Sustainable Energy in Latin America and the Caribbean: potentialities for the future
Sustainable Energy in Latin America and the Caribbean: Potentialities for the future

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Foreword

Founded in 1931, the International Council for Science (ICSU) is a non-governmental organization that plans and coordinates interdisciplinary research to address major issues of relevance to both science and society. Over the years the geographical breadth of ICSU activities has changed. Increasingly a major emphasis for ICSU has been the development of scientific capacity in developing countries and the integration of these scientists in international research initiatives.

The creation of three ICSU Regional Offices, established in Africa, Asia and the Pacific, and Latin America and the Caribbean also marks a fundamental change in ICSU structure, the aim of which is two-fold. Firstly, it should enhance the participation of scientists and regional organizations from developing countries in the programs and activities of the ICSU community. Secondly, it will allow ICSU to play a more active role in strengthening science within the context of regional priorities through scientific collaboration.

Especially in regards to Latin America and the Caribbean, this is an important step in bridging the ‘islands of competence’ that exist in every country and that together will be able to advance significantly the scientific research agenda in the region. The first step towards the establishment of a Regional Office was the appointment in 2006 of the Regional Committee for Latin America and the Caribbean, integrated by renowned scientists of the region.

The Regional Office for Latin America and the Caribbean was the third to be established and was inaugurated in April 2007. It is hosted by the Brazilian Academy of Sciences, in Rio de Janeiro, Brazil, and supported by the Brazilian Ministry of Science and Technology, ICSU and CONACYT Mexico.

Based on the ICSU Strategic Plan 2006-2011, the Regional Committee has selected four priority areas to be developed:

- Mathematics Education;
- Biodiversity: knowledge, preservation and utilization of biodiversity of all countries of the Latin American and Caribbean region, and to ensure that the scientific community of the smaller countries of the region are fully integrated in DIVERSITAS;
- Natural Hazards and Disasters: prevention and mitigation of risks specially of hydrometeorologic origin with special attention to the necessary social science research;
- Sustainable Energy: assessment of the existing capacities in the LAC region and the social impact of the use and development of new energy resources.

Four Scientific Planning Groups were appointed to develop proposals that reviewed the current status of the priority area on the region and to formulate a set of detailed objectives and targeted areas of research to be developed in the next few years.

Engaging highly qualified scientists from Latin America and the Caribbean, the Scientific Planning Groups did an outstanding work within a restricted time limit. We thank each and every one of the participants for their enthusiasm and dedication.

This document is the final report of the Scientific Planning Group in Sustainable Energy, which is being submitted to the scientific community in the expectation of effectively influencing the development of scientific research in this area in the years to come.

Alice Abreu
Director of ICSU-LAC

José Antonio de la Peña
Chair of the Regional Committee for LAC
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Executive Summary

This document aims to address Research, Development and Innovation issues regarding use of Renewable Energy resources in the LAC; which is fundamental in decreasing natural risks and saving biodiversity. Besides, its use allows to greatly improving living conditions of communities which are not grid-connected.

An overview of the global and regional energy situation is presented, indicating the risks of maintaining the present structure of the world energy matrix with high dependence on fossil fuels. These include the quick reduction on the proven oil reserves related to global oil consumption, the environmental hazards associated to fossil fuels – specially the greenhouse gas emissions and the consequent global climate changes – and the concentration of the world reserves on a small number of countries. On the other side, the potentialities of renewable energy main sources (Biomass, Wind and Solar Energy, besides small hydro power plants) in LAC are discussed, and a preliminary list of R&D local institutions is presented.

Renewable energy was responsible for 100% of the energy sources until the beginning of the XVIII century. Scientific and technological development and the discovery and access to coal reserves and, at the end of the XIX century, the discovery of crude oil and its derivatives, turned the global society dependent on fossil energy sources, including natural gas. During almost one century – from 1880 to 1970 – the adjusted price of the crude oil on the international market oscillated around US$15.00/barrel, allowing the world society to embrace a dream of virtually infinite energy at low cost, a bonus without an onus. As from June 2008, oil price rose to US$147.00/barrel, over 100% increase in just one year.

As the global society is getting aware of the cost and risk of maintaining the world energy matrix, several initiatives are aiming to reduce the impact of the emissions of Greenhouse Gases to the atmosphere, like the Kyoto Protocol, which presently is the paradigm for international actions. National governments are issuing public policies to promote the use of renewable energy and recycling to reduce the negative impacts of the widespread dependency on fossil fuels. These incentives include the end user, the business chain and the RD&I institutions.

Scientific and technological advances are paramount to progressively change the present energy matrix to a more sustainable one, in the near future. The analysis of the different renewable energy sources indicated that biomass, solar and wind energy are promising for centralized or distributed energy production in LAC. These together with small scale hydropower plants are also important for small and isolated communities, located on off grid regions.

The successful development and implementation of an strategic plan for sustainable energy practices and technologies requires to be supported by three main building blocks:

i. Research on specific scientific and technological issues that can both contribute beyond the state of the art of the technology and the industry own development and to the adaptation of state of the art technologies to local and regional scenarios in terms of energy resources characteristics, cultural aspects of the communities involved, and other local and regional circumstances.

ii. Capacity building at institutional and individual levels by means of joint research programs with recognized scientific and technological institutions worldwide in a north-south and south-south cooperation schemes.

iii. Design and implementation of public policies based on scientific information to create the enabling environment necessary for the full and sustainable implementation of sustainable energy practices and technologies.

