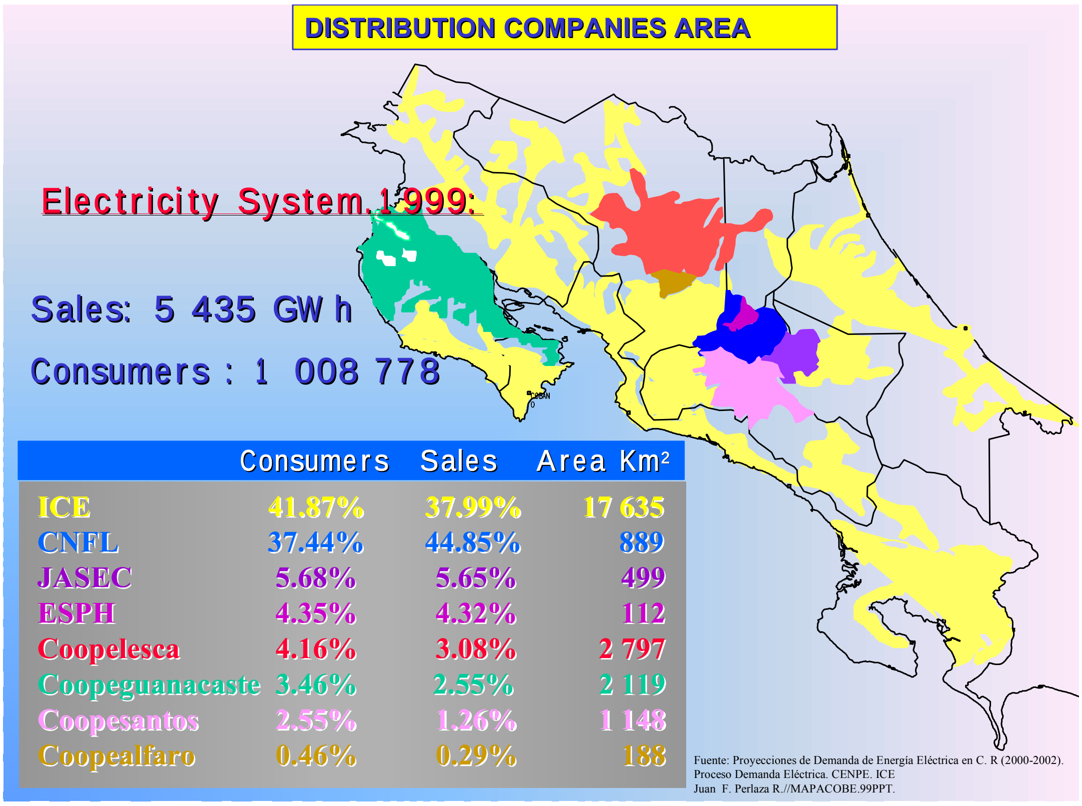
Source: Original, with data on the sector in 1998.

[8] The above reflects a relevant characteristic of the Costa Rican electricity sector: It produces electricity with more environmentally efficient energy than other countries in the region.

New private actors in the field of production have concentrated on small hydropower, wind and geothermal projects, while the National Electricity Company (ICE) has continued with the most important part of the production. According to the new regulatory framework, the new capacity in private sector projects could achieve no more than 30% of the total capacity (Law #7505).

Transmission activities have been considered a national monopoly and have continued in the hands of the ICE as a public enterprise. The distribution process included local and regional monopolies and a different pricing system, all of which are comprised of co-operatives or regional municipalities. There is a great deal of controversy about introducing competition and quality control in these companies (Orozco, 1996).

Finally, the consumption of electricity is highly concentrated in residential and industrial activities. Due to the fact that cooking in urban areas depends mainly on electricity, the urban sector is a large consumer of electricity. Costa Rican electricity rates, traditionally subsidised in residential consumption (Singh and Acuña, 1996), have caused an important increase in demand. This has led to the installation of thermal power plants based on imported fuel, and has affected the environmental and economic efficiency parameters that the Costa Rican electricity sector has sustained when compared with other countries in the region (Jiménez, 1997).



	Consumers	Sales	Area Km²
ICE	41.87%	37.99%	17 635
CNFL	37.44%	44.85%	889
JASEC	5.68%	5.65%	499
ESPH	4.35%	4.32%	112
Coopelesca	4.16%	3.08%	2 797
Coopeguanacaste	3.46%	2.55%	2 119
Coopesantos	2.55%	1.26%	1 148
Coopealfaro	0.46%	0.29%	188

Figure: Costa Rican Distribution Companies

Another important aspect to consider in the case of Costa Rica is the source of innovative activities in the sector. Of course, during the planning period this sector has been oriented mainly by the use of the natural resource base and the importation of the relevant technologies in order to develop the existing capacity.

As a State monopoly, production activities have been concentrated in the ICE. Therefore, innovative dynamics operated within this company, which also was in charge of the telecommunication activities. Because the main source of electricity was water, engineering research and development activities were concentrated on the different technical aspects of the development of these projects. More recently, as the sector has been opened up to private production, many different types of expertise and relationships have been developed in order to generate the new supply capacity.

At least three different sources of institutional and technological changes, which did not exist previously, have been developing in the 1990s. Environmentalist groups and consumer organisations have been promoting and influencing the parliamentary process toward additional renewable energy sources. In some cases, they are also direct actors in the process of implementing pilot projects and illustrative experiences in order to create confidence in new technologies. Private producers also have been promoting new energy sources such as windmills and small hydro projects with a set of new networks, which are integrated within groups of national and international expertise. Knowledge and technology transfer has been promoted at this new organisational level along with different links with the natural resource base such as forestry and land management activities. The government's new environmental policy is another source of innovative pressure and some results have been shown in recent years through the national agency in charge of the Global Agreement on Climate Change. So far, four new windmills and two small hydro projects have been included in the activities recently, and new ones are on the list for the coming years. A new innovative organisational structure has been created to support this agreement; in addition, new expertise and technological development are also being promoted (Eco-markets, 1999).

Another interesting example is the procurement policy, which includes ICE's obligation to buy electricity from the renewable energy capacity developed within the framework of the new laws. It has also shown that it is capable of creating a new cluster of renewable energy sources, with different effects on the technological and institutional framework. Indeed, scale problems, connectivity and transmission pricing are still a problem in the relationships between the new actors (private owners) and the State company. Some new projects have been developed with ICE's supervision and there are many plans for increasing the supply with small hydro and windmill alternatives. The *Build, Operate and Transfer* (BOT) mechanism was recently used in a 50-MW geothermal project (ICE, 2000).

A unit to study and promote direct solar application in heat and electricity demand has also been created in recent years with the support of governmental and non-governmental resources. So far, new pilot projects have been implemented and some of them with enormous success.[9] A new cluster of small enterprises is involved in producing components and some prototypes for direct solar heating, and direct solar applications, but many technical problems still exist at the level of technological development. All of these projects have resulted in a slow but interesting change in the composition of supply resources and also actors within the sector. It mainly shows a change in composition of the supply as well as new space for private producers within the small hydro, windmill, biomass and solar businesses.

The rest of the sector has continued to be dominated by old public, municipal, or co-operative companies. Some of those enterprises also have been motivated to work with the new renewable options; for example, Conelectrica R.L. is a consortium of rural electrification co-operatives that has invested in a 16-MW hydro project in San Lorenzo. ESPH has been also developing some new projects in renewable resources. Co-generation in sugar cane industry was allowed during the nineties under specific rules and regulations also.

[9] There are four different initiatives so far: the Coopeguanacaste project in Guanacaste, the Peninsula de OSA project (ICE-ASIADE), the Caballo Island project and the CNFL promotion project. Some interesting results and applications for rural electrification and tourism activities have been promoted, but the political confidence and institutional capacity to manage and publish these experiences are still lacking.

Sugar-cane industry in Costa Rica:

The sugar industry developed as an export-oriented commodity. A mayor shock of the industry was associated with the Cuban Embargo at the beginning of the sixties. The impact of local regulated prices and profits control in mayor transformation processes were also part of local organizations structure until the nineties.

Today, an important percent of the producers are small and medium side farms. During the last period 2000 - 2001, the production was distributed in 53.65 % white sugar and 46.35 on crudo sugar of the total of 7.161.665 bultos (equivalent to 50 kg each). The secondary part is controlled by 16 mayor sugar-mills and the process of exportation and international commercialization is dominated by few actors. Local organization of the industry have been publicly established since the fifties. The public sector's main agency is LAICA, where private and public interest confront.

The amount of exports in 2001 were 3.328.137 bultos. The production of energy was concentrated in two mills that are interconnected to the national grill while biomass use is concentrated on classical heat facilities and internal electricity needs.

Ethanol Potential

All these scenarios paying respect to potential energy crises are even more complicated under the present global political conditions, where the US politics is committed to go to a war with the Irak and oil scenarios are not very easily forecasted. Considering these circumstances, the Costa Rican Government is very interested in ethanol and bio-fuel options. Mayor interest groups are related to sugar-cane industry and crops option in the south of the country. The Costa Rican new president mandate in the National Plan for Development (2002-2006) includes the substitution of MTBE (methyl tertiary butyl ether) in gasoline by ethanol or similar options for the utilization of bio-fuels.

For the implementation of this mandate, the public authorities have organized a group with different representatives from the Agricultural Ministry, RECOPE, the Ministry of Environment and mayor interest groups. The first exploited option will be the possible substitution of MTBE for ethanol. Terms of reference for a pioneer study are in fact being developed and CINPE is joining the group as a part of the University Academic Consortium. The mayor aim of this study is the quantification of the potential use as well as the investigation of the technical and economic conditions where these substitution process is possible.

The mayor potential for sugar is in north area, closed to Guanacaste province, as well as north-west areas of the Central Valley.

Considering the above said, the mayor potential of ethanol is associated with the substitution of fuel based MTBE use. The main opportunity under the regulatory framework thereby is security of supply and the increasing demand for environmental quality. The table followed is presenting qualitative analysis of the potential and the opportunities, considering regulation, institutional and political framework, economic figures and social interest.

Matrix of opportunities for ethanol in Costa Rica

Institutional and political Positive factor in term of high priority in political terms	*Social interest* Very high in term of diversify the industry and develop new relevant value added. Strong power of environmental groups.
Economical Low productivity and few modernized sector with an important number of small producers	*Regulation* Very regulated economic activity under quotas and internal market structure. Possible for developing new interest groups and alternative pricing policies.

The matrix is showing that political actions are crucial for the introduction of ethanol in the first phase of the development. Once demand is clarified and well established, State subsidies and market regulation should be relaxed and strategically oriented as in many cases of rising technology diffusion processes.

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Additional information is provided in the Power Point Presentation Viewgraphs available at the LAMNET project web site **www.bioenergy-lamnet.org/events/events.html**.

3rd LAMNET Workshop – Brazil 2002

Sugar Cane Biomass Alternatives for Electricity Generation

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- Abstract -

The electric energy in Cuba is produced in a high proportion in thermal power plants burning fossil fuel because there are no other sources such as hydro or nuclear that can cover the countries energy demand. The price of fossil fuels - and their possible increase in the near future - indicates the necessity of developing other energy sources. The sugar cane biomass offers possibilities to produce this energy with excellent environmental results.

In Cuba, since the beginning of the last century, electric energy has been co-generated at the sugar industry using the sugar cane bagasse as the fuel source. The sugar cane can provide biomass that can be used as fuel, one of them – the Sugar Cane Bagasse - is obtained at the factory. The High Fiber Sugar Cane (HFSC), the Sugar Cane Crop Residues (SCCR), and the grinding of the whole cane (WC) are other available sources of fuels from sugar plants.

In order to achieve economical results producing electric energy at the sugar factories and to be able to work the year round, it is necessary to use a second fuel. This second fuel: petroleum gas, fuel oil, coal or biomass as wood or from the sugar cane can depend of the availability of these fuels. From an environmental standpoint biomass would be the first alternative. At the sugar cane industry in Cuba there are a number of factories - around 30-40% of the actual factories- that can be considered in order to co-generate and generate electric energy the year round.

There are factories that use middle steam pressure which have the ability to co-generate and generate electric energy all the year in order to satisfy the electric energy needs of close towns or to supply the electricity to the National Grid. Also using high pressure steam technology it is possible to achieve higher generation: as 110-130 kW-h/ton cane, these installations can be considered as Independent Power Plants.

Actually there are possibilities to prepare and implement projects for the cogeneration and generation of electric energy at the Sugar Cane Industry in Cuba.

Additional information is provided in the Power Point Presentation Viewgraphs available at the LAMNET project web site **www.bioenergy-lamnet.org/events/events.html**.

3rd LAMNET Workshop – Brazil 2002

Development of bio-oil production plants in Brazil

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- Abstract -

Biomass residues such as wood, bagasse or rice husks can be converted into a bio-oil through a process of fast pyrolysis. The main advantage of this route is that hard-to-handle, ash containing and low energy density biomass is converted into an ash-free versatile high energy-density liquid fuel. In the Netherlands, the construction of a 40 ton/day bio-oil production demo plant is expected to be in operation by the end of 2003, to produce a liquid able to substitute fossil fuels.

As the oil classifies as a green energy source it serves as a possible tool to reach the CO_2 emission reduction targets. Bio-oil can be considered as an important breakthrough in the transition from power generation using conventional fossil fuels to the future use of clean sustainable green fuels. Success of bio-oil production and its applications will open new perspectives for biomass technologies, especially in biomass rich countries, and may lead to international trade with western countries.

Brazil is one of the biggest countries in the world, with an enormous variety and quantity of biomass available in most of its areas. It has a large crop production, wood industries and livestock. At the same time its demand for energy increased significantly over the last decades: Brazil has passed through a huge energy crisis at the end of 2001 as a result. A first assessment carried out together with local partners shows that the cost for bio-oil production in Brazil is expected to be around 25 to 40 Euro/ton (2 – 3 Euro/GJ_{oil}

Co-combustion of bio-oil in a natural gas fired thermal plant confirmed the possibility of using bio-oil as a partial and direct substitute for fossil fuels in energy generation. A number of other applications are now being investigated and developed in different projects, with special attention to projects of bio-oil usage in conventional diesel engines, bio-oil reforming for fuel cells and Fischer-Tropsch process to produce diesel.

In this presentation the possibilities for bio-oil production in Brazil will be explained. The immediate application of co-firing bio-oil in thermal plants proven in recent tests will be presented, and other bio-oil application research projects summarised.

Additional information is provided in the Power Point Presentation Viewgraphs available at the LAMNET project web site **www.bioenergy-lamnet.org/events/events.html**.

3rd LAMNET Workshop – Brazil 2002

Biomass Fermentation: Fermentogas – the clean Fuel Saver

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Fermentogas – Starting Point:

- Proven modular fermentation technology, based on Kompogas know-how
- Proven technology for co-fuelling existing diesel motors with Fermentogas
- Proven for various feedstock materials

Fermentogas – the clean Fuel Saver:

- Rural electrification, fuelling existing diesel powered minigrids (50 kW)
- Fuel Saver for multimegawatt diesel power plants
- New biomass power plants to generate electricity by fermentation instead of combustion

Fermentogas – Action Plan:

- Feasibility study including cost analysis
- Detailed design of pilot plant, financing issues
- Pilot plant, learning curve for the technology in rural environment
- Large scale introduction of technology, modular technology, local construction

Fermentogas – Energy Production:

10,000 t biogenous feedstock

↓

1,180,000 Nm^3 Fermento-Gas

↓

2,200,000 kWh electrical energy

and

3,800,000 kWh thermal energy

Additional information is provided in the Power Point Presentation Viewgraphs available at the LAMNET project web site **www.bioenergy-lamnet.org/events/events.html**.

3rd LAMNET Workshop – Brazil 2002

Current Status and Opportunities of the LAMNET Project Database

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- Abstract -

In order to ensure an efficient dissemination and a long-term availability of the project results, the LAMNET project includes a shared Database which currently contains general information and energy facts of numerous Latin American and African countries surplus China. The first version of the database is already online and can be accessed by entering the project website under: **www.bioenergy-lamnet.org**.

The Database is programmed in HTML (Hypertext Markup Language) and is therefore compatible with all Internet Browsers. It can be expanded with all kinds of media e.g. pictures, graphs, trailers etc. The content will be updated, enhanced and increased during the whole project duration.

Additional information is provided in the Power Point Presentation Viewgraphs available at the LAMNET project web site **www.bioenergy-lamnet.org/events/events.html**.

Discussion Round: Results and future activities of the LAMNET project

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In this discussion round the members of the LAMNET project were informed about the status of preparation of LAMNET activities in 2003 including the indicative dates and locations of project workshops. Suggestions concerning the future focus of the LAMNET thematic priorities were brought to the panel and will be discussed in the Steering Committee of the LAMNET project.

LAMNET Project Workshops in 2003

- 21-24 April 2003: 4th LAMNET Workshop in China, Guangzhou, Guangdong Province
- June/July 2003: LAMNET Workshop in Central/South America
- September 2003: LAMNET Workshop in China, Beijing
- 12-14 November 2003: LAMNET Workshop in Cuba, Havana

A further potential venue for a LAMNET workshop in China was presented by Prof. Li Dajue of the Beijing Green Energy Institute. The **Xiedao Green Ecological Holiday Village (Eco-Village)** located the east suburb of Beijing. It is only 10 km from the Beijing Capital Airport. It is a model of sustainable agriculture and was officially appointed as the base for green ecological garden in Beijing by the State Administration for Environmental Protection and the China Environmental Science Society.

LAMNET Newsletter

The 2nd issue of the LAMNET newsletter was distributed at the 3rd LAMNET workshop in Brasilia. The newsletter can be downloaded at www.bioenergy-lamnet.org and hardcopies are available through WIP (wip@wip-munich.de, rainer.janssen@wip-munich.de).

The 3rd issue of the newsletter will be available around June 2003. Contributions by LAMNET members and others to be published in the LAMNET newsletter are highly welcome.

LAMNET Leaflets on Biomass Key Topics

The first two thematic leaflets prepared in the framework of the LAMNET project were distributed at the 3rd LAMNET workshop in Brasilia. The topics are:

- Refined Biofuels – Pellets and Briquetes
- Modern Bioenergy Village Complex

The newsletter can be downloaded at www.bioenergy-lamnet.org and hardcopies are available through ETA and WIP (eta.fi@etaflorence.it, wip@wip-munich.de).

LAMNET Website

The website of the LAMNET project www.bioenergy-lamnet.org will provide the main dissemination platform for all project results. The documentation of LAMNET activities including the proceedings of LAMNET workshops are continuously being made available at the website. Additionally, this website provides technical information in the field of bioenergy as well as useful links to other organisations engaged in the promotion of bioenergy worldwide.

LAMNET Database

This database is embedded in the LAMNET project website to ensure an efficient dissemination and a long-term availability of the project results.

The preliminary structure of the database is already available now. Early in 2003 Prof. Moreira of CENBIO will prepare a draft of the potential scientific content of the database for Brazil based on data provided by CENBIO. This draft will then be transmitted to the members of the LAMNET project in order to collect relevant data in all LAMNET member countries.

Suggestions for LAMNET Thematic Priorities

- Rural electrification (for workshops in China), Antonio Valdes, CIEM, Cuba
- Innovative technologies for biogas production including cost comparison, Antonio Valdes, Cuba
- Small and cost effective RE/Bioenergy systems, Denis Tomlinson, Illovo Sugar, South Africa
- Biofuel burning micro-turbines, Andre Martins Carvalho, CEMIG, Brazil
- Research cooperation policies, Wolfgang Palz, Germany
- Industrial partnerships for cooperation, Wolfgang Palz, Germany
- For China: policiels, planning and training activities, Wolfgang Palz, Germany
- Preparation of training materials of different bioenergy technologies, Petros Axaopoulos, A.U.A., Greece

Wednesday Morning Session: Ethanol Based Fuel Cell Technologies

3rd LAMNET Workshop – Brazil 2002

Introductory Lecture: Principle and Applications of Fuel Cells (Methanol/Air as Example)

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1. Conversion of Chemical Energy into Electricity

The energy of a chemical reaction depends only on the difference in energy of the reacting spaces before and after the complete reaction. Different pathways are possible, e.g. purely chemical or purely electrochemical routes. The chemical reaction proceeds in a homogeneous reaction volume as the combustion of gasoline or alcohol with oxygen. The energy obtained is a combination of mechanical energy and heat. *Electrochemical pathways* are proceeding at two different electrochemical interfaces, anode and cathode, separated by an ion conducting electrolyte. The total reaction takes place in an electrochemical cell, the fuel cell. Fig. 1 shows as an example the reaction of methanol with air or oxygen in a Direct Methanol Fuel Cell (DMFC).

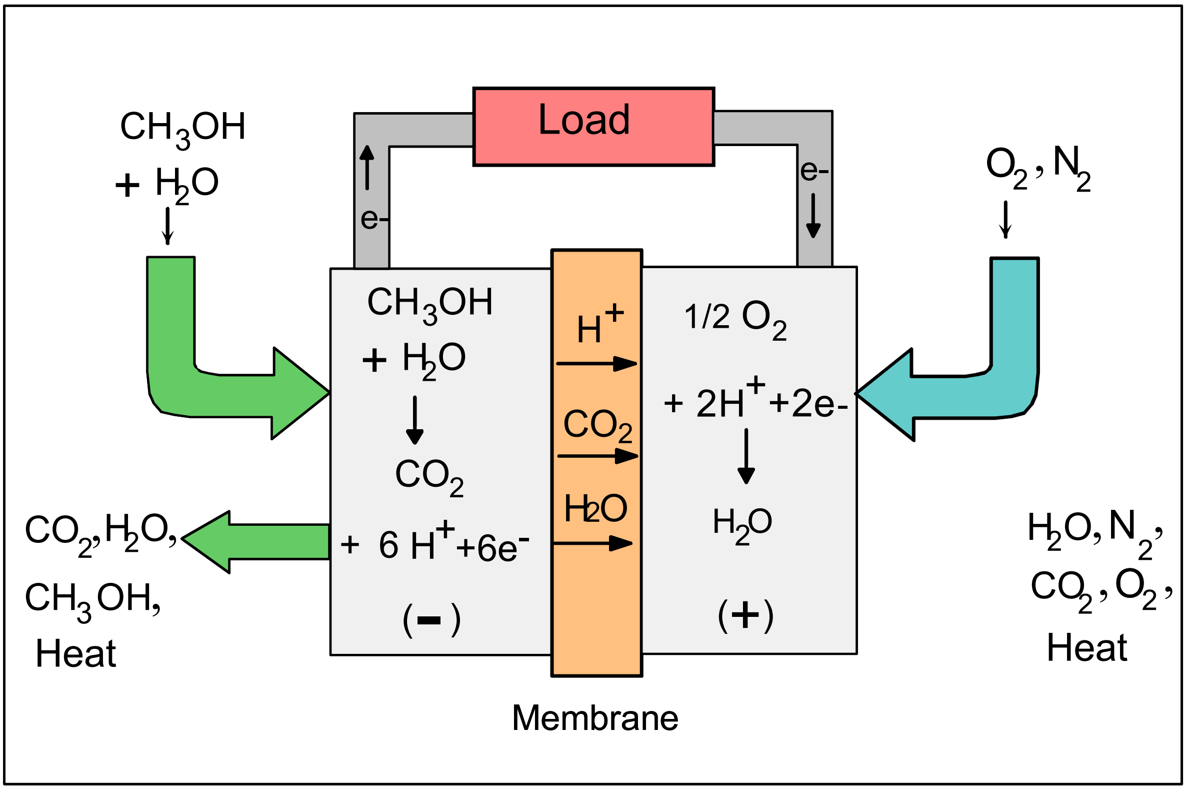


Fig. 1: Flow of reactants, water, CO_2 and heat in the case of a Direct Methanol Fuel Cell (DMFC).

Methanol and water are circulated at the gas side of the anode interface. Protons formed move through the polymer electrolyte together with water and the reaction product CO_2:

$$CH_3OH + H_2O \rightarrow CO_2 + 6H^+ + 6e^- \quad (1)$$

The electrons, moving via the load resistance, react at the cathode interface with oxygen:

$$3/2O_2 + 6e^- + 6H^+ \rightarrow 3H_2O \quad (2)$$

Summing up equations (1) and (2), one has as the total chemical reaction:

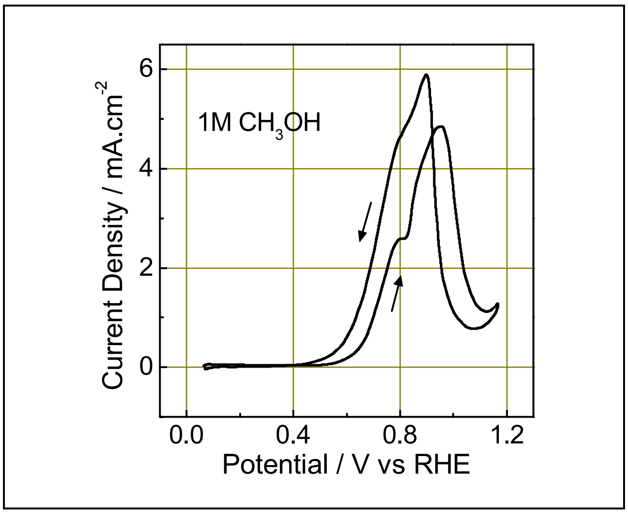
$$CH_3OH + 3/2O_2 \rightarrow CO_2 + 2H_2O \quad (3)$$

With the direct electrochemical reaction of methanol, the power is given by the product cell voltage times current, E_{cell} x I = watts (volt x amperes), and the energy obtained after a certain time can be calculated by the product volt x Ah = Wh. With a complete reaction 6 electrons per molecule of methanol are obtained. Assuming the maximum possible (reversible) cell voltage of 1.21V for a methanol/air cell as well as 6 electrons per molecule of methanol, the respective energy amounts to 6kWh per kg methanol. This energy content is comparable to the one of gasoline [1, 2].

2. Activity of Fuel Cell Electrodes

The standard free energy of reaction (1) is ΔG = -692.2 kJ/mol. From this follows for a 6 electron charge transfer the thermodynamic standard cell voltage of 1.21V [2]. But, in a practical cell, we have to consider the reaction kinetic of both electrodes and the IR drop in the electrolyte.

A first view on the reaction kinetics can be obtained via cyclic voltammograms (CV), using selected electrode materials [1, 3]. Fig. 2 presents the well known cyclic voltammogram for methanol at a platinum electrode in acid solution. The CV for hydrogen is given for comparison. An important information is, that at platinum the oxidation of methanol does *not* start at the thermodynamic data near the hydrogen potential in the same electrolyte at ca. +20mV, but above 400mV (note the arrow for a change of potential in the positive direction). What are the possible reasons?



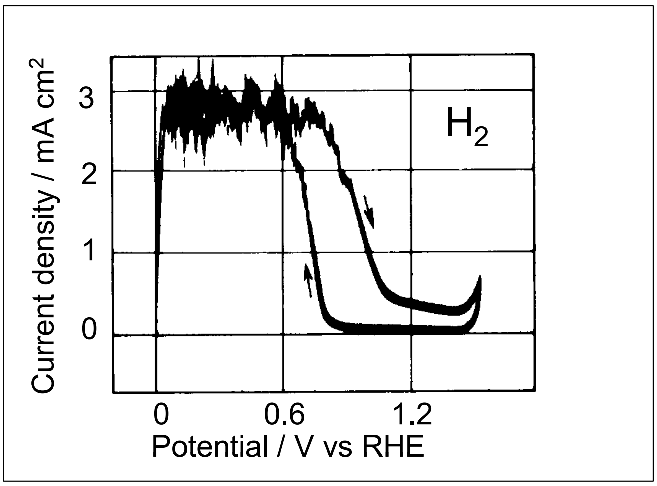


Fig. 2: Cyclic Voltammogram for methanol on porous platinum in 1M $HClO_4$ and for H_2 on smooth polycrystalline Pt in 0.5M H_2SO_4 for comparison, scan of electrode potential 50mV/s, 20^0C [3].

It is more than a decade that Kunimatsu did find, by analysis of insitu IR spectra, in CH_3OH/H_2SO_4 solution on platinum surfaces at 400mV RHE bands for linearly bonded CO. Improving the IR technique, Iwasita obtained in addition spectra with bands of bridge bonded and multi bonded CO, with bands of COH and $HCOOCH_3$. $HCOOCH_3$ is a product of the solution reaction of HCOOH with methanol. It has to be considered that in addition to the reaction path via CO to CO_2, formic acid and formaldehyde are formed as intermediates in solution [4]. Finally, formic acid and formaldehyde are also oxidized to CO_2 at the electrode, that is, all the three pathways of methanol oxidation result in 6 electrons per molecule.

An important step in electrocatalysis was the observation that the rate of methanol oxidation is increased in replacing pure platinum as a catalyst by the use of PtRu alloys. Due to the above observation that CO is an adsorbed intermediate, and due to the fact that the oxidation of CO requires a second oxygen atom, and Ru is splitting water at low potentials easier than Pt, the following bifunctional mechanism was assumed:

$$\text{Ru-H}_2\text{O} \rightarrow \text{Ru-OH} + H^+ + e^- \quad (4)$$

$$\text{Pt-CO} + \text{Ru-OH} \rightarrow \text{Pt} + \text{Ru} + CO_2 + H^+ + e^- \quad (5)$$

From this model about the mechanism it is to be expected that the distribution of Ru and Pt sites in the surface of the catalyst must be a sensible factor for improving the catalyst activity.

3. The 40W DMFC System from Smartfuelcell, Brunnthal (Germany)

The oxidation of methanol in acid electrolyte, as in the DMFC of Fig. 1, has the advantage that according to equation (3) two molecules of water are formed per molecule of methanol. This fact supports the closed system operation where sufficient water has to be introduced in the fuel compartment, together with methanol. The 40 watt unit of Fig. 3 is using its electronic device for controlling the flow of methanol and air, for circulating water and for the adjustment of the operating temperature, at e.g. 60^0 C, including respective heat balance regulations [5]. In addition, the control device takes care for the exhaust of the final product CO_2. An example of the remarkable long time performance is given in Fig. 4.