A selected list of identified RD&I priorities includes:
1. **Biomass**
   1.1 Biomass Productivity, which includes plant biology and agronomic practices
   1.2 Processing biomass into end use energy or energy carriers, including heat and electricity production; biomass for domestic cooking; fueling diesel cycle engines with biofuels; sugar cane biomass hydrolysis and fermentation; direct conversion from sugar to fuels; and biogas
   1.3 Biorefineries processes

2. **Solar Energy**
   2.1 Resource assessment
   2.2 Passive solar heating and day lighting of buildings
   2.3 Solar thermal for heating and cooling
   2.4 Solar photovoltaic electric energy production
   2.5 Solar thermal electric energy generation

3. **Wind Energy**
   3.1 Wind Resource estimation
   3.2 Wind turbines
   3.3 Wind farms
   3.4 Grid integration
   3.5 Environment and public support

4. **Related technologies, including energy carriers and standards and certification**
   4.1 Hydrogen production and utilization
   4.2 Grid connection protocols and procedures
   4.3 Risk assessment methodology;

The document also proposes several activities that may contribute to capacity building of institutions and individuals, and hopes to bring useful information to help establishing sound and sustainable public policies on renewable energy in the Latin American and Caribbean countries.
1. Introduction

The history of humankind is a corollary of the energy sources availability and use, since the most ancient eras to a visionary future. Civilization, culture, development and other evolutionary aspects of the Human gender are a consequence of the evolution on the discovery of new - normally improved - energy sources and the efficiency of its utilization for the benefit of the society. (“Debeir et a - Les servitudes de la puissance: une histoire de L’energie”)

Renewable energy (RE) was responsible for roughly 100% of the energy sources until the beginning of the XVIII century. Scientific and technological development and the discovery and access to coal reserves and, at the end of the XIX century, the discovery of crude oil and its derivatives, turned the global society dependent on fossil energy sources, including natural gas. During almost one century - from 1880 to 1970 - the adjusted price of the crude oil on the international market oscillated around US$15.00/barrel, allowing the world society to embrace a dream of virtually infinite energy at low cost, a bonus without an onus. As for June of 2008, oil rose to US$147.00/barrel, over 100% up in just one year, as shown on Figure 1.

Figure 1. Historic prices of crude oil 1861-2007
Until the last quarter of the XX century, just a few academic scientists looked deeper inside the externalities of the increasing share of fossil fuels on the world energy matrix. Also, studies regarding the relation between oil availability (reserves) and consumption were confined to academic mathematical models, as well as the society does not react to long range contingencies like the phasing out of the oil wells, even when statistics are demonstrating that oil production is surpassing the incorporation of new proven reserves (Figure 2). The uneven distribution of these reserves, and the concentrated nature of the oil business, also provoked distortions and biases on the geopolitics and income distribution, leading to either disclosed or covered disputes for the major oil reserves. And, last but not least, scientists established the strong relationship between burning fossil fuels and the Global Climate Changes presently underway, that will disturb the global society arrangements, dramatically increasing the frequency of extreme climatic events (like snow, wind or rain storms, tornados, droughts or floodings) and the change on the Earth temperature, forecasted to increase from 2°C to 6°C throughout this century.

Suddenly, the world is turning back to renewables. The global society is getting aware of the cost and risk of maintaining the world energy matrix highly dependent on fossil fuels. International organizations look for arrangements aiming to reduce the impact of the emissions of Greenhouse Gases to the atmosphere, being the Kyoto Treaty the first initiative and the paradigm for international actions. National governments are issuing public policies to promote the use of renewable energy and recycling to reduce the negative impacts of the widespread dependency on fossil fuels. These incentives include the end user, the business chain and the RD&I institutions.

The general feeling is that the world has to count on the present state of the art technology to boost initial actions, but strongly depends on successive and novel technological breakthroughs to overcome the negative effects of over one and half a century of fossil fuel burning and to look for a more sustainable future,
where fossil energy sources will be almost completely replaced by renewable energy, as shown on the prospective energy timeline presented on Figure 3.

There are several energy issues to be addressed, extremely diversified on its economic, environmental and social backgrounds, being the challenge to identify the RD&I linkages to each one of these issues. Among them, it is worthwhile mentioning:

**a)** Quite a lot of problems afflict society globally, like the environmental degradation (climate changes pollution, recycling,) deforestation (dramatic reduction on tropical forests), the reduction of the availability of fish shoals on the oceans, poverty, migrations, famine, energy security, employment among others. Governments must act to regulate conflicts and impose society claims. In the case of a changing world - from fossil to renewables - governments should issue public policies to restrict fossil fuel use while fomenting larger renewables share, taking opportunities to improve employment generation but not at non-affordable environment costs or by reducing the world food production. While supporting the present, governments must look to the future, preparing the infrastructure for the change. Actions might include economic compensation, taxes to force migration, regulatory legislation, incentives for RE generation, education and, especially, pave the road to the future by financing RD&I on renewables.

**b)** The global society should openly discuss access to present energy sources of estimated 2 billion people living on complete poverty. A wise approach would be a quick and intense action allowing the energy inclusion on the basis of the increment of renewable sources, meaning that financial subsides will have to be mobilized, to avoid more intense use of energy fossil fuels. Also grants from institutional donors will have to be directed to regional RD&I on renewables to support practical programs. This is not a theoretical issue as the phenomenon is occurring right now in developed countries as well as in China, India, Vietnam, Cambodia and other Asian countries and it is likely to happen on African and Latin American and Caribbean countries. The same approach would

![Figure 3. Timeline of the energy demand, crude oil phasing out and introduction of renewable energy on the world energy matrix. Source: D. L Gazzoni, non-published](image-url)
be satisfactory for isolated communities, present on almost all underdeveloped and developing countries.

e) The global way of life has being shaped on the premise of permanent supply of energy on its actual status, meaning portability and relative low cost. Sustainable development should be approached in all of its primary dimensions - economic, environmental and social. In the past, development issues have tended to be considered more narrowly, mainly in their economic dimensions. The impetus for the sustainable development movement is in part a reaction to that way of thinking. RD&I should not narrowly focus on economic arguments but closely look to culture, habits, sociological aspects and autonomous local scientific development, to help fast moving to a new sustainable standard of life and well being.

d) No particular attention has been given so far to renewable energy development. Basic research, meaning studies on basic sciences, should be performed to avoid imposing limitations for the technological development. After the fossil fuel era, energy independence will be possible, with own technology. This approach includes mathematical models, prototypes, and small scale pre-commercial evaluation pilot plants, among other integrated studies, not to mention basic scientific lines like physiology, materials science, genetics, biochemistry, theoretical physics and others.

From the analysis, it is derived that the bridge to a more sustainable energy future will be paved through new technological paradigms, starting from present biomass first generation biofuels, early wind and photovoltaics devices and solar thermal energy, to the hydrogen era, extremely efficient wind and PV devices, new approaches to dig up energy from other renewable sources, coupled with energy storage at low cost, high density and portability. The challenge we have to face is to build up this bridge on time, before the phasing out of oil and natural gas reserves and before Global Warming, caused by fossil fuel burning, produces a reduction on the world well being and an augmentation of the poverty. At the same time, the supply of biomass for other uses, like food, fodder, fiber, forest, flowers, pharma and feedstock for chemical industry must cope with the demand of the global society and not be set to a priority lower than energy production.

Latin America and the Caribbean have to be part of the global effort, with some important particularities. Presently, the region is placed midway between intensive energy use countries (the developed world) and the poor countries of Africa and Southeastern Asia. In this sense, our average per capita energy consumption is not so high that changes would be especially painful, although pointing to the need to scale up. Also, the national energy matrices of our countries do not show extreme dependence on fossil fuels, exception made to Argentina, Ecuador, Mexico and Venezuela (oil producing countries) and to some Caribbean Islands that did not have the chance to effectively mobilize its natural renewable energy resources.

But not only “hard” engineering and technological sciences are involved, and we must closely look to environmental and sociological aspects
of the energy issue, including the traditional knowledge accumulated by
millennia. Many issues related to integrated natural resources management
and to biodiversity conservation, as well as its sustainable use, require indeed
a coupling of technological and traditional knowledge. Traditional knowledge
holders tend to view people, animals, plants, and other elements of the universe
as interconnected by a network of social relations and obligations. For this report
purposes we consider that “Traditional knowledge is a cumulative body of knowledge,
know-how, practices and representations maintained and developed by peoples with extended
histories of interaction with the natural environment. These sophisticated sets of understandings,
interpretations and meanings are part and parcel of a cultural complex that encompasses
language, naming and classification systems, resource use practices, ritual, spirituality and
worldview.” The worldview embraced by traditional knowledge holders typically
emphasizes the symbiotic nature of the relationship between humans and the
natural world.

While the relevance of Science & Technology -S&T- to sustainable
development is generally acknowledged, a large gap persists between what the
S&T community thinks it has to offer, and what society has demanded and
supported. In recognition of this gap, the S&T community is increasingly calling
for a “new contract” between science and society for sustainable development.
To become an attractive partner for society in the proposed “new contract,” the
S&T community needs to look for inspiration and complement its traditional
approaches with several new orientations. R&D priorities should be set and
implemented so that S&T contribute to solutions of the most urgent sustainability
issues.

Finally, we have to take into account that there are several RD&I
institutions on the region, including a network of important biomass for food and
feed technological institutes, universities, technical institutes, private enterprises
R&D departments, that can be instrumental to compose the global effort for the
energy matrix change to a sustainable future. Networking (national, regional and
global), financial support from important donors and from local governments,
technical assistance and society support will be the corner stones of the R&D
actions, envisioning a new energy arrangement with sound social, environmental
and economic fundaments.
2. A global and regional overview of the energy situation

Fossil fuel use, especially crude oil, expanded very quickly throughout the world because of its portability, easiness of use, low cost and relative abundance. As a consequence, the world experienced very high rates of development during the XX century, in the sense of better standards of life based on more intense use of energy on transportation, heating, cooking, health, culture and educational services. At the same time, crude oil turned to be the basis of the chemistry, leading to new materials like plastics, polymers, pharmaceuticals, pesticides and fertilizers, among others.

Presently, a direct relation between Human Development Index and energy consumption is clearly observed. A study developed by the UNDP (UNDP, 2006) demonstrated that while the world averaged 0.741 on the HDI (2004), countries showing the highest HDI, between 0.9 and 1, presented also the highest electricity consumption, like Japan, France, Netherlands, Italy, United Kingdom, Germany, Israel and Republic of Korea (ca. 7GWh/person/yr), Australia (11GWh/person/yr), USA (14GWh/person/yr), Canada (18GWh/person/yr) and Norway (25GWh/person/yr). On the bottom HDI levels, Niger with 0.3 and Zambia with 0.4 showed per capita electricity consumption below 200kWh/person/yr. The best ranked Latin America countries, Brazil, Argentina and Mexico, presented HDI between 0.8 and 0.85, with electricity consumption below 2GWh/person/yr.

For understandable economical reasons, crude oil companies throughout the decades have focused on extracting the easy-to-reach cheap crude oil. At first, oil was extracted near the surface on land. This oil typically was of the “light and sweet “ type or put more simply, refined into byproducts such as unleaded gas and heating oil very easily. But, during the last three decades, the world has discovered less new oil wells than actual consumption. As for recent years, new proven reserves account for only 27% of actual consumption.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated overall oil reserves</td>
<td>3000 Gb</td>
</tr>
<tr>
<td>Produced, to, date</td>
<td>873 Gb</td>
</tr>
<tr>
<td>Reserves</td>
<td>928 Gb</td>
</tr>
<tr>
<td>Discovered, to, date</td>
<td>1801 Gb</td>
</tr>
<tr>
<td>Yet, to, Find</td>
<td>149 Gb</td>
</tr>
<tr>
<td>Yet, to, Produce</td>
<td>1077 Gb</td>
</tr>
<tr>
<td>Ultimate recovery</td>
<td>1950 Gb</td>
</tr>
<tr>
<td>Current consumption</td>
<td>22 Gb/yr</td>
</tr>
<tr>
<td>Current discovery rate</td>
<td>6 Gb/yr</td>
</tr>
<tr>
<td>Current depletion rate (ann. prod. as % of Yet, to, Produce)</td>
<td>2%</td>
</tr>
</tbody>
</table>