In future, liquid methanol, or possibly also *ethanol*, could be a basis not only of the stand by applications of today, but for new mobile units also. For this type of application, we have to wait for new ideas in the development of respective electrocatalysts, in order to increase cell voltage and cell power.

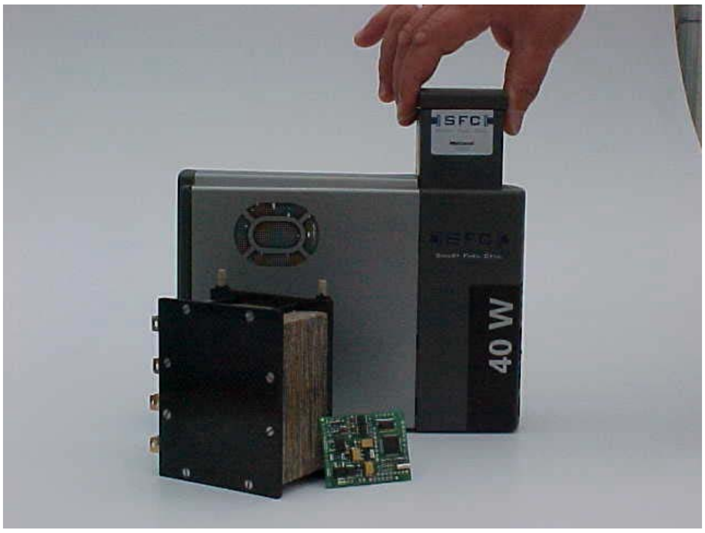


Fig. 3: 40 Watt PEM DMFC fuel cell system of Smartfuelcells, Brunnthal/ Germany, working at ambient air, $200mA/cm^2$ at 400mV cell voltage, 12 volt stabilized, 60^0C, 1 mg/cm2 PtRu (50:50), , cell stack and electronic card in front, 2.5 l methanol container in the box , obtainable energy 1 Wh/cm^3 methanol [5].

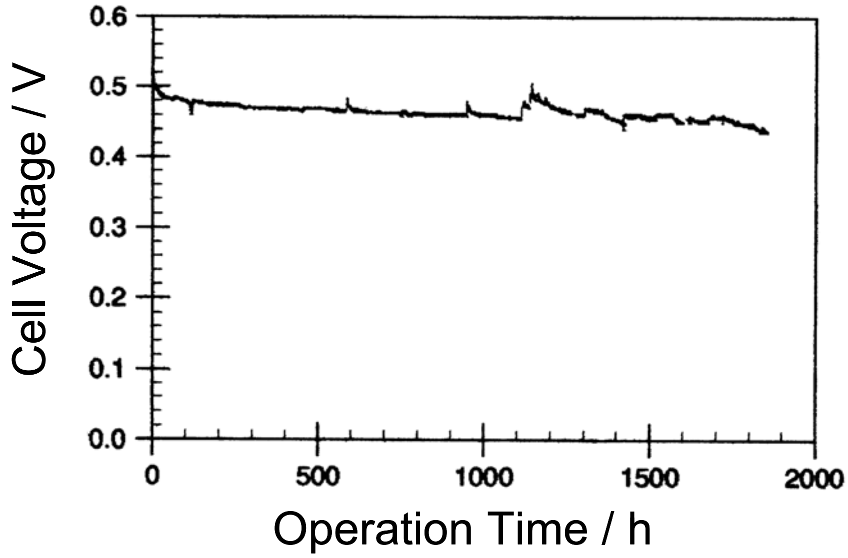


Fig. 4: Lifetime performance of Smartfuelcell methanol electrodes in 0.4M CH_3OH at 200mA/cm^2 and 110^{0}C, degradation rate 13µV/h [5].

4. Outlook

During recent years, special progress was obtained in three areas:

(1) Volume and weight of cell stacks for hydrogen/oxygen (air) was decreased using very thin Nafion membranes (100 to 20µ) as proton conducting electrolyte, at the same time minimizing the thickness of the catalyst layer of Pt nano-particles and optimizing the gas distribution over the electrode interfaces at temperatures near 100^{0}C.

(2) Complete hydrogen systems, including gas and water circulation, of 1kW to 200kW were build with automatic control of fuel (oxygen) stoichiometry and stack (fuel, oxygen) temperature. The good data in power density do allow the application as power sources in vehicles also.

(3) Beside the hydrogen system, the Direct Methanol Fuel Cell was developed for temperatures of 60-90 degree with a similar technology as discussed above, but approaching a more simple system due to higher content of water as reaction product. On the basis of present catalysts (mainly PtRu bicatalysts for the methanol anode) an acceptable power per active surface is available, and a use in smaller systems from some watts to 1kW for several mobile and stationary application is suggested.

Important fields for future studies are:

Reducing the system costs, especially taking care for the development of new membranes with sufficient life time data as well as using less amounts of platinum metal catalysts.

Renewed investigation of alkaline systems as an alternative option, using non-noble metal catalysts and a simplified technology.

Other alcohols than methanol like ethanol or glycol should be studied also as a possible fuel for liquid-fuel fuel cells. Here, the study of suitable catalysts is still in an early stage. Key for a possible break-through is the development of a catalyst for the direct pathway of oxidation to CO_2. In the case of using platinum metal catalysts, the kinetics of the first steps of oxidation to acetaldehyde or acetic acid are already comparable to the kinetic of methanol oxydation.

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3rd LAMNET Workshop – Brazil 2002

The production of hydrogen from ethanol for fuel cell systems

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- Abstract -

The interest in developing fuel cell technology for commercial applications is recent – it dates in the middle of the nineties. In the automotive sector, this technology is considered the most promising to substitute the internal combustion engine because it offers Zero or ultra-low emissions, larger efficiency (2 times larger than the conventional motor) and opens opportunities for the use of renewable energies.

The orientation of the world geared toward renewable fuels gave a strong impulse to fuel cell technology and motivated all big automotive manufacturers to develop alternative and innovative drive systems. The fuel cell technology goes beyond the basic research, entering into the field for the development of products that shall be commercialized, starting with small series in 2004. Until there several prototypes are being produced for demonstration projects in several countries.

Ballard Power Systems is recognized as the world leader in developing, manufacturing and marketing zero-emission proton exchange membrane ("PEM") fuel cells for use in transportation, electricity generation and portable power products.

The most recent fuel cell vehicles from DaimlerChrysler and Ford equipped with Ballard Fuel Cell Systems are the F-Cell (Mercedes-Benz A-Class) and the Ford Focus powered by compressed hydrogen. The Mercedes-Benz FC Sprinter, is the first fuel cell vehicle in customer's hand. The Necar 5 (Mercedes-Benz A-Class) and the Mazda Premazy are the new generation of the methanol system, which have been successfully tested in Japan and the Necar 5 has recently completed the cross country route from San Francisco to Washington; Together with DaimlerChrysler, Ballard has also developed the new generation of fuel cell bus, that will be in revenue service in 10 cities in Europe from 2003-2005. The next bus development is being done together with Gillig, for the bus demonstration project in California.

Besides the systems for automotive applications, Ballard is also developing systems for energy generation, using different fuels for the production of hydrogen. Auxiliary power units (APU), that offer several advantages, such as: improvement of the quality and efficiency of the on-board electronics, generation of electricity on board of the vehicle and for the execution of mobile services, like waste collectors, concrete mixers, transportation of food, etc, without any noise and without the emission of pollutants. Europe, the United States, Canada and Japan are playing a very important role in the development of this technology and huge investments made there will accelerate the entering into the market of the corresponding products.

The discussion on what shall be the alternative fuel to complement diesel and gasoline, is the subject of the moment. The energy crisis, the variations of the price of oil and the need to reduce carbon dioxide producing the green house gas effect are factors driving the world to change its concept of energy generation and the use of fuel in the transportation, stationary, marine, space, computers and telecommunications sectors.

The fuel for the fuel cell, hydrogen, can be obtained from different renewable and fossil sources and different fuels such as natural gas, methanol, ethanol and gasoline. Except for the system that stores hydrogen on board of the vehicle, the other systems contain additionally a catalytic reformer, also on board of the vehicle, that extracts the hydrogen contained in the molecule of the fuel. The other substances are purified by the system. The methanol system, for instance, is considered ultra-low emission because it reduces carbon dioxide in 30% and does not exhaust carbon monoxide, nor NO_x, nor Particulate.

Ethanol is purer than gasoline and contains less carbon. Therefore a fuel cell system using ethanol, once optimized, has the potential to be more efficient, to have lower emissions and a better performance than most of the liquid fuels available. In spite of the fact that some tests have been done with ethanol, there is no fuel cell system working on ethanol yet. In order to know what are the emissions, efficiency and cost-effectiveness of this system and in order to get a concept, which can be used for commercial applications on the automotive or power generation sector, there is a need of a methodological test analysis with different samples of ethanol in laboratory.

Brazil is the world leader in the use of ethanol as a fuel is Brazil, the only country with an alternative fuel infra-structure available today (25.000 gas stations). Thank to Pro-Alcohol, a national program which defined the use of alcohol (from sugar-sane) as a fuel over petroleum, Brazil has mastered technology and know-how allowing the large-scale use of a renewable fuel. Ballard has recognized this know-how and the important role of the Brazilian market in the commercialization of the fuel cell technology, therefore since 4 years has been trying to start a project together with the ethanol and sugar-cane producers and the Brazilian Government. This shall be a 3 years project which includes tests and analysis with different ethanol samples in Brazil and a study for potential applications of fuel cell systems.

For the Brazilian Government, the fuel cell will assure the future of the ethanol as a fuel for automotive application, open new markets for the use of ethanol such as the energy power generation, develop know-how and the national industry, create new business and jobs, form and train manpower, preserve the environment, encourage the use of renewable energies and increase international commerce. This is an opportunity for Brazil to integrate the pool of countries which are developing the fuel cell technology, using its knowledge about ethanol as a fuel.

In addition, the use of ethanol as a fuel does not increase the green house gas effect because the carbon dioxide produced is practically consumed by the plants during the photosynthesis. Also, it generates a chain of sustainable development, most important to the whole country. On the way to commercialization, Ballard is involved in strategic public-private partnerships worldwide in order to establish the technical, economic, and policy bases for the development and commercial application of the fuel cell technology. Time is a key factor in the introduction of new technologies and the time is know for the developing countries to join the OECD countries in the fuel cell development and in the efforts to reduce $C0_2$ and local pollution.

Additional information is provided in the Power Point Presentation Viewgraphs available at the LAMNET project web site **www.bioenergy-lamnet.org/events/events.html**.

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Research on the reforming of ethanol

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Hydrogen Generation from Ethanol by Allothermal Reforming

Thomas Rampe, Peter Hübner, Bernhard Vogel, Angelika Heinzel

Abstract:

The use of biomass for energy generation is an effective solution for the reduction of CO_2 emissions and preserves the fossil energy resources. Taking these aspects into consideration ethanol, a CO_2 neutral fuel, is suited to substitute the conventional fossil fuels based on petroleum or natural gas. Funded by the European Commission, a research project for the use of bioethanol as fuel for generation of hydrogen by a reforming process was started in 1998. The motivation of this project is to use the fallow land in the European countries to supply bio fuels for energy generation. The feedstock of the fermentation process are starch containing crops such as corn, maize, sugar beet and sugar cain. Beside the opportunity to use the ethanol as raw material for the chemical industry to produce products like acetaldehyde or ETBE which is used as a octane enhancer it is possible to insert ethanol directly as a fuel as a gasoline replacement or as a blending additive. Ethanol as a liquid fuel has the advantages that it is on one hand easy to handle with respect to the storage and transportation and on the other hand it has a relative high mass specific energy content. Another application field is to use the ethanol as a feedstock for a steam reforming process to generate a hydrogen rich gas stream. The hydrogen is used as a fuel for a polymer electrolyte fuel cell (PEFC).

Possible applications of the fuel cell technology are either stationary systems such as small CHP-units and or mobile applications for vehicles. The electrochemical energy conversion process of H_2 in a fuel cell causes no emissions of CO or NO_x. But hydrogen has some disadvantages: it is not available all over Europe, it is difficult to store and difficult to handle. These were the reasons why the reforming technology for generation of hydrogen became interesting even for small scale applications: decentralised stationary systems or even on board of a vehicle. The PEFC reaches high electric efficiencies of about 50 % and thus is an interesting power generator, especially in the small power range in comparison to conventional systems. The main target of the project is to develop and investigate a fuel cell system in the kW range. The work carried out at FHG ISE includes the reforming process and the shift process for gas purification. For the reformer process, a catalyst screening is carried out. The influence of different parameters on the reforming reaction is evaluated. The operation pressure is varied in a range of 2–9 bar. The temperature range is 600 to 800 °C, the steam-to-carbon ratio is varied between 2-4 (mole C to mole H_2O). Based on these investigations a combined burner/reformer unit is developed to supply a hydrogen flow with an energy content of about 3 kW.

The project is carried out with the partners: Universität Duisburg; Nuvera and is funded by the EU within JOR3-CT97-174

1. Introduction

During an EU-project the hydrogen generation from ethanol by an allothermal reforming process has been investigated. The product gas of this process will be used for the stationary power generation in a fuel cell system. In a catalytic steam reforming process the ethanol is converted in combination with water into a hydrogen rich gas which consist of H_2, CO, CO_2, CH_4 and H_2O. The allothermal reforming process of alcohol is generally characterised by the equation (1.1):

$$C_nH_{2n+1}OH_{(l)} + (2n-1)H_2O \rightarrow 3nH_2 + nCO_2 \quad \text{equ. 1.1}$$

For the case of ethanol as fuel for the steam reforming process the stoichiometric reaction is defined as follows (1.2):

$$C_2H_5OH + 3H_2O \Leftrightarrow 2CO_2 + 6H_2 \quad \text{equ. 1.2}$$

The reforming process is an endothermic reaction, which consists of two reaction steps. The first reaction step (1.3) represents the endothermic cracking process in which the ethanol and water react to carbon monoxide and hydrogen. The following reaction step (1.4) characterises the exothermal heterogeneous water gas reaction where additional hydrogen is formed.

$$C_2H_5OH + H_2O \Leftrightarrow 2CO + 4H_2 \quad \text{equ. 1.3}$$

$$CO + H_2O \Leftrightarrow CO_2 + H_2 \quad \text{equ. 1.4}$$

The CO in the reforming product gas will deactivate the anode catalyst of the PEM fuel cell. Therefore a gas cleaning process is necessary. A catalytic high and low temperature shift reaction reduces the CO content of the reforming product gas to about 0,2 Vol. %. Then, a pressure swing adsorption process reduce the CO value further to about 20 ppm before the hydrogen streams into the PEM fuel cell. The pressure of the main process will be determined through the adsorption pressure level of the pressure swing adsorption process (PSA). The necessary pressure level for the adsorption process is about 7 bar. The regeneration of the adsorbents is carried out by pressure reduction and also by cleaning the adsorbents with part of the hydrogen from the product gas. The waste gas of the regeneration process of the PSA is a low calorific gas, which can be used as fuel for the burner in the allothermal reformer. The figure 1.1 represents the flow sheet diagram of a PEM fuel cell system (1) with the reformer part, the two shift reactors, the fine gas cleaning process and the PEM fuel cell. Moreover, the ethanol/water inlet stream of the reforming process, the gas composition of the several process steps, the heat flow of the endothermic and exothermal processes and the heat losses are presented.