Table 1. Crude oil statistics relating to oil peak  
Source: Colin J. Campbell  
(http://greatchange.org/ov-campbell/outlook.html)
Energy consumption and efficiency vary dramatically in different parts of the world. In 2005, the global average annual per-capita consumption of modern energy (i.e., excluding traditional biomass and waste) was 1,519 kilograms of oil equivalent (kgoe). While the average in high-income countries is 5,228 kgoe, in low-income countries it is only 250 kgoe. Traditional biomass and waste account for 10.6 percent of total global primary energy supply. In low-income countries, these sources represent on average 49.4 percent of the supply, with some countries approaching 90 percent.

Energy consumption depends, primarily on population growth and per capita income increment. FAO estimations are that the world population will continue growing until 2050, in spite of progressively decreasing annual rates, when it is supposed to stabilize and even decrease towards the end of the century. On the economic ground, the world is experiencing a never-before steady period of high economic progress, especially on developing countries. Table 2 presents statistic for LAC oil production and reserves.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>2,233</td>
<td>2,600</td>
<td>1,972</td>
<td>1,972</td>
<td>0.14%</td>
<td>7,55</td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>2,358</td>
<td>6,681</td>
<td>11,772</td>
<td>12,182</td>
<td>0.89%</td>
<td>18,45</td>
<td></td>
</tr>
<tr>
<td>Colombia</td>
<td>1,700</td>
<td>2,798</td>
<td>1,453</td>
<td>1,506</td>
<td>0.11%</td>
<td>7,39</td>
<td></td>
</tr>
<tr>
<td>Ecuador</td>
<td>1,235</td>
<td>3,453</td>
<td>4,866</td>
<td>4,664</td>
<td>0.34%</td>
<td>23,45</td>
<td></td>
</tr>
<tr>
<td>Mexico</td>
<td>54,880</td>
<td>48,472</td>
<td>13,670</td>
<td>12,908</td>
<td>0.94%</td>
<td>9,60</td>
<td></td>
</tr>
<tr>
<td>Peru</td>
<td>0,536</td>
<td>0,774</td>
<td>1,078</td>
<td>1,078</td>
<td>0.08%</td>
<td>25,56</td>
<td></td>
</tr>
<tr>
<td>Trinidad &amp; Tobago</td>
<td>0,564</td>
<td>0,723</td>
<td>0,809</td>
<td>0,809</td>
<td>0.06%</td>
<td>12,77</td>
<td></td>
</tr>
<tr>
<td>Venezuela</td>
<td>55,521</td>
<td>72,667</td>
<td>80,012</td>
<td>80,012</td>
<td>5.83%</td>
<td>77,62</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>0,455</td>
<td>1,109</td>
<td>1,269</td>
<td>1,270</td>
<td>0.09%</td>
<td>24,91</td>
<td></td>
</tr>
<tr>
<td>LAC</td>
<td>119,482</td>
<td>139,276</td>
<td>116,902</td>
<td>116,401</td>
<td>8.48%</td>
<td>41,21</td>
<td></td>
</tr>
</tbody>
</table>

During the last five years, the world average GDP growth ranged from 3.5 - 4.5%. During this period, Latin America and Caribbean GDP grew above the world average, and the forecast for 2008-2009 is a 5% growth rate (Figure 4).
If it is assumed that, on the medium range, current energy policies will not be strongly shifted, the world’s energy needs would be well over 50% higher in 2030 than today, according to the EIA World Energy Outlook 2008 Basic Scenario. It is considered that China and India will account for 45% of the increase in demand. These trends lead to continued growth in energy-related emissions GHG and to increased reliance of consuming countries on imports of oil and gas - much of them from the Middle East and Russia. This scenario would heighten concerns about climate change and energy security. The Global Climate Changes key conclusions of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), released in early 2007, were astonishing and point to an increase of extreme weather events (snow storms, tornados severe droughts or flooding) as well as ocean level rise and global average temperature increase:

Most of the GHG (Greenhouse Gases) emissions (Figure 5) are attributed to the use of fossil fuels, being coal the most dangerous one and natural gas the less aggressive to the environment. The challenge is to put in motion a transition to a more secure, lower-carbon energy system, without undermining economic and social development. Nowhere will this challenge be tougher, or of greater importance to the rest of the world, than in China and India. Vigorous, immediate and collective policy action by all governments is essential to move the world onto a more sustainable energy path. Measures to improve energy efficiency stand out as the cheapest and fastest way to curb demand and emissions growth in the near term.

Considering the above mentioned aspects, the major threats facing the Humankind, derived from its dependence on fossil fuels, are: a) Reduction of the world oil reserves and climbing prices; b) uneven distribution of the fossil fuel reserves; c) greenhouse gas emissions leading to Global Climate Changes

In Latin America and the Caribbean annual per capita consumption of energy varies significantly from country to country, being 300 GJ/capita in Trinidad and Tobago and only 10 GJ/capita in Haiti. Another indicator pointing to the highly diverse nature of the region is the energy intensity of the different countries, varying from 36 MJ/$(ppp) in Trinidad and Tobago (a large exporter

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Figure 5. World per capita and total emissions of carbon dioxide. 
Source: UN Millenium Indicators Database
of natural gas) to 4 MJ/$(ppp) in Barbados. The Latin America and the Caribbean region's average value is around 11 MJ/$(ppp), slightly above the world average of about 10 MJ/$(ppp). LAC overall energy consumption can be visualized on Table 3 and the LAC energy matrix is shown on Figure 6.

<table>
<thead>
<tr>
<th>Country</th>
<th>Population 10^3 inhab. (A)</th>
<th>GDP 10^6 USD (B)</th>
<th>Final energy consumption 10^3 Boe (C)</th>
<th>Per capita GDP (2) Usd/inhab. (B/A)</th>
<th>Per capita final consumption Boe/inhab. (C/A)</th>
<th>Energy intensity (1) (2) Boe/10^6 USD(C/B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>38,971</td>
<td>340,315.95</td>
<td>361,886.41</td>
<td>8,732.54</td>
<td>9.29</td>
<td>1.06</td>
</tr>
<tr>
<td>Barbados</td>
<td>270</td>
<td>1,914.03</td>
<td>2,067.76</td>
<td>7,089.00</td>
<td>7.66</td>
<td>1.08</td>
</tr>
<tr>
<td>Bolivia</td>
<td>9,627</td>
<td>10,193.52</td>
<td>26,613.39</td>
<td>1,058.85</td>
<td>2.76</td>
<td>2.61</td>
</tr>
<tr>
<td>Brazil</td>
<td>190,127</td>
<td>764,552.24</td>
<td>1,355,368.32</td>
<td>4,021.27</td>
<td>7.13</td>
<td>1.77</td>
</tr>
<tr>
<td>Colombia</td>
<td>46,772</td>
<td>105,573.95</td>
<td>169,013.85</td>
<td>2,257.20</td>
<td>3.61</td>
<td>1.60</td>
</tr>
<tr>
<td>Costa Rica</td>
<td>4,399</td>
<td>21,028.85</td>
<td>24,049.31</td>
<td>4,780.37</td>
<td>5.47</td>
<td>1.14</td>
</tr>
<tr>
<td>Cuba</td>
<td>11,240</td>
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(1) Final Energy Consumption / Gross Domestic Product  
(2) Information of 2006 (base year 2000)
It is important to state that higher living conditions are required which means higher energy per capita consumption. The idea to achieve this is saving energy (=avoiding unnecessary waste of energy) and substituting fossil fuel by renewable sources rather than reducing the overall amount or per capita consumption of energy.

Population and income growth are key drivers for energy consumption in the world. Forecasts for population growth in the LAC region indicate that the peak of the annual population growth was achieved in the 60’s (2.8%) and future trend is a continuous slow from present 1.2% to estimated 0.25% in 2050. Studies indicated a direct and linear relationship between population growth and energy consumption. Under social and economic \textit{ceteris paribus} conditions, each one point of population growth means one point on energy consumption indexes.

Between 1970 and 1980 the economic growth was accompanied by lower energy use per unit of output (lower energy intensity), pointing to efficiency gains and better use of energy resources. The trend was reversed, however, between 1980 and 1985 (per capita income contracted and energy intensity increased), and the same unfavorable pattern continued between 1987 and 1990. This suggests that there was no improvement in energy efficiency during the economic recession of the 1980s. In the first three years of the 1990s, income recovered but energy intensity remained high. There was scarcely any improvement in energy intensity between 1990 and 2000. The energy intensity indicator has followed fairly similar trends in the different sub-regions, but its absolute value varies considerably. Energy intensity is highest in the Caribbean countries, mainly because of the more frequent use of energy-intensive, low-efficiency equipment. The Southern Cone countries have the lowest absolute values, owing to the use of more advanced equipment and energy technologies in their production processes. The Andean countries showed no significant changes in the period considered.
3. General Objectives

The successful development and implementation of an strategic plan for sustainable energy practices and technologies requires to be supported by three main building blocks:

i. Research on specific scientific and technological issues that can both contribute beyond the state of the art of the technology and the industry own development and to the adaptation of state of the art technologies to local and regional scenarios in terms of energy resources characteristics, cultural aspects of the communities involved, and other local and regional circumstances.

ii. Capacity building at institutional and individual levels by means of joint research programs with recognized scientific and technological institutions worldwide in a north-south and south-south cooperation schemes.

iii. Design and implementation of public policies based on scientific information to create the enabling environment necessary for the full and sustainable implementation of sustainable energy practices and technologies. The scientific information necessary for policy makers may include, inter alia:

- Lifecycle environmental analysis of renewable and conventional energy technologies including energy and GHG emissions balances (carbon footprint)
- Lifecycle costs analysis of implementation of technologies
- Multicriterial analysis of environmental, social and economic impacts
- Development of sustainability criteria and indicators for the use of energy resources
- Design of public policies and their economic, social and environmental impacts
- Regulatory framework necessary for the implementation of public policies

The general objective of this document is to provide the basis for the research, development and deployment of sustainable energy practices and technologies that can be integrated in the primary energy matrix of Latin America.
The following chapters offer an overview of the state-of-the-art renewable energy technologies and the current situation of the deployment of these technologies in Latin America and the Caribbean, including the research and development activities, main institutions involved. The priority areas of research for the near and mid-term future are highlighted in the document.

The document also proposes several activities that may contribute to capacity building of institutions and individuals.

It is expected that the proposals will be helpful for the establishment of effective public policies for the implementation of renewable energy programs in LAC countries, as a central follow up to the activities discussed.
The LAC power market - facts and statistics