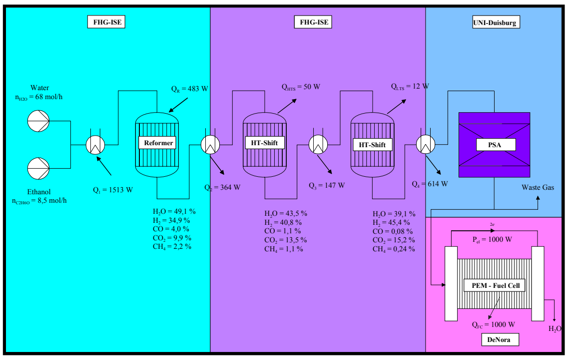

Figure 1.1: Flow sheet diagram of a PEM fuel cell system

2. Catalyst Screening

2.1 Structure of the experimental reactor

The catalyst screening is carried out in a tube reactor with an inner diameter of 47 mm. The catalyst material is arranged as bulk material in an ideal tube reactor. To guarantee isothermal conditions, the catalyst material is mixed with inert material in a proportion of 1 to 10. Quarz sand with a particle size of 200 - 300 □m serves as inert material. The sand acts as a thermal buffer that provides a constant temperature of the bulk material during the endothermic steam reforming reaction.

The illustration 2.1.1 represents the schematic design of the tube reactor. After the ethanol/water flow has passed the vaporiser the mixture streams through the tube coil into the kinetic reactor. In the tube reactor the gas first flows through a 20 mm thick layer of sand that is supposed to avoid discharge of catalyst materials. This layer is followed by 110 cm^3 catalyst/sand mixture in which the reaction takes place. Two thermocouples are placed in the upper and lower third of the mixture layer in order to control the temperature gradient over the height of the catalyst bed. A silica filter at the bottom of the reactor avoids the discharge of sand or catalyst material. Isothermal flow reactors can be classified by the following characteristics:

- plug flow
- dispersion negligible
- secondary flow negligible

The reformer product gas usually is composed of hydrogen, carbon dioxide, carbon monoxide and methane. All carbon containing gases are analysed quantitatively with an NDIR spectrometer. The volume of the generated gas is measured by a gas meter and the difference is attributed to the hydrogen content of the gas. For some examples, the gas composition was additionally controlled by measurements with the FTIR-spectrometer, and ethylene (C_2H_4) and acetaldehyde (CH_3CHO) as side products could be detected principally at reforming temperatures as low as 600 °C with palladium and platinum as catalyst material .

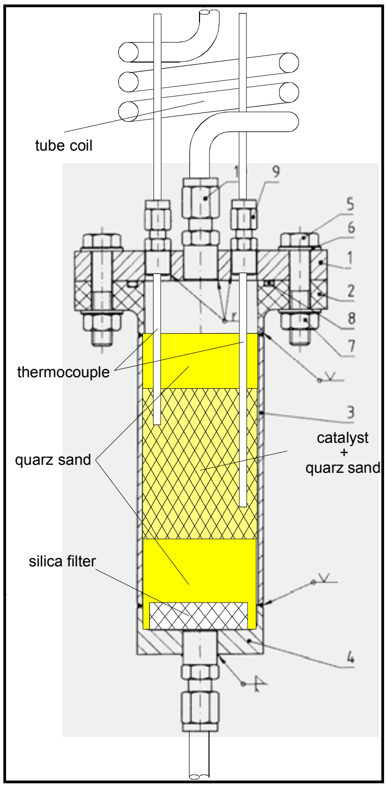

Fig.2.1.1:kinetic reactor for steam-reforming

2.2 Parameter of the catalyst screening

The following table 2.2.1 shows the different catalysts, which have been investigated.

Name	Sign.	Composition
Nickel	Ni	nickel on Al_2O_3
Ruthenium	Ru	ruthenium on Al_2O_3
Platinum	Pt	platinum on Al_2O_3
Palladium	Pd	palladium on Al_2O_3
Perovskite	Pe	lanthanum, manganese, cobalt, strontium
Nickel-Platinum	PN	nickel; platinum on Al_2O_3
Nickel-Palladium	NP	nickel; palladium on Al_2O_3

Table 2.2.1:catalyst materials chosen for the experiments

To evaluate the reforming behaviour of the several catalyst materials, it is necessary to find the optimal temperature range for the catalyst screening. As first example, the ruthenium catalyst was investigated at a fixed pressure p = 9 bar and a steam to carbon ratio s/c = 4 in a temperature range from 500 - 700 °C, by heating up the reactor in 50 K steps. The H_2 content in the product gas stream was recorded and is given in table 2.2.2.

Reaction temperature	H_2 content [mole %]
500	36,8
550	44,9
600	59,6
650	67,7
700	69,0

Table 2.2.2:H_2 content; s/c-ratio = 4; p = 9 bar

The amount of hydrogen continuously increases with temperature, therefore the decision was made to investigate all other catalysts at the two temperatures 600 and 700°C as basis information. By these two measurements it can be seen, if a lower temperature is applicable or not. The s/c ratio, which is selected for the catalyst investigations is determined by the limits for carbon formation. Thermodynamic calculations are made with the program EquiTherm. These calculations show the possibility of carbon formation at low steam concentrations, at s/c $\leq$ 1,5. For this reason the lower s/c limit for the catalyst screening is 2,0. The influence of pressure on the thermodynamic equilibrium of the reforming reaction is known, a low pressure favours complete ethanol conversion and a high hydrogen yield. In the following table 2.2.3 the parameters of the catalyst screening are listed:

s/c-ratio:	2, 3, 4
Pressure:	p = 2, 5, 9 bar
Temperature:	600; 700; 800 (Ni-catalyst) °C

Table 2.2.3: Parameters for the catalyst screening

2.3 Results of the catalyst investigations

The figures 2.3.1 and 2.3.2 show the hydrogen mole stream of the ethanol steam reforming reaction in dependence on the s/c-ratio at a temperature of t = 700°C and a pressure of p = 2 bar (2.3.1) or 9 bar (2.3.2). The legend sign of the catalyst corresponds to the table 2.2.1.

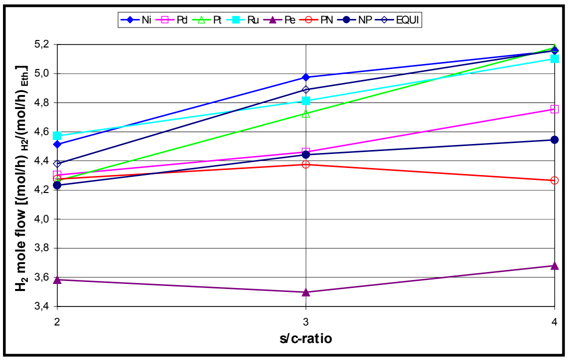

Figure 2.3.1: Normalised hydrogen stream in dependence on the s/c ratio; p = 2 bar, t = 700°C

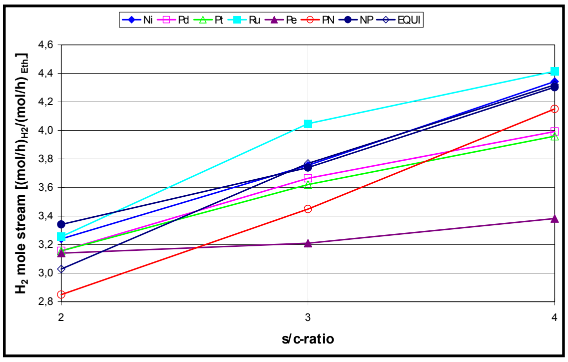

Figure 2.3.2: Normalised hydrogen stream in dependence on the s/c ratio; p = 9 bar, t = 700°C

All catalysts show in principle the same behaviour, a higher pressure leads to a decrease of the hydrogen yield and a rise in S/C-value leads to a better ethanol conversion and a higher hydrogen output. The perowskite is the worst one among the investigated catalysts. Additionally the diagrams show the thermodynamic calculation with the program EquiTherm. The hydrogen yield with the nickel catalyst is better than the equilibrium. This is a sign, that the heterogeneous water gas reaction takes place at the end of the reforming reaction.

The following figure 2.3.3 represents for example the composition of the reforming product gas of the nickel catalyst (Ni). The hydrogen content is even decreasing for higher s/c values, though the absolute quantity of hydrogen is rising with higher s/c. The comparison of the three graphs for the three pressure levels 2, 5 and 9 bars with identical s/c-ratio show the strong influence on the gas composition. The main result is the increasing amount of residual, unconverted methane for higher pressure levels.

The variation of product gas composition in dependence on s/c-ratio and pressure corresponds with the thermodynamic calculation of equilibrium. The values of the H_2 mole fraction are nearly identical with the measured equilibrium data. So for example s/c = 3 and for the pressure 1, 4, 8 bar the H_2 values are calculated to 44,9; 41,2 and 37,1 mole %, while the measured test result are 44,5; 41,4 and 37,3 mole %.

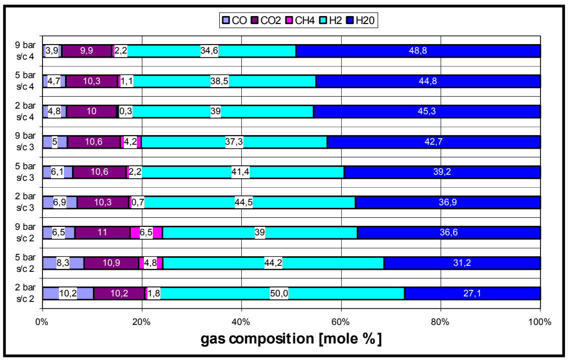

Figure 2.3.3:Gas composition of nickel catalyst in dependence on s/c-ratio and pressure; t =700

3. Reformer investigation

3.1 Design of the ethanol reformer

Based on the results of the catalyst screening an allothermal compact reformer was developed. Figure 3.1.1 illustrates schematically the design of the reforming reactor for an 1 kW fuel cell system. A burner arranged in the centre of the reactor casing supplies the necessary heat for the endothermic reforming reaction and the evaporation heat for the liquid reactants (water and ethanol). Moreover the heat for the starting phase to heat up the casings of the reforming reactor and the both CO-Shift

reactors is supplied by the burner. The radiation burner consists of a cylindrical porous volume. The material of this ceramic body is silicon carbide. The reaction zone of the combustion should be located in the pore volume, so that the ceramic body begins to radiate and the heat is transferred to the inner surfaces of the reactor tube.
The fuel for the radiation burner (waste gas and ethanol) and the air flow separately over the top of the burner into the porous body. The combustion reaction takes place in the porous volume. The exhaust gas leaves the combustion chamber at the bottom of the burner case. This waste heat can be used for the preheating of the air flow which is necessary for the combustion process. The liquid ethanol/water mixture flows at the bottom of the reformer into an internal heat exchanger. This heat exchanger has a function of a preheater and a vaporiser. After the evaporation of the reactants the gaseous ethanol/water mixture streams over the bottom of the reactor into the catalyst fixed bed. The catalyst material is arranged in an annulus between the inner and the outer reactor tube concentric to the cylindrical radiation source. The particle size of the bulk material has a diameter of about 4 mm. The volume of the catalyst fixed bed is about 300 [cm^3]. The material is a commercial nickel catalyst.

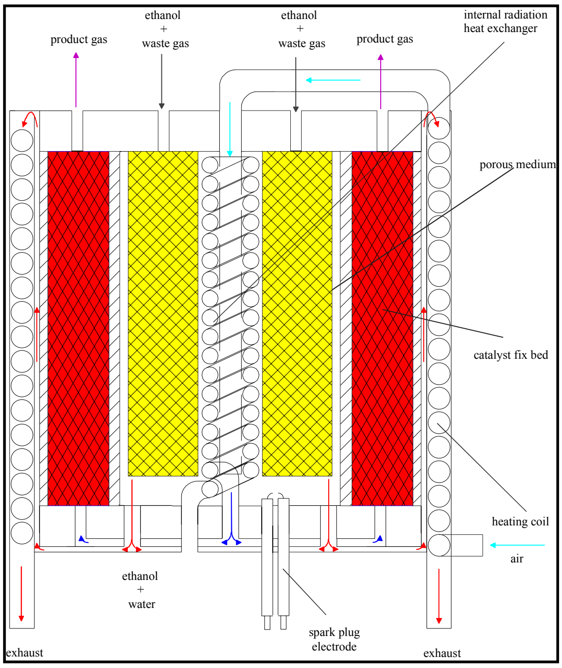

Figure 3.1.1: Schematic design of the compact reformer

3.2 Results of the reformer investigation

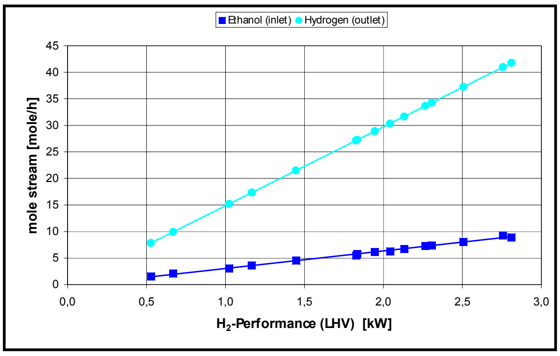

Figure 3.2.1: Performance range of the reformer

Figure 3.2.1 illustrates the investigated power range of the compact reformer. The generated hydrogen performance is in a range from 0,5 up to 3 kW (LHV_{H2}). Moreover the ethanol inlet and the hydrogen outlet mole stream are shown. The diagram 3.2.2 presents the mole stream of the dry product gas in dependence on the generated hydrogen performance (LHV_{H2}) at the reformer outlet.

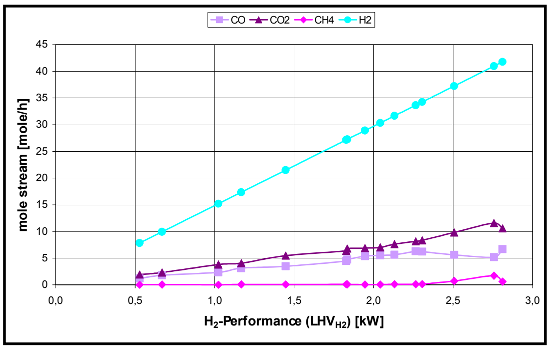

Figure 3.2.2: Mole stream of reformer product gas

4. Burner Development

The heat supply for the endothermic reforming reaction and for the evaporation of the reactants is realised with a porous burner. The advantages of this kind of combustion type is on the one hand the 3-dimensional reaction zone with a large reaction volume, being the reason of the effective burnout of the fuel and consequently of low CO-emission. On the other hand the high effective thermal conduction (about 100 times higher than in a free flame) is an immense advantage. It guarantees a homogeneous temperature profile in the reaction zone, so that no temperature peaks occur. This means low mechanical stress of the reformer material and moreover no thermal NO_x-emission building.