- The installed electrical generation capacity of the LAC region totals approximately 253 GW in 2003.
- In 2003 52% of the installed power is hydroelectric, 45% is thermoelectric, 2% is nuclear, and 1% utilizes sources such as geothermal, wind, solar and biomass.
- Power production in the 26 OLADE countries was 1,021 TWh in 2003, an increase of 42.5 TWh (4.3%) compared to 2002.
- Many LAC countries report high level of transmission and distribution power losses which is in average about 19% for the region.
- Power consumption in Latin America and the Caribbean was 820.7 TWh in 2003, an increase of 34.2 TWh (4.3%) compared to 2002.
- Coal met only 5% of primary energy demand in Latin America in 2003, of which 65% was used in Brazil. Latin America has proven recoverable coal reserves of 16 billion tons.
- About 42% of coal production is dedicated for export to the EU and United States.
- LAC’s proven natural gas reserves amounted to 7.5 $10^{12}$ m$^3$ in 2003, 5% of the world’s total. Venezuela holds 54% of the proven reserves, followed by Bolivia (10%), Argentina (10%), Mexico (8%) and Trinidad and Tobago (7%).
- LAC’s natural gas production in 2003 was 197 $10^9$ m$^3$. Production is expected to expand significantly over the next three decades, reaching 516 $10^9$ m$^3$ in 2030.
- The region’s proven oil reserves stood at 114.5 billion barrels at the end of 2003, i.e. 10% of the world’s total.
- LAC’s production of crude oil and LNG averaged 9.4 mb/d in 2003 and is expected to increase to almost 12 mb/d by 2030. Production is dominated at present by Venezuela, Mexico and Brazil.
- Compared to the world oil refining capacities LAC has a share of almost 9%.
- South European and US companies dominate the LAC power sector.
- Electricity tariffs in many countries allow the utilities to make profit. However, political uncertainties and legal framework instabilities in the region cause financial risk.
- The LAC region is split into 2 operating power networks with different frequencies: the southern countries operate on 50 Hz whereas the northern countries operate on 60 Hz.
- LAC countries are moving towards integration of the power networks, including the Central Americans countries, through the implementation of the SIEPAC (Sistema de Interconexión Eléctrica de los Países de América Central – System of power interconnection in the Central American countries) project under the Framework Agreement of the Central American Electrical Market and the creation of the Regional Electricity Market.
- In order to meet the growth of power demand annually roughly 12 GW of new power plants have to be installed.
- In the LAC 73% of the power plants have nominal outputs less than 50 MW, 23% are in the range of 50 to 400 MW and 4% are in the range of between 400 to 1000 MW.
- In the LAC region the main types of power plants are diesel engines (mainly for decentralized power production in remote areas) and power plants with conventional steam or gas turbines.
- Gas turbines account for 27%, steam turbines for 56%, gas combined cycle plants contribute 7% and diesel engines 6% of the power generation. The balance of 4% is made up by geothermal and nuclear power plants.
- 85% of the power generation is based on oil and natural gas. Coal actually plays no major role in the LAC power sector although large reserves are present in the region.
- A replacement potential of actually around 9 GW can be identified for the running decade.

**Box 1**

The LAC power market - facts and statistics


- The installed electrical generation capacity of the LAC region totals approximately 253 GW in 2003.
- In 2003 52% of the installed power is hydroelectric, 45% is thermoelectric, 2% is nuclear, and 1% utilizes sources such as geothermal, wind, solar and biomass.
- Power production in the 26 OLADE countries was 1,021 TWh in 2003, an increase of 42.5 TWh (4.3%) compared to 2002.
- Many LAC countries report high level of transmission and distribution power losses which is in average about 19% for the region.
- Power consumption in Latin America and the Caribbean was 820.7 TWh in 2003, an increase of 34.2 TWh (4.3%) compared to 2002.
- Coal met only 5% of primary energy demand in Latin America in 2003, of which 65% was used in Brazil. Latin America has proven recoverable coal reserves of 16 billion tons.
- About 42% of coal production is dedicated for export to the EU and United States.
- LAC’s proven natural gas reserves amounted to 7.5 $10^{12}$ m$^3$ in 2003, 5% of the world’s total. Venezuela holds 54% of the proven reserves, followed by Bolivia (10%), Argentina (10%), Mexico (8%) and Trinidad and Tobago (7%).
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- LAC’s production of crude oil and LNG averaged 9.4 mb/d in 2003 and is expected to increase to almost 12 mb/d by 2030. Production is dominated at present by Venezuela, Mexico and Brazil.
- Compared to the world oil refining capacities LAC has a share of almost 9%.
- South European and US companies dominate the LAC power sector.
- Electricity tariffs in many countries allow the utilities to make profit. However, political uncertainties and legal framework instabilities in the region cause financial risk.
- The LAC region is split into 2 operating power networks with different frequencies: the southern countries operate on 50 Hz whereas the northern countries operate on 60 Hz.
- LAC countries are moving towards integration of the power networks, including the Central Americans countries, through the implementation of the SIEPAC (Sistema de Interconexión Eléctrica de los Países de América Central – System of power interconnection in the Central American countries) project under the Framework Agreement of the Central American Electrical Market and the creation of the Regional Electricity Market.
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- Gas turbines account for 27%, steam turbines for 56%, gas combined cycle plants contribute 7% and diesel engines 6% of the power generation. The balance of 4% is made up by geothermal and nuclear power plants.
- 85% of the power generation is based on oil and natural gas. Coal actually plays no major role in the LAC power sector although large reserves are present in the region.
- A replacement potential of actually around 9 GW can be identified for the running decade.
4. Renewable Energy Technologies

This chapter describes the state-of-the-art of several technologies that transform renewable natural resources into useful forms of energy. The chapter also includes the situation of these technologies in Latin America and the Caribbean, including status of development, research activities, main institutions involved and priority research areas.

The renewable energy resources and the associated technologies included in this analysis are solar, wind, biomass and small hydro, all of them for both on-grid and off-grid schemes. These are the more important for the region, in terms of both their potential and availability. Energy resources such as geothermal and ocean (in all its forms) are not included in this document. Research and development activities on hybrid systems that integrate two or more technologies and energy resources are also suggested.

Besides the research areas related to the technologies themselves, this chapter also mentions related research needs such as the integration of renewable energy technologies to the current energy systems and energy storage. Systems integration includes areas of study such as distributed generation and grid connection and control. Energy storage R&D issues mentioned in this chapter are mostly dealing with hydrogen production, storage, transport, distribution and use.

Energy efficiency, even though recognized as a major component in rational energy scenarios, is not directly included as a topic for research in this document, since energy efficiency involves not only technological issues but also, and mainly, public policies and measures dealing with social behavior.

A. Biomass

Present status of production of energy from biomass in the LAC region

The Brazilian success story on biofuels production and use has generated considerable interest in biofuels across LAC. A number of countries have taken important regulatory and legal initiatives to lay the groundwork for future expansion and investment. A few countries have begun to attract international investors, and others have announced plans for major expansions of their biofuels sector. In some places, the Brazilian government has actively forged relationships that are yielding joint projects and research. Figure 7 presents the per capita household consumption of biomass in the LAC region.
Many of the necessary ingredients for a vibrant biofuels sector are present. The abundance of arable land, the existence of optimal climatic conditions in the region, and excess production of feedstocks used for biofuels in many LAC countries make the region well suited to become a productive center in a global biofuels trade. Added to their natural endowments is the concentration of activity and labor in their agricultural sectors, a reality that makes biofuels an attractive rural development strategy, as can be observed through Table 4 and Figure 8.
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<th>Equivalent potential arable land / total area (%)</th>
<th>Actual arable land 1994 (1000 ha)</th>
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<td>3,915</td>
<td>71</td>
<td>21,378</td>
<td>2,285</td>
</tr>
<tr>
<td>TOTAL</td>
<td>2,047,262</td>
<td>1,028,473</td>
<td>743,243</td>
<td>36</td>
<td>143,352</td>
<td>13.9</td>
<td>471,439</td>
<td>108,772</td>
</tr>
</tbody>
</table>
R&D related to biofuels in the region is unevenly distributed. Brazil is the leading R&D country in the region. A broad range of research activity exists in Colombia, including public-private partnerships and research sponsored by the state oil company, Ecopetrol. There is also ongoing university research into palm oil-based biodiesel, and work by the sugar and palm oil producers associations to improve yields and identify optimum varietals for feedstock. In Costa Rica, a promising ethanol initiative between Petrobras and RECOPE is underway. In Argentina, where there is a long history of interest in biofuels, private sector investors have established a Biofuels Research Center. Several universities are promoting biofuels, and particularly biodiesel, through research and involvement in initiatives like the New Technologies for Biofuels Network. Elsewhere in the region, R&D efforts are much more limited. In Brazil, there’s a long term research initiative including public and private sector, for the ethanol chain (agronomic and industrial innovations) and, more recently, for biodiesel and other energy carriers.

As a whole, the region has made important advances toward establishing a regulatory framework for biofuels. And a number of countries, including Colombia, Guatemala, and Argentina have advanced well beyond the initial steps. However, governments and regional institutions will need to coordinate and facilitate investment and research. On the other hand, some parts of the region still demand large quantities of firewood for residential as well as industrial purposes. Besides being an inefficient and polluting energy source, the origin of this resource is mostly native forests, not always close to the point of consumption - implying high costs for the transport of firewood or charcoal.

This process also destroys a valuable CO$_2$ sink. The most serious aspect related to the use of firewood, including charcoal production, is the accelerated deforestation of certain regions with enormous damage to the environment, which significantly contributes to the region’s CO2 emissions. Unconditional use of this source of energy is due to poor accessibility to modern sources.

Environmental questions of a local nature, such as those related to hydroelectric generation or monocultures as energy sources, are common in the majority of the region’s countries. Questions of a global nature, particularly
emissions from burning fossil fuels, are common to all countries, all of which must introduce measures to reduce such global impacts.

i. **Firewood** - It is not easy to estimate the firewood used for domestic consumption and normally data is extrapolated based on average consumption over the population considered to use firewood. According to the UN, the world average consumption is 500kg biomass / person / year. Considering that the LAC region has 575 million inhabitants and that estimated 23% of the population depends on firewood as a primary energy source, it is estimated that the region burns, annually, 66 million t of firewood for energy purposes (Table 5).

<table>
<thead>
<tr>
<th>Country</th>
<th>Million</th>
<th>% of total population</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>706</td>
<td>56</td>
</tr>
<tr>
<td>Indonesia</td>
<td>155</td>
<td>74</td>
</tr>
<tr>
<td>Rest of East Asia</td>
<td>137</td>
<td>37</td>
</tr>
<tr>
<td>India</td>
<td>585</td>
<td>58</td>
</tr>
<tr>
<td>Rest of South Asia</td>
<td>128</td>
<td>41</td>
</tr>
<tr>
<td>Latin America</td>
<td>96</td>
<td>23</td>
</tr>
<tr>
<td>North Africa/Middle East</td>
<td>8</td>
<td>0.05</td>
</tr>
<tr>
<td>Sub-Saharan Africa</td>
<td>575</td>
<td>89</td>
</tr>
<tr>
<td>Total, Developing Countries</td>
<td>2.390</td>
<td>52</td>
</tr>
</tbody>
</table>

Table 5. Number of people relying on traditional biomass for cooking and heating
Source: UNDP Energy Services for the Millennium Development Goals, 2005

ii. **Biodiesel** - Two major countries are involved with biodiesel production and use. According to the Argentine legislation, a blend of 5% biodiesel in diesel oil will be mandatory, effective from 2010, meaning a market of 750 million liters of biodiesel. However, Argentina, which produced 200 million liters in 2007 and seeks to produce 800 million liters in 2008, plans to export 2 billion liters of soybean biodiesel in 2010.

The development of biofuels in Argentina has heavy incentives from the government. While exports of soybean oil, for example, are charged at 24.5%, sales of biodiesel pay only 5% tax, with 2.5% returnable as credit rates. In Brazil, there is a mandatory legislation to blend 3% biodiesel on diesel oil (effective Jul 1st, 2008), a market of 840 million liters. For 2013 the blending will be incremented to 5%, requiring over 2 billion liters of biodiesel. Since 2001, a series of laws and regulations have established fuel blending mandates, regulatory standards, and incentives for biofuels production.