Figure 4.1: Ceramic body of the porous burner

High power density and a stable burner operation is realised as well as a modulation range up to a ratio of 20:1 (2). This is important for the use of a low calorific gas as burner fuel like the waste gas from the regeneration process of the PSA device. The picture 4.1 shows the ceramic body which is used for the radiation burner of the allothermal ethanol reformer. The material of the body is Silicon/Carbid. The hollow ligaments of the ceramic body are filled with silicon. This porous body is manufactured by the Fraunhofer Institute IKTS in Dresden. The porosity of the used porous body is about 30 ppi.

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Latin America Thematic Network on Bioenergy - LAMNET

3rd Project Workshop - Brazil

Timing: 2nd December 2002 – 4th December 2002

Location (3-4 Dec): National Confederation of Industry – CNI
Brazilian Banking Sector North (SBN) – Square 1 – Block C
Edificio Roberto Simonsen
70040-903 Brasilia – DF, Brazil

WORKSHOP PROCEEDINGS

3rd LAMNET Workshop – Brazil 2002

The Electrocatalysis of Ethanol Oxidation

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ABSTRACT

In this paper, the main characteristics of ethanol electrooxidation are presented and the results of electrochemical and spectroscopic methods are discussed. The total oxidation reaction should produce 12 e^-/molecule. However, on Pt catalysts, the reaction follows parallel pathways forming acetaldehyde, acetic acid and carbon dioxide as soluble products. Thus much lower yields of charge per ethanol molecule are obtained. An increase of the CO_2 production is observed at PtRu electrodeposits. Further research looking for more effective catalysts to produce the total oxidation is necessary.

INTRODUCTION

Electrocatalysis as a heterogeneous process

Small organic molecules (methanol, formaldehyde, formic acid, ethanol) are considered candidate materials for operating at the anode of a Fuel Cell (FC). The primary goal of electrocatalysis of FC reactions is finding electrode materials where such reactions occur at potentials as close as possible to their thermodynamic equilibrium potential. This has to be so, in order to have the highest possible potential difference between anode and cathode. However, this is a difficult task since even the simplest alcohol molecules (e.g., CH_3OH) present bonds that have to be stretched, broken or modified in order to convert the molecule into CO_2. Such processes have usually very high activation energies and can therefore occur, at appropriate rates, only in the presence of a catalyst.

From studies of heterogeneous catalysis in the gas phase, it is well known that Pt is a good material to adsorb organic molecules and break intermolecular bonds. Through this process the molecule is broken in particles, which may remain at the catalyst surface as adsorbed radicals, or forms minor stable products which can pass to the gas phase. Similar processes can occur in an electrochemical cell if a Pt sheet is used as an electrode in the presence of an aqueous electrolytic solution of the organic species. However, in the electrochemical cell the catalyst is also an electrode at a given potential. Therefore, the species formed can exchange electrons and become oxidized (or reduced). During the oxidation, water provides, if necessary, oxygen atoms to convert the adsorbed species into CO_2. The role of Pt as catalyst, water as oxygen donor, and the electrode potential as responsible for the electron transfer is displayed in the following scheme representing the electrooxidation reaction of methanol:

1) $Pt(H_2O)_{ad} + CH_3OH \rightarrow Pt(CH_3OH)_{ad} + H_2O$ (methanol adsorption),

2) $Pt(CH_3OH)_{ad} \rightarrow Pt(CO)_{ad} + 4H^+ + 4\,e^-$ (methanol dissociation, e^- exch.),

3) $Pt(OH_2)_{ad} \rightarrow Pt(OH)_{ad} + H^+ + e^-$ (water dissociation, e^- exch..),

4) $Pt(CO)_{ad} + Pt(OH)_{ad} \rightarrow CO_2 + H^+ + e^-$ (CO_2 formation, e^- exch.).

It should be noted that methanol dissociation (Eq. 2) occurs in several steps, but for simplicity, it has been written here as a one step process.

Any of the above processes may be too slow and limit the total rate of reaction. The steps involving electrons can be accelerated by increasing the electrode potential and thus, some energy is lost when current flows through the cell. The increase in potential in order to produce a given current is called overpotential. The nature of the electrode material is a deciding factor determining the overpotential required for a given current level because organic molecules can be adsorbed and dissociated only on metals presenting an appropriate electronic structure. For this purpose, metals having d-orbitals vacancies have shown to be good substrates for adsorbing and dissociating hydrogen. Correspondingly, high current densities for H_2 oxidation occur at relatively low overpotentials and therefore the H_2 /O_2 fuel cell can present an optimum performance. However, organic species are much more complex than H_2 molecules and organic oxidations present, in general, serious kinetic limitations due to their complex oxidation mechanism. This is exemplified above (Eqs. 1-4) for methanol and will be shown in the next sections for ethanol.

Ethanol as a candidate fuel for FC

The desired reactions in an ethanol FC can be formulated as follows:

Anode: $C_2H_5OH + 3H_2O \rightarrow 2CO_2 + 12H^- + 12e^-$ $E^o = 0.085V$

Cathode $O_2 + 8H^+ + 8e^- \rightarrow 4H_2O$ $E^o = 1.23V$

Total $C_2H_5OH + 3O_2 \rightarrow 3H_2O + 2CO_2$ $E^o = 1.145V$

For each reaction, the thermodynamic standard potentials (vs. the standard hydrogen electrode) and the equilibrium potential difference are also given. The cell voltage under standard conditions, 1.145V, is the value for the reversibly working cell, producing CO_2 and delivering 12 electrons per ethanol molecule. Accordingly, ethanol would be very appreciated candidate substance for driving a fuel cell. However, thermodynamic potentials have no useful meaning since no practical system operates under reversible conditions! As explained in the previous section, in order to obtain measurable currents from ethanol oxidation at platinum electrodes, very high overpotentials (>0.4V, i.e., well above the standard value of 0.085V.) are necessary. This can be observed in Fig. 1, where the cyclic voltammogram (CV) during the oxidation of 1mol L^{-1} C_2H_5OH on a monocrystalline Pt(111) electrode is shown. In a CV experiment, the potential is first increased at a constant rate, from 0.05V up to 1.6V and then decreased back to the initial value. In doing this, the current grows and decreases forming peaks at the potentials at which different electrode processes take place.

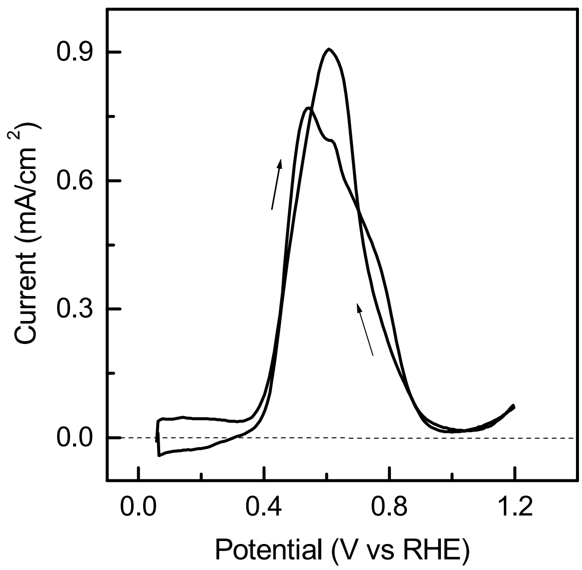

Figure 1: Cyclic Voltammogram for a Pt(111) electrode in 1 mol L^{-1} C_2H_5OH + 0.1 mol L^{-1} $HClO_4$ solution. Sweep rate: 50 mV/s. Room temperature (25 °C).

Obviously, without the help of additional methods, it would be very difficult to establish the nature of the processes that are occurring under the peaks of the voltammogram. Therefore, useful analytical tools have been developed for this purpose, thus allowing to establish the nature of the reaction products and intermediates [1] as a function of the applied potential. On-line mass spectrometry, also called DEMS and in situ Fourier transform infrared spectroscopy (FTIRS) are successfully used in electrocatalysis. These methods are briefly described in the next section.

Use of spectroscopic methods to study ethanol electrocatalysis

On line mass spectrometry

This method uses a mass spectrometer connected directly to the working electrode of a cell, which has been specially designed for this purpose (Fig. 2). The cell has the working electrode assembly at the bottom (see details in the enlargement). This consists of a PTFE membrane covered with the catalyst (porous Pt deposit), which is placed on a porous steel disc. This assembly is the interface between the liquid in the cell and the vacuum at the entrance of the MS. Due to the porous nature of both electrode and membrane, all volatile substances produced on the electrode can enter the MS being immediately detected. Details on the MS construction have been described elsewhere [2]. The most important characteristic of the MS is the very fast entrance and elimination of the analyzed species. Due to this property, the masses can be detected during the application of any potential program as, e.g., a cyclic voltammogram and the responses follow the time dependence of the applied program. This is illustrated in Fig. 3, for the electrooxidation of D-labeled ethanol on a Pt porous electrode. We observe the typical current CV for a polycrystalline Pt electrode (a) and the mass CV for the oxidation products detected through the mass signal m/z = 44 for CO_2 (b) and m/z = 47 for acetaldehyde (c). It is clear, that the current in the CV represents the overlapping of at least two processes: one leading to CO_2 and another one producing acetaldehyde. Thus, this experiment demonstrates that ethanol oxidation on polycrystalline Pt is not complete, leading to a partial oxidation product, acetaldehyde. Moreover, the experiment shows that during the negative-going sweep of the voltammogram, acetaldehyde prevails, only minor quantities of CO_2 being formed.

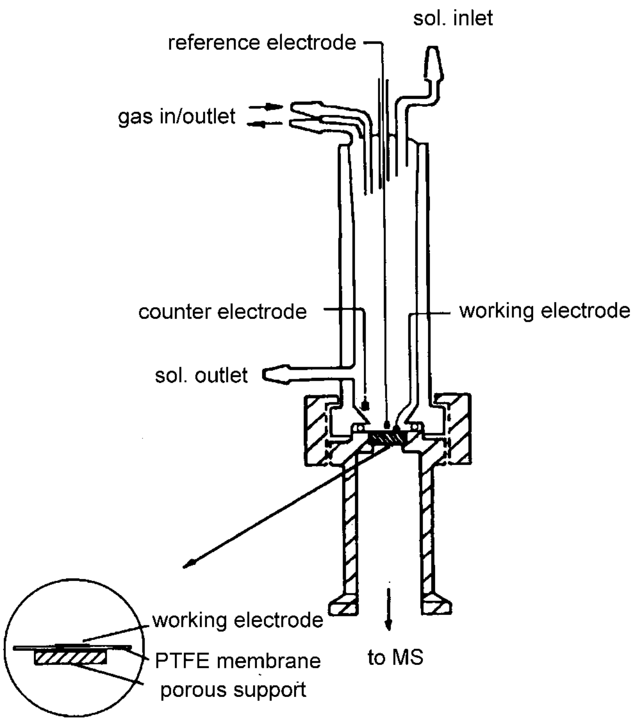

Figure 2: Electrochemical cell for on-line mass spectrometry experiments (DEMS).

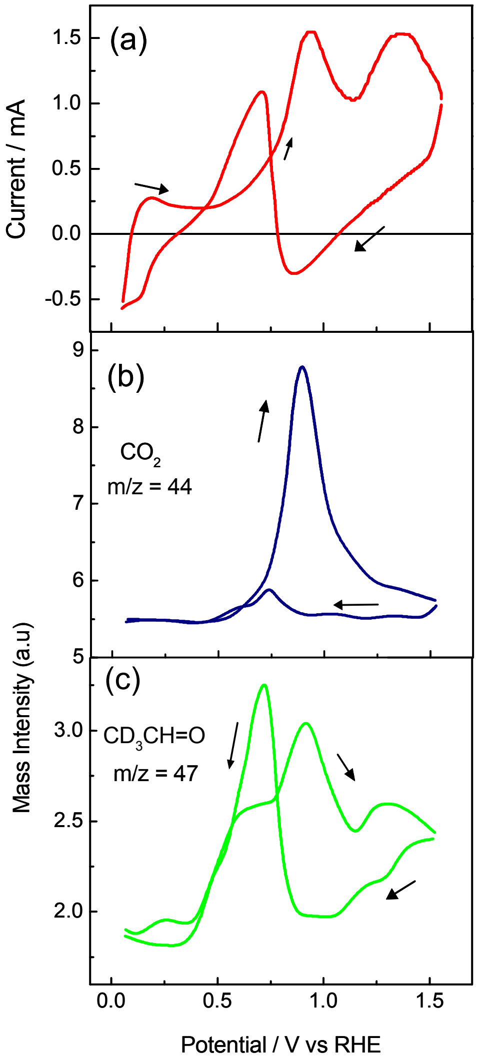

Figure 3: On-line MS experiment for ethanol oxidation. During a cyclic voltammogram at 10 mV/s the current (a) and the mass signals for CO_2 (b) and acetaldehyde (c) were simmultaneously recorded. Electrolyte: 0.05 mol L^{-1} C_2D_5OD + 0.05 mol L^{-1} H_2SO_4.

In situ FTIR Spectroscopy

In this method, the electrochemical cell (Fig. 4a) is mounted in the path of the IR beam. A mirror-polished disc is used as a working electrode. It is placed against the IR window, at the bottom of the cell letting in between a thin layer of electrolyte (1-10μm) (Fig.4b). The use of this thin layer configuration minimizes the absorption of IR light by the solvent. Spectra are calculated as the ratio of two single beam spectra obtained at two different potentials. The spectrum at one of these potentials is used as a reference. Preferentially, a potential where no reaction occurs is taken for this purpose. So, the changes occurring at the second potential are monitored. Since the solution is confined in the thin layer cavity between electrode and IR-window, soluble species need very long time to diffuse into and away from the cavity and thus, spectral features will be observed due to formation and consumption of species. More details on the method are given elsewhere [3].

Fig. 5 shows spectra obtained during the application of a series of potentials at a Pt(100) electrode in the presence of ethanol [4]. A spectrum at 0.05V was used as a reference. The negative bands refer to substances formed at the indicated potentials, while the positive bands are due to ethanol consumed during its oxidation.

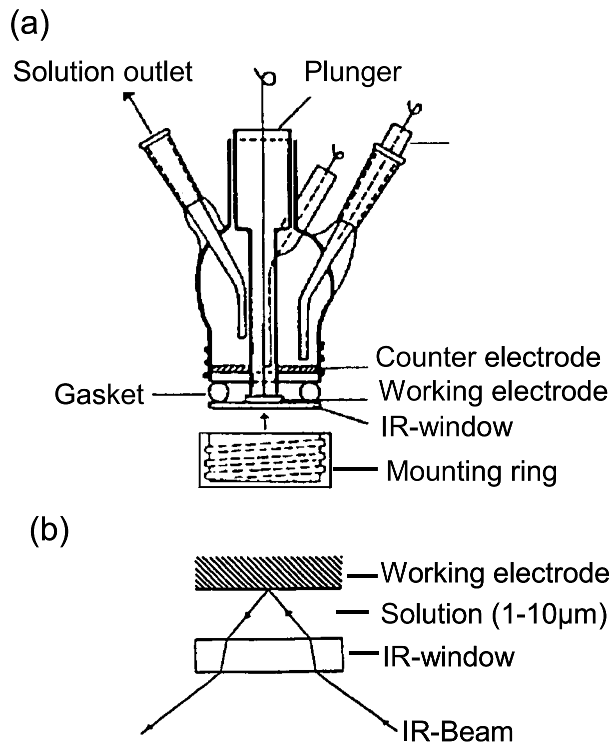

Figure 4: (a) Electrochemical cell for FTIR measurements. (b) Schematic representation (not to scale), of the thin-layer configuration for in situ IR measurements.

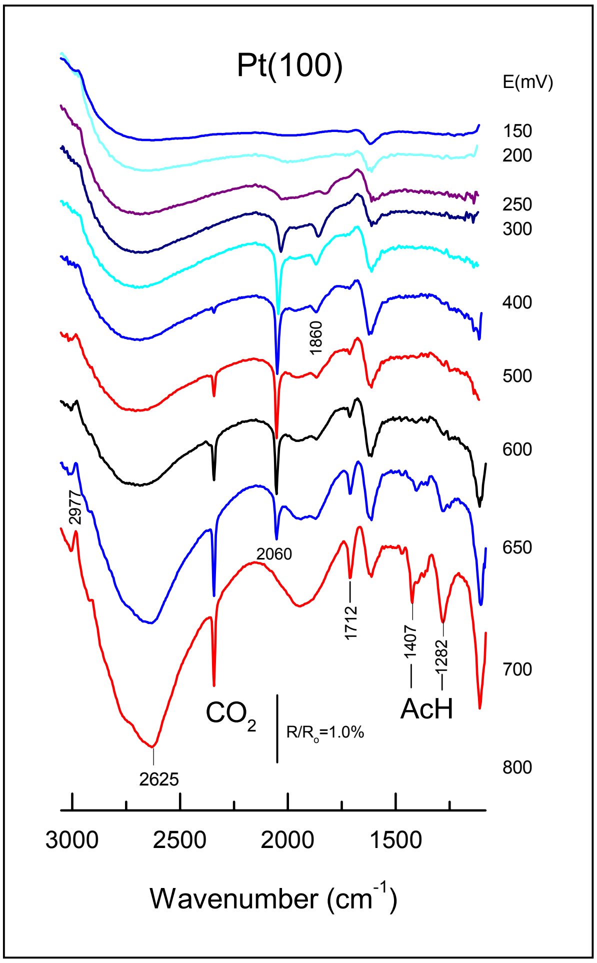

Figure 5: In situ FTIR spectra (256 scans, 8 cm^{-1} resolution) at Pt(100) in 0.1 M CH_3CH_2OH + 0.1 M $HClO_4$. The reference spectrum was collected at 50 mV and the sample spectra were measured after applying potential steps towards more positive potentials as indicated in the figure [4].

The negative bands observed are due to the products CO_2, acetic acid and acetaldehyde. Band assignments are given in Table 1. Also, two bands due to linearly and bridge bonded CO as adsorbed reaction intermediate are observed at ca. 2050 cm^{-1} and 1850 cm^{-1}. Another adsorbed molecule fragments containing C-H bonds have been reported from IR and on–line MS experiments on polycrystalline Pt [7]. However, such intermediates are finally oxidized to CO_2, at very high potentials.

Wavenumber / cm^{-1}	Functional group or chemical species	Mode, comments, refs.
2977	CH_3, CH_2	C-H str. [5]
2625 (broad)	COOH	O-H str. [5]
2341	CO_2	C-O asym. str. [5]
2055-2060	adsorbed CO	linearly bonded
1860	adsorbed CO	bridge bonded
1712	COOH or CHO	C=O str., carbonyl [5]
1412	CH	C-H deformation
1370/1281	COOH	coupl. C-O str.- OH def. [5]
1100	ClO_4^-	Cl-O str. (F) [6]

TABLE 1: Assignment of some of the fundamental bands in the spectra of Fig. 5

Parallel pathways of ethanol oxidation

The results presented in the preceding sections show that ethanol oxidation undergoes parallel pathways leading to different soluble products as shown in the scheme of Fig. 6. We observe, that depending on the final product, 2, 4, or 12 electrons can be delivered per ethanol molecule. This scheme describes in a synthetic manner, one of the main problems of ethanol electrooxidation, (1) a considerable loss of the available energy occurs when the ethanol molecule is oxidized to acetaldehyde or acetic acid and (2) acetaldehyde is an undesirable, highly volatile substance.

$$C_2H_5OH + 3(H_2O) \longrightarrow 2CO_2 + 12H^+ + 12e^-$$

$$\downarrow - 2H^+ - 2e^-$$

$$CH_3CH \quad + 3(H_2O) \longrightarrow 2CO_2 + 10H^+ + 10e^-$$

$$+ H_2O \downarrow - 2H^+ -$$

$$CH_3COOH$$

Figure 6: Parallel pathways during ethanol oxidation at Pt electrodes in acid solutions.

Use of a binary PtRu catalysts for ethanol electrooxidation

It is well known that PtRu materials are good catalysts for methanol oxidation [8]. The benefits of Ru has been assigned to the promotion of water dissociation (see Eq. 3). Ru is able to dissociate water at potentials as low as 0.2V, lowering in this way the potential for the oxidation of the methanol intermediate CO (see Eq. 4). A similar effect should be expected for ethanol oxidation, since also in this case CO is formed as a reaction intermediate in the pathway producing CO_2 (Fig. 6). Thus, infrared results showing an increase of CO_2 production in the presence of Ru, have been reported [9]. In Fig. 7 FTIR spectra for ethanol oxidation at two different PtRu materials are shown, both of identical atom composition Pt:Ru = 50:50. One is a smooth alloy and the other, an deposit of Pt and Ru on Au, prepared through electrolysis in a solution containing equal molar concentration of Pt and Ru. The resulting deposit contains approximately the same atom ratio of Pt and Ru. It can be clearly seen that the latter produces a higher ratio of CO_2 to acetic acid than the former. With other words, the surface structure of the catalyst plays an important role in determining the yields of products.

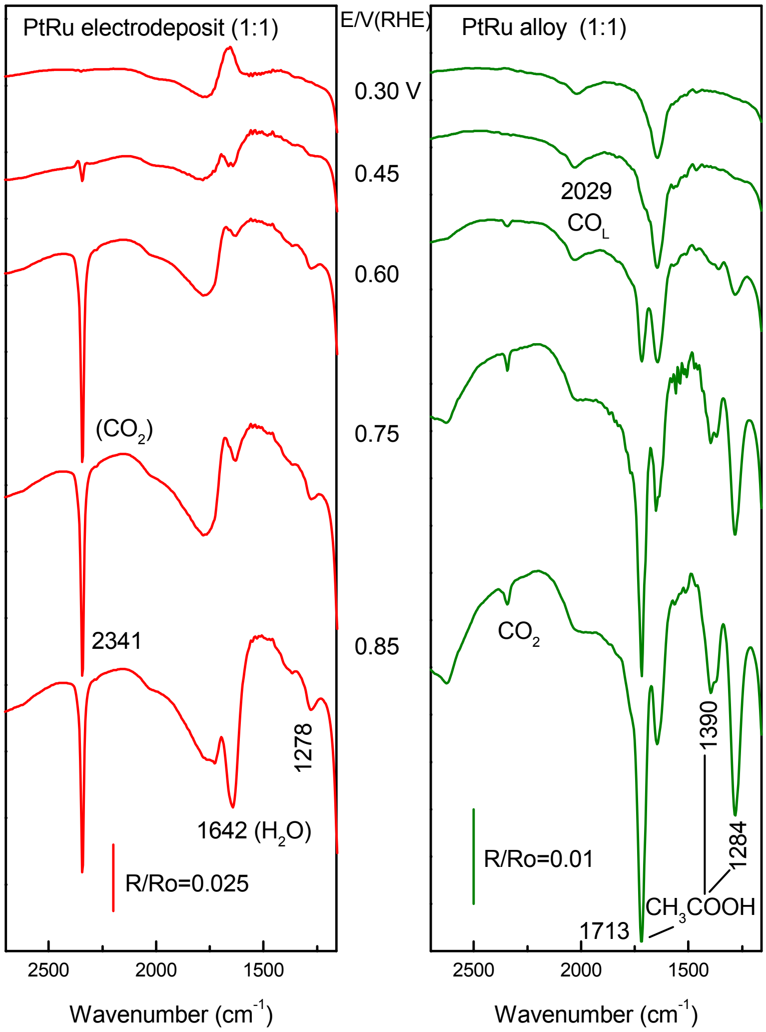

Figure 7: FTIR reflectance spectra during oxidation of 0.1M C_2H_5OH in 0.1M $HClO_4$, using a (1:1) Pt Ru electrodeposit on a gold substrate and a (1:1) PtRu alloy. Note the differences in the ratio of the bands for CO_2 (2341 cm^{-1}) and acetic acid (bands at 1284 cm^{-1}, 1390 cm^{-1} and 1717 cm^{-1}).

Outlook

The results above show the complexity of the ethanol electrocatalysis. The main difficulty lies in the finding of a catalyst being able to break the C-C bond, forming small molecule fragments, which should be able to be oxidized at relatively low potentials. Preliminary experiments using PtRu electrodeposits indicate an enhanced activity of this catalyst towards the total oxidation reaction. This result shows the directions that can be followed in the search for more appropriate catalysts for the reaction.

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3rd LAMNET Workshop – Brazil 2002

Challenges and opportunities of ethanol based Fuel Cells

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The Brazilian National Reference Center for Hydrogen Energy (CENEH) was launched in March 2001 and it is located at the University of Campinas, São Paulo State. The objectives of CENEH are the implementation of research activities and studies on fuel cells and the energetic use of hydrogen, the collection and diffusion of information and, finally, assistance in the formulation of energy policies.

In November 2002 a Brazilian Program on Fuel Cell Systems was launched which aims at the coordination of investment and R&D projects in this field promising the opportunity to open new markets for the use of ethanol and to create new business opportunities in Brazil.

Advantages of Fuel Cells:

- Direct conversion of chemical energy into electric energy
- Conversion efficiency superior to thermal devices
- No moving parts, low noise levels
- Modular structure facilitate adjustment to the load and thereby increase reliability
- Fast response to load changes
- Very low or zero emission of SO_x, NO_x, CO_2 and organic compounds

Disadvantages of Fuel Cells:

- High costs
- Low lifetime and recyclability
- Hydrogen production/distribution infrastructure is not existent
- Use of large quantities of noble metals
- Little public awareness

Environmental Aspects

- When evaluating costs associated to emissions, technologies that use hydrogen and renewable energies as ethanol will take advantage
- Devices operating under thermal cycles usually are less efficient and more pollutant than systems with fuel cells
- Brazilian case: good perspectives in associating ethanol with fuel cells (direct use or hydrogen from reforming)

Final Considerations

- News about fuel cells may imply that the technology is ready for commercialisation and that fuel cells may be easily found in the market

but:
  - Few models are commercially available
  - Costs are still very high
  - Materials may be difficult to obtain (noble metals)

- In the case of ethanol, the production and distribution infrastructure must ensure that the fuel is free from contaminants which can poison the fuel cells
- As the lifetime increases, the effects of micro-contaminants will be better known
- Standards should be developed for handling and storing ethanol and hydrogen
- Market niches may be profitable if well exploited
- Back-up systems and portable applications, in which the efficiency and durability are not necessarily high, constitute an important niche market for direct fuel cells

Additional information is provided in the Power Point Presentation Viewgraphs available at the LAMNET project web site **www.bioenergy-lamnet.org/events/events.html**.

3rd LAMNET Workshop – Brazil 2002

Panel Discussion: Challenges and opportunities of ethanol based FC

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The following statements were agreed upon in this panel discussion on ethanol fuel cells:

- Today, the fuel cell technology is not ready for commercialisation yet. The costs are at approximately 5000 US$/kW and a competitive price of 1700 US$/kW still has to be realised.
- Fuel cells have a higher efficiency and a lower pollution level compared to combustion engines and will therefore contribute to the world’s future cleaner energy supply. Hydrogen, which is believed to become an important energy carrier of the future, will be converted to energy services in fuel cells.
- Bio-Ethanol is a fuel with a low level of contaminants and it can be provided at fuel stations (e.g. in Brazil) with high purity. Bio-Ethanol therefore is a promising fuel for fuel cells, but research on potential micro-contaminants has to be performed to ensure safe operation of FC.
- Today, the complete oxidation of ethanol still is a problem and research is required in order to find a good catalyst.
- Ethanol Fuel Cells, both direct conversion or via reforming, are currently still in the R&D stage.
- Nevertheless, it is believed that mobile applications of ethanol based fuel cells have a very large potential and it is recommended to boost research and investment in this field.

Wednesday Afternoon Session: Innovative Bioenergy Technologies

3rd LAMNET Workshop – Brazil 2002

Decentralised energy self-sufficient supply and disposal systems

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1. Summary

Sources of fossil energy and water are increasingly diminishing. Particularly on islands there is a partial or complete lack of these resources. For that reason concepts with the goal of replacing fossil energy using an absolute minimum of water must be developed.

Sources of fossil energy can only be replaced with techniques that make use of solar energy such as photovoltaic, wind, implementing water for energy such as hydroelectric dams and through production of energy in processes such as anaerobic fermentation (the use of methane gas that is formed in fermentation, for instance in a co-generated power-station (coupling of power and heat) for the production of heat and energy.) Small villages, rural settlements, hotels and chalets are often located outside of the bounds of the conventional energy supply and disposal systems that communities and public offer. Because this locations are often situated in very ecologically sensitive areas, it is particularly necessary to make very rational use of water and energy there.

The current concepts for the supply of electricity to islands and island systems are mostly based on the use of solar cells with battery storage and a diesel power unit to bridge the peak loads and periods of bad weather. Including water and waste disposal in these systems, demands a new ecological-oriented, holistic perspective without which the energy needed for waste disposal can double the energy consumption for the entire island systems.

Here, new and comprehensive concepts for supply and waste disposal are called for which can provide a reliable and self-sufficient operation. In this paper, the separate components of energy and water supply as well as sewage purification and treatment of organic waste for a self-sufficient supply and waste disposal system for island and island systems will be presented.

2. Introduction

In order to decrease global warming and the resulting negative effects on our climate, it is necessary to radically reduce the emission levels of CO_2 caused by our use of energy. Beyond that, it is a matter of principle to conserve the limited resources and to reduce the levels of pollution caused by the use of energy. The reliable supply of energy which can fulfil both economic and ecological demands, is an essential foundation for the economic and ecological development of modern industrial society, where international competition is strong. Research and development focussing on the rational use of energy and renewable energy sources make considerable contributions to the spread of a scientific and technical foundation for the economic system and thereby to securing quality of life.

A large range of procedures using renewable energy sources already exists, for instance wind and solar energy, hydro- and geothermal power and the use of biomass. Technologies for the energetic use of biomass have already reached a high technological level. Included are the already widely used thermal conversion and the production of biogas using typical basic substratum and relatively simple installations (for instance in agriculture).

The energetic use of biomass not only allows the reduction of CO_2 and conservation of resources, but also has the advantage of generating employment in various regions, giving added income to farmers as well as providing products and opening up markets for middleclass enterprises. There is also a future market, particularly for the producing nations, to export these technical installations.

European Dimensions

In its white book, "Energy for the Future: Renewable Sources of Energy," the European Commission has set an ambitious goal for the future use of renewable energy. By the year 2010, 12% of the gross use of federal energy in the European Union should be provided by renewable energy sources. In order to attain this goal, the use of biomass and other technologies must be tripled. Concretely this means that a considerable increase in production of heat and fuel and an increase of 10 fold in the production of electricity will be covered by use of biomass. Of the 120 million additional tons RöE, renewable energy such as biomass should make a sizable contribution to the gross federal consumption of the European Union, namely approximately 90 million tons RöE, this being 75 % of the entire sources of energy. The resulting investment sum for the European sector by the year 2010 in bioenergy is 400 billion DM.

Because of these estimates, the energetic use of biomass has considerable short and middle term market potential. The mentioned 90 million t RöE (which corresponds to a biomass equivalent of 340 million t of wood, approximately) must be planted, harvested or gathered, prepared and transported. This will lead to a considerable increase in employment in the area of biomass production and suppliers, for instance from agriculture and forestry.

3. Supply and Disposal Concepts

With appropriate choice for dimensions, various supply and disposal components can be designed to a self-sufficient system for installations on islands. Management systems (for instance in reference to energy) which take the technical procedural necessities as well as cost aspects into account are especially important for an operation which is both suitable for the situation and economically viable. The goal of developing supply and disposal concepts should be to replace the fossil energy sources using the absolute minimum of water.

The supply and disposal concepts should be appropriate for the various different conditions of locality, for instance isolated hotels, farms, chalets etc. For example the co-generated power-station (coupling of electricity and heat) is only available on the market with the size of approx. 5 $kW_{electric}$. In order to assure that this is employed economically, adequate fuel must be available.

The following is a discussion of individual components for energy and water supply as well as sewage purification and organic waste treatment.

3.1 Energy Supply

Where no central energy supply is available, diesel power units are often used. But because of its detrimental effect on the environment, a diesel power unit is not a good alternative. Using renewable energy sources is advisable because of the solutions they offer. With respect to the geographical and topographical location of settlements, villages or isolated hotels and chalet, the following self-sufficient systems can be implemented and when necessary, they can be linked together as hybrid systems (see Figure 1):

- Photovoltaic systems
- Wind power systems
- Water turbines
- Solar collector panels
- Co-generated Power-Stations (fuelled with biogas or plant oil) and
- Oil, natural or Propane gas storage as a security measure

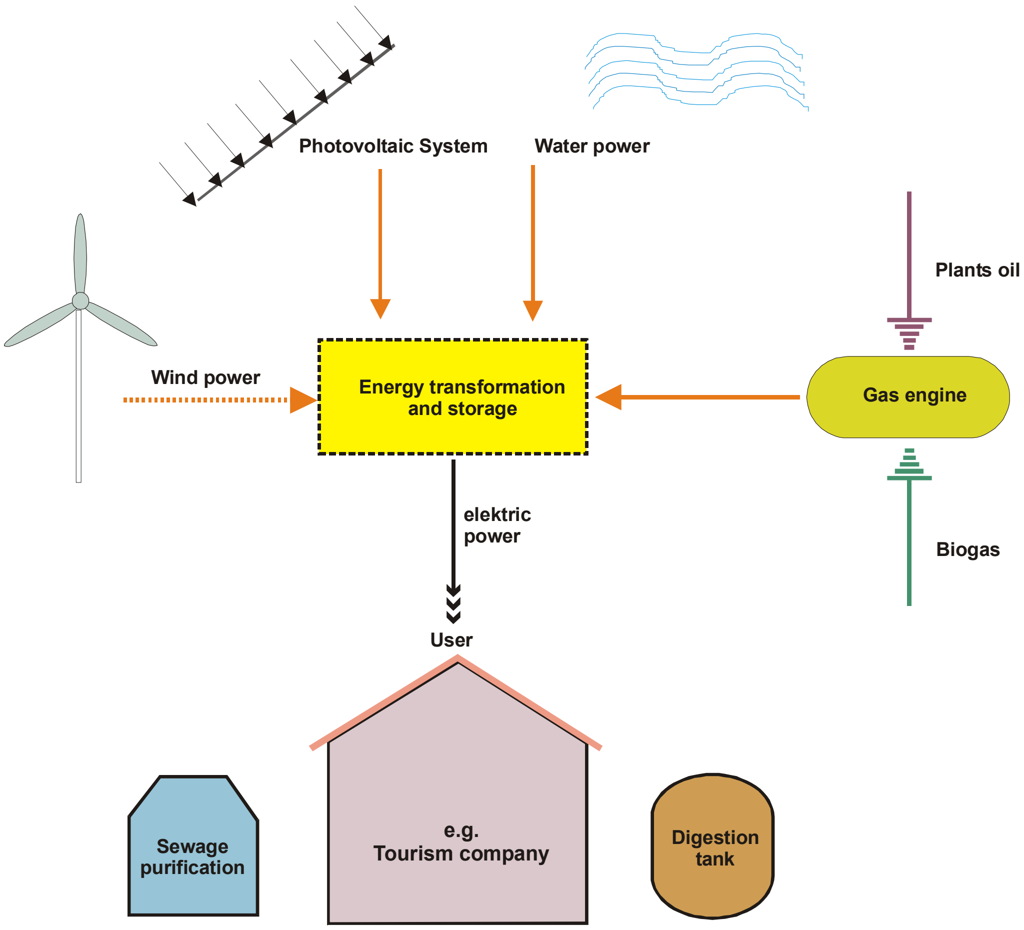

Figure 1: Renewable Energy Supply

3.2 Water Supply

The supply of water for drinking and other uses is made available for decentralised consumers by pipes for drinking water from public water suppliers, wells or springs, rain or surface water.

There is much potential to save or to avoid using water: For instance, drinking water quality should not be used for cleaning and watering.

In the following, only the decentralised water supply will be discussed, this being a difficult problem to solve for isolated structures.

3.2.1 Water Transport

If wells are used to supply drinking water, then the water available must be hauled up with pumps. Because running these pumps only requires a steady flow of low-energy, renewable energy sources can be used here. The dimension and size of the pumps is dependent on the height and amount of the water to be hauled up; the energy supply can thus be suited to individual needs. Wind and/or solar energy can be used as the energy source for pumping systems in wells.

3.2.2 Use of Rain Water

By using rain water, the use of water can be economised, valuable water resources can be conserved and less cost is involved to produce and transport drinking water.

Even though Europe belongs to a region of the earth with the most abundant supply of water, there are big regional differences in availability of water. There are areas where water is lacking as well as areas in which the water level is falling due to the high degree of surface sealing. For that reason, using drinking water sparingly and making use of rain water are effective strategies for water conservation.

By using rain water to flush toilets, sprinkle the lawn and to wash clothes, ca. 33 % of the daily use of water can be saved; using it for drinking water after it has been purified will bring 100 % conservation. From an ecological point of view it is sensible to store and use rain water close to where it fell and allow it to seep into the ground, instead of letting it run out as quickly as possible directly or indirectly into surface water reservoirs. Hereby there is not only a reduction of the water pollution load, but also increased evaporation and ground water levels, contributing to improvements in the regional hydrological balance.

3.2.3 Water treatment

If the water, taken for drinking, comes from wells, springs, surface and rain water, it can carry along various contents from its origin. For that reason the water must be purified and degerminated.

From the various technologies for purification of water, only the use of filters as a particularly simple process requiring only low specific energy and membranes as a particularly efficient and diverse method will be dealt with.

Water purification of water using Filters

Slow and fast reacting filters are used for this process, whereby the slow reacting filter (5-20 cm/h) have a physical, chemical and biological effect. The effective portion of the filter is situated mostly in its top layer which can be peeled off when the filter is used up (increased resistance of the filter). Usually sand is used as filter material.

Fast reacting filters (4 - 7 m/h for open, 10 - 20 m/h for closed filters) can be backwashed and act as space filters. Depending on the various purposes for filtration, different materials are used, for instance quartz, sand, anthracite and activated carbon. For special tasks, filter materials are used which react specifically to the contents in the water.

These methods of filtration require only minimal specific energy. Other than having a pump, slow reacting filters need energy only for peeling off the top of the filter layer (if it is automatic) and fast reacting filters need energy only for the backwashing. These can be supplied through renewable energy sources.

Water Purification using Membranes

Using membranes, various different contents can be filtered out of the water such as bacteria, dyes, calcium, salt etc. The disadvantage of the procedure is the relative high use of energy, which however can be provided by renewable energy sources. Figure 2 shows the schematic plan of a simple installation using membranes and renewable energy sources.

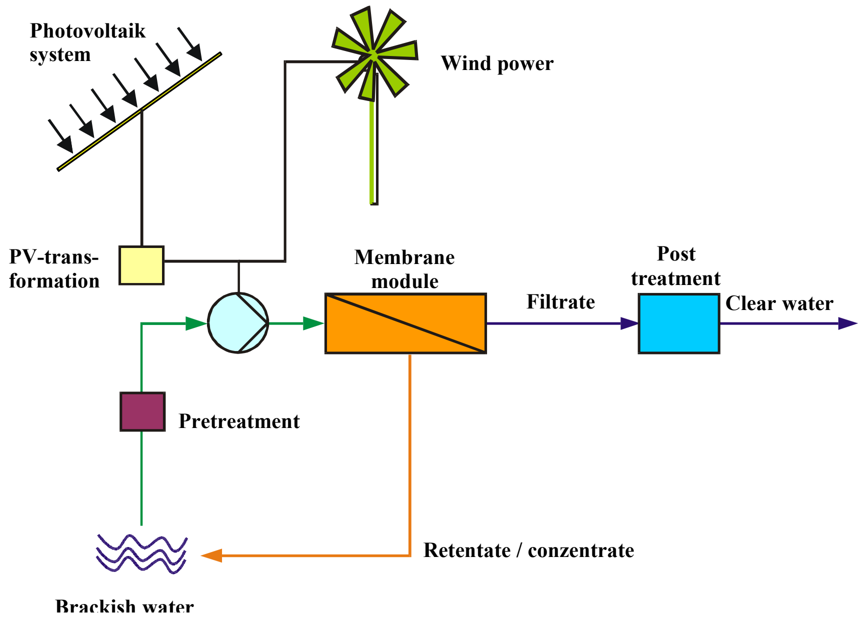

Figure 2: Water Purification Installation

Depending on which measure of water purification and the size of the particles that need to be removed, different procedures will be applied:

- micro-, ultra- or nanofiltering,
- electrodialysis and
- reverse osmosis.

In very warm climate zones condensation is made use of to obtain fresh water.

<u>Desalination</u>

A special field of the water treatment is the desalination of sea water. Actually the methods for desalination of seawater are thermodynamic ones or based on reverse osmosis. All of them are working on a very high energy level. Therefore labscale experiments were used to develop another desalination-technology focusing on a lower energy consumption. One of the possibilities to be used for drinking water extraction is the membrane distillation.

At the moment engineers of ISET are working with this technology for finding out the special conditions of a perfect operation. Figure 3 shows the experimental plant at ISET e.V., Hanau.

Figure 3: Experimental plant of membrane distillation

Water De-germination

In order to destroy possible bacteria, drinking water must be de-germinated. De-germination through UV and the combination of UV-H_20_2 can be recommended here. The use of UV lights for de-germinating drinking water has long been practiced successfully.

The advantage of this procedure is that no chemical substances are introduced and no chemical reactions are initiated while destroying the bacteria. The disadvantage is that de-germination effects are short-lived; after 24 hours the water can begin to germinate again.

A relatively low energy d de-germination process using UV can be easily implemented, combining photovoltaic installations as the energy supplier. If, in addition to UV radiation, H_2O_2 is used, many organic contents in the water can be eliminated. Figure 4 shows a water de-germination system through UV designed by the Company VitaTec UV-Systeme GmbH, Freigericht/Germany in co-operation with ISET e.V. Kassel/Germany).

Figure 4: Water de-germination system (Ca. VitaTec in co-operation with ISET e.V.)

3.3 Sewage Purification

Taking the surrounding population and the location into account, small and decentralised sewage treatment plants can be constructed for isolated hotels, farms, small settlements, chalets etc.

In the case of a permanent decentralised sewage disposal, the purified water should be dumped into an appropriate receiving body of water, or after thorough inspection in individual cases, it can be allowed to seep into the ground. Only sewage (not rain water) should be allowed to be dumped into small and decentralised sewage treatment plants. Only installations that can deal with the demands to minimise the noxious substances should be implemented (in Germany this is in correspondence to §7a WHG), i.e. the small and decentralised sewage treatment plant must fit the requirements for biological treatment.

The following can be applied for the biological level:

- Procedure with technical sewage aeration: activated sludge plants or fixed bed, trickling filter and rotating disc filter installations (DIN 4261, Part 2),
- Natural procedures: sewage treatment systems using plants, ditches with two-layers of sand, sand filter pits and soil filter
- Procedure with anaerobic digestion

The choice of which method will be used is dependent on the specific topographical, geographical and climatic conditions and from the kind of sewage that is to be purified.

The following components of sewage purification should in any case be applied:

- Separation of coarse matter
- Equalising or regulation tank
- Biological purification – aerobic and anaerobic (for methods with technical aeration, in including separation and return of sludge)

The purified sewage can then be re-used for sprinkling and irrigation and/or cleaning purposes.

3.4 Treatment of Organic Waste

In this paper, only the treatment of organic waste is dealt with because it can be used for the supply of energy and heat. Organic waste includes biological waste and human excrement. Until now biological waste has only been composted in the best of cases, and then used to fertilise other plants. The surplus sludge from the sewage treatment is usually simultaneously stabilised at the small sewage treatment plants and used for agricultural purposes. With this method, carbon is converted but no profit is made out of it.

In order to make use of the carbon in organic waste, the biological waste and the excess sludge from sewage treatment is allowed to anaerobically ferment which means shutting off its contact to the air. In order to make economic use of the fermentation, further organic substances such as faeces, urine, sewage from the kitchen including fat and screenings from sewage treatment (only organic matter) are fermented together. The biogas or digester gas that is produced in this fermentation process is made up of 60 to 70 % of methane gas and can be used in a co-generated power-station to produce electricity and heat. Some portion of the resulting heat is needed, however to maintain the fermentation process. The rotted sludge can then be composted and used as fertiliser. In figure 5, anaerobic fermentation of the different substances is depicted.

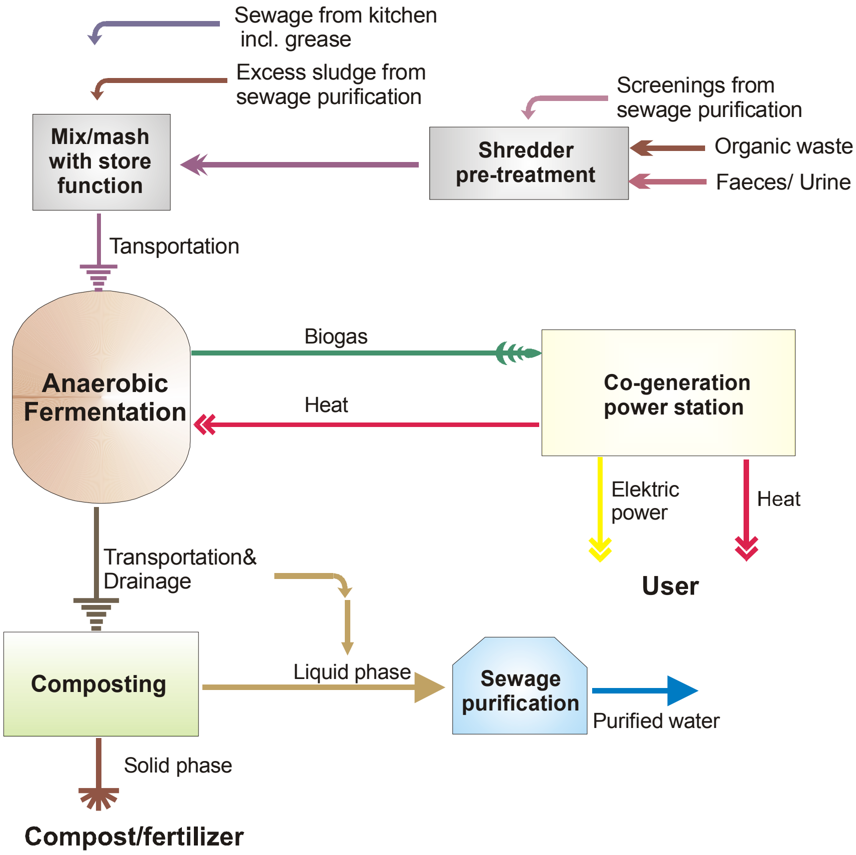

Figure 5: Anaerobic fermentation

4. Example of an Energy Self-Sufficient Supply and Disposal Concept

A possible comprehensive concept which conserves water and produces energy is the anaerobic fermentation of faeces, urine, biological waste, sewage water from the kitchen and excess sludge from sewage purification. In combination with a treatment of residual sewage from bath basins, showers, bath tubs and washing machines and the liquid phase of the anaerobic fermentation. This can be added into doses from a buffer container.

The purified sewage can then be re-used for sprinkling and irrigation and/or cleaning purposes. The heat and energy from the biogas which is produced in the co-generated power-station can be used for the operation of fermentation and purification of the sewage water. The surplus can be channelled to the consumer (households, chalets, etc.). The remaining need for heating can be generated with solar energy. The solar system can also be used to secure the supply of energy to purify and de-germinate spring or rain for drinking and other uses.

Such a concept has the following advantages:

- emission free production of electricity through photovoltaic, wind and/or hydro-power
- emission free generation of heat through solar cells (water- or air collectors)
- acquiring digester biogas (fuel)
- thorough use of fuel through co-generated power-stations (coupling of electricity/heat)
- conservation of water by using the dry latrine
- only the purification of residual sewage, making for very clean sewage
- reduction of waste by using fermentation of the biological portion
- saving of diesel oil
- no soot- and smell-emissions
- an installation which is very simple and easy to operate

Taking a hotel as an special example

Using this concept with anaerobic fermentation and purification of residual sewage in a small hotel which operates all year with 20.000 overnight guests, with an energy requirement of approx. 190.000 kWh/year,
the following components are necessary:

- photovoltaic generator with approx. 100 m^2
- solar collector panel with approx. 65 m^2
- digestion container with approx. 8 m^2
- gas storage
- co-generated power station
- purification of residual sewage water
- if necessary storage for propane, natural gas or oil to be used as a reserve source

This example is a very special example, the concept depends extremely to the various different conditions of locality.

In table 1, the individual components for the provision of energy with the application of energy, the energy offered and the total energy consumption is depicted.

Table 1: Total energy of a small, special hotel with a self-sufficient supply of energy.

Energy Supply	Energy Use	Total Energy
Biogas Solar collector panel	Hot water/heating Hot water	63.000 kWh
Biogas Photovoltaic system	Electricity Electricity (lightning, kitchen appliance, pumps, degermination etc.)	39.200 kWh
Wood	Heating house/kitchen	72.000 kWh
Natural gas or oil	Cooking, lightning	12.800 kWh
	Total Amount	**187.000 kWh**

Result: *With the use of biogas and solar cells and collector panels up to 9.000 litre of heating oil can be conserved.*

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Additional information is provided in the Power Point Presentation Viewgraphs available at the LAMNET project web site **www.bioenergy-lamnet.org/events/events.html**.

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Technological and economical analysis of innovative bioenergy systems

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Survey on bioenergy technologies that have reached a commercial state of development

The following technologies can play a strategic role for a sustainable rural development:

1. **Innovative, cost-effective (25 $ per ton of pellets), low-energy input (40 - 50 kWhe/t), Pelletisation Units** for simultaneous drying & pelletisation (ϕ 6 – 12 mm) of a variety of types and mixtures of humid biomass (without any binding compound).

   Capacity range available: 1 $\rightarrow$ 5 t/hr.

   Mobile Units will be commercially available until 2004. This technology is of universal value for the exploitation and large-scale utilisation of any type of biomass, because it solves the problem of permanent storage of the resources, and it simplifies the handling and logistics of biomass (Humidity of pellets ~10%; specific density ~1.4 g/cm^3; bulk density ~0.6 – 0.7 t/m^3).

   The lifetime of pelletisation machines exceed 15 years (substitution of bearings every 20,000 hr of operation)

2. **Small Cogeneration Units**

   Capacity range commercially available by the end of 2003: 25, 50 and 100 kWe

   These systems are based on pellets combustion/boiler and high efficiency steam-engine and generator units.

   Various types of liquid and gaseous biofuels can be utilised (i.e. biogas, low grade bioethanol (95°), vegetal oils, LHV/MHV gas, etc…)

   Total electrical efficiency : ~22%.

   Useful heat (steam) available ~2.3 kWth per kWe produced.

   Pollutant emissions control within the EC/Swedish standards.

   Specific investments similar to that of MWe biomass generators (~1,200 $/kWe).

   Cooling/freezing or tri-generation can be easily obtained (steam is available) adopting conventional technologies. Potential markets: (groups of houses, villages, shopping centres, hotels, tourist centres, clinics, schools, agro-industrial processing centres, S.M.E., Co-operatives, small sea-water desalination systems for remote sites etc…)

3. **Syn-Gas Generators** (via Steam Reforming of Charcoal pellets)

   Resource: any type of biomass (i.e. agro/forestry residues, wastes, herbaceous crops, dedicated energy crops etc…)

   Technology: innovative 3-step process (patent pending).

   A small unit (3.5 kg pellets/hr) will be able to supply and distribute cooking MHV gas to ~100 village peoples (all the year around). Commercial Units up to 60,000 t pellets/year able to supply cooking fuels for 200,000 people can be made available.

The production cost of this Bio-syn-gas in the E.U. is estimated at ~140 $/t (315 $/TOE) assuming a cost of biomass (residues, wastes…) of 40 $/t (10% humidity). In China, Africa and Developing Countries the production cost may be ~80 $/t (180 $/TOE), and therefore competitive with LPG (consumer cost in Italy at 1,620 $/TOE, in rural China 210-400 $/TOE in Africa 630 $/TOE. The same technology can be utilised also for 100% hydrogen production (adding a conventional CO-shift reactor).

Economic evaluation anticipates hydrogen production costs in the EU of ~1,500 $/t from low-grade biomass costing 40€/d.t. Today, hydrogen from biomass is more expensive than hydrogen obtained from Natural gas (1,200 $/t), but it is less expensive than hydrogen obtained from coal or heavy oil, due to the higher purification costs.

This syn-gas can be utilised eventually to feed small Micro-Turbine-Gas cogeneration units (30-100 kWe).

4. **Micro Distilleries for Bioethanol**

Capacity range: 5 – 10 m^3/day

Many types of sugar and starch crops can be utilised. Normally, low grade (95°) bioethanol production is envisaged.

Great advantages offered by special varieties of sweet-sorghum (developed in China) Decentralised production of bioethanol in small distilleries (in parallel to centralised production by large plants) can be envisaged.

5. **Biofuel Driven Microgas-Turbine Cogeneration/Trigeneration Systems** (low-grade ethanol, vegetal-oil, bio-syn-gas, biogas,…..)

- Specific investment: ~850 € / KWe (generator only)
- Very low NOx and CO particulate emissions
- Very low operating (man power) cost
- Very suitable for trigeneration: production of electricity + heat + cooling
- Interesting for peak-power supply
- Potential interesting markets: Hotels, schools, tourist resorts, clinics, islands, Small desalination plants, agro-industries

6. **Clean Carbonisation Plants for Charcoal Pellets Production from any Type of Biomass** (agro-forestry residues, wastes, grasses, energy crops or biomass mixtures etc…)
   - Capacity range: 500 t/y – 30,000 t/y
   - Specific investment ~360 $ per ton of charcoal per year
   - Production cost of charcoal (Biomass cost ≈ 40 €/d. ton ~ 40% humidity): ~160 $/t. (in China: 100 - 120 $/ton)

7. **Plants for the Production of Activated-coal from Low Quality Biomass** (agro forestry residues, wastes grass, energy crops, or mixtures …)
   - Capacity range: 100 t/y - 10,000t/y
   - Specific Investment : ~1,200 $ per ton of activated coal per year
   - Production cost (Biomass Cost about 40 €/t) :~660 $/t
   - Utilisation for all purification process of liquid-gases; i.e. drinking water purification
   - Purification Process for petrochemical complexes, agro-industrial processing plants etc.

8. **Biogas Plants**

9. **Heating, Climatisation, Freezing Units utilising Biofuels**. A large variety of commercial absorption refrigeration systems are available.

10. **Biomass Power Plant** (3 - 5 MWe) fuelled by Solid Biomass or Liquid Bio-fuels (low-grade bioethanol/gas turbines) are commercially available in the EU.

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Republic of South Africa: Renewable Energy Strategy

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The strategy to promote the use of renewable energies in South Africa runs along three lines:

1. *Independent Industry Action*

- Increased generation for the own account of the sugar cane industry by extending the utilisation of bagasse and trash
- Pelletisation to store or transport bagasse
- Boiler and power generation up-grades

2. *Co-operation with the National Electricity Regulator (NER) and the main energy provider ESKOM*

- Improved efficiencies with surplus to the grid at a commercially acceptable rate
- Transmission arrangement 'wheeling' between sugar production centres

3. *Green Energy Independent Power Producers*

- Maximise renewable energy supply though Government support for renewables
- New technologies: power generation, ethanol, bio-gas, bio-diesel

Green Energy Status in South Africa

- World Summit for Sustainable Development – Johannesburg 2002
  - Green Energy Supply through Citi Power from Independent and the National Power Producers
- Government Commitment to Kyoto
  - Increase energy from renewables from 9% to 14% by 2012
- Potential sources for future Green Energy objectives
  - Biomass, Solar power, Wind power, Small Hydro and Waste to Energy
- White Paper on the promotion of Renewable Energy and Clean Energy
  - Part I: August 2002
  - Part II – Clean Energy Development: 2003

Additional information is provided in the Power Point Presentation Viewgraphs available at the LAMNET project web site **www.bioenergy-lamnet.org/events/events.html**.

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Pellets derived from Biomass Residues – a New Market Perspective

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- Abstract -

The most economic form in which biomass can be found is that of waste materials: organic byproducts of food, fiber, and forest production. Also third world countries have an abundance of vegetable waste, in the form of coconut fibre, cotton bush, sugar cane waste, rice husks and many more.

The major problem with these materials is that in most cases after disposal they have a high volume to weight ratio, making storage and transport not only difficult but uneconomical; for this reason, together with fermentation risks and for possible attacks from insects, they are often burnt in the field. An enormous waste of energy!

It is estimated in fact that the overall energy potential of biomass residues is about 85 EJ/year (Yamamoto, CRIEP 2000) in comparison with about 450 EJ of present total World energy consumption.

Biomass pelleting represents a promising way to overcome the above mentioned problems and to exploit a wider ratio of biomass residues; it produces in fact a refined fuel, with a higher calorific value (about 17 MJ/kg) and a low moisture content (≤ 10%): thus giving an energetic value also to biomass waste usually not suitable for thermochemical processes (combustion, gasification, pyrolis and carbonisation), facilitating biomass management and transportation (also lowering its cost) and storage.

In particular an innovative Italian pelleting technology seems to have many advantages: it is able to process biomass with high moisture content (35%), with a low energy consumption (often no pre-drying is required) and at a low operating temperature; it is therefore able to produce pellets at a lower cost in comparison with traditional systems, allowing the exploitation of many different types of biomass residues.

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Opportunities for biofuel-burning micro-turbines

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- Abstract -

The main objective of this project is to assess the technical feasibility and the market potential of biofuel-driven microturbine systems for power/heating applications, which is considered a short-term option to deploy innovative, efficient technology for distributed power generation, and which can contribute to the market development of biofuels in Europe.

Microturbines with an output of 20 kW to 100 kW offer the following advantages:

- They can easily burn different fuels (natural gas, diesel, gasoline, methane)
- Simple, compact systems- they can be directly connected to high speed turbo generators
- Low emissions
- Low investment cost
- Reduced maintenance costs
- They work for base load/peak shaving, delivering reliable electricity both for stand-alone and grid-connected applications

Several microturbine manufacturers have begun to offer commercial products at the end of last decade. Most of these microturbine are based on conventional fuel like gasoline, natural gas and diesel. In comparison with other micropower technologies is the flexibility with respect to the used fuel is high for microturbines. This high flexibility of microturbines make them suitable for a wide range of potential applications. It can be expected that the market of biofuels-driven microturbines is large if targets for parameters like cost, efficiency, durability, reliability and environmental emissions are met.

Biofuels are liquid fuels produced from biomass feedstock via a number of chemical processes. The biofuels that have advanced the most are vegetable oil, but especially biodiesel (produced from vegetable oil) and bioethanol. These fuels show the potential to substitute fossil fuel (with or without engine modification) and they are mainly used in the transport sector today, although their applications include small scale heat production in certain countries (e.g. Italy).

Nevertheless, biofuel market penetration still experiences significant barriers and constraints mainly due to large production costs and the costs associated with technologies adaptation and modification. The main advantages of using biofuels include their direct substitution for fossil fuels, an existing pipe distribution network, and a commonly held acceptance that the levels of harmful emissions are lower than for their fossil fuel equivalent.

Microturbines are already a highly efficient, commercial technology, and experiences with the utilisation of liquid biofuels are on-going, though there is no very long track of record.

In this project, the technical potential and economic perspectives of the utilisation of biomass-derived liquid fuels in micro (gas) turbines will be assessed. The aim is to contribute to the development of this efficient, environmentally-friendly technology as well as to stimulate the market penetration of liquid biofuels in Europe in the power production sector.

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