Colombia’s fuel oxygenation program now covers 57% of the country. Peru has established an initial legal framework for the promotion of biofuels and put in place a Program for Biofuels Promotion and a Technical Commission for Biofuels. For its part, Chile is just beginning to address biofuels. There is currently no production, and the Renewables Law passed in 2003 still awaits needed regulatory guidelines. With its significant production of wood chips, Chile’s greatest potential likely will be in cellulosic biofuels research. Ecuador has
instituted policies to promote fuel diversification and has significant potential feedstock resources in sugar and palm oil.

There is also a threat to producing biofuels using vegetable oils or animal fats as feedstocks, because the continuously high world economic growth has led to a dramatic increase in the demand for these products for the nutritional market. As an average, oils prices have rose from US$300 (2001) to US$1400 (2008), making it too costly to produce biodiesel from nutritional feedstocks, as demonstrated by the fluctuation of major vegetable oil prices on the Chicago Board of Trade (Figure 9).

As for the conflict between biofuels production from biomass and other soil uses for producing other agricultural products, Table 1 show data demonstrating that, as for 2010, only 4,9% of the potential arable land as established by FAO were in use in LAC countries. From the total cultivated area, only 3% were dedicated to biofuels production. A forecast study anticipate that, by 2030 it is estimated that 16,7% of the arable land will be cultivated, being about 10% dedicated to biofuels. Even considering that the FAO numbers did not ambitiously accounted for environmental protection, Global Climate Changes and urbanization, the study considered that from the FAO numbers only 40% would be realistically converted into agricultural area. In this case, in 2010 around 11,4% of the potential arable land will be cultivated, incrementing this number to 39,3% in 2030. Based on this study, it is possible to asseverate that, for the LAC region, no foreseeable conflicts can be anticipated for integrating food and other demands from agriculture with biofuels production.

<table>
<thead>
<tr>
<th>Soil use Year</th>
<th>Food M ha</th>
<th>Exports M ha</th>
<th>Biofuels M ha</th>
<th>Firewood M ha</th>
<th>Total M ha</th>
<th>Increment M ha</th>
<th>Potential area %</th>
<th>Potential area corrected %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>114</td>
<td>-</td>
<td>2</td>
<td>5,5</td>
<td>122</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2010</td>
<td>139</td>
<td>2</td>
<td>4</td>
<td>4,8</td>
<td>150</td>
<td>28</td>
<td>4,9</td>
<td>11,4</td>
</tr>
<tr>
<td>2015</td>
<td>149</td>
<td>12</td>
<td>5,7</td>
<td>4,2</td>
<td>172</td>
<td>49</td>
<td>8,4</td>
<td>19,8</td>
</tr>
<tr>
<td>2020</td>
<td>156</td>
<td>25</td>
<td>9,5</td>
<td>3,6</td>
<td>194</td>
<td>72</td>
<td>12,3</td>
<td>28,9</td>
</tr>
<tr>
<td>2025</td>
<td>162</td>
<td>31</td>
<td>9,7</td>
<td>3,1</td>
<td>207</td>
<td>85</td>
<td>14,4</td>
<td>33,8</td>
</tr>
<tr>
<td>2030</td>
<td>171</td>
<td>36</td>
<td>10</td>
<td>2,7</td>
<td>220</td>
<td>98</td>
<td>16,7</td>
<td>39,3</td>
</tr>
</tbody>
</table>

Figure 9. Vegetable oil prices

Table 6. Present and forecast soil use for Latin America and Caribbean area.
Source: D. L. Gazzoni, non published data
BOX 2

Ethanol from sugar cane in Brazil

After the initial growth with the Pro-Álcool program (to 12 M m³ / year, in 1984) ethanol production in Brazil stabilized at this level until 2002, when the implementation of the Flex Fuel cars led to a new period of strong growth (from 12.5 M m³ in 2002 to ~24 M m³ in 2008). Internal demand scenarios point to 40 M m³ in 2020, with exportation in the 10 – 15 M m³ range.

In 2006, 425 M t sugar cane were processed in 325 sugar mills (6.6 M ha) yielding 26 M t sugar and 15.7 M m³ ethanol (with 50% of the cane). Brazil is the world’s second ethanol producer, and the largest exporter of sugar and ethanol (2005). Ethanol substitutes for 45% of the gasoline, in a fleet of 22 M vehicles. Flex-fuel cars corresponded to 90% of the sales of new units (2008).

The technology level in the Brazilian Center-South, 2006, led to 82.4 t cane/ ha (no irrigation), with 35% mechanical harvesting; each t cane produced 85 l ethanol and 2.1 kWh surplus electricity. Greenhouse gases net emissions in ethanol production were 0.27 t CO₂ eq. / m³ ethanol, leading to more than 80% GHG reduction when substituting for gasoline. The ratio of (renewable energy)/ (fossil energy used in ethanol production) is 9.2.

Substantial improvements in cane productivity, conversion efficiencies and management, since 1975, led Brazil to be the lowest cost producer of etanol and sugar worldwide. However, new technologies for sugar cane biomass (bagasse and trash) utilization to produce energy (fuels and electricity) may become commercial in the next years; their full integration with the sugar mill operations may increase the energy output in 50%.

iii. Ethanol - Fuel ethanol production and use is growing worldwide. In 2006 the world production reached 50.4 Mm³, 36% in the US (corn based), 34% in Brazil (sugar cane), 8% in China (corn); 4% in Europe where other grain and beets are also being used as feedstock (Figure 10). The main drivers for the use of biomass based ethanol as fuel have been the need to reduce GHG emissions from fossil fuels; and the long (and short) term problems with oil based fuel availability and cost.

![Figure 10. World ethanol production for fuel and other uses. Source: International Energy Agency / USDA / Brazilian Ministry of Agriculture](image-url)
Public policies in many areas of the world are leading to rapid expansion of production: E-10 (10% blends with gasoline) are targets for many regions for 2010, and higher blends are proposed (or already being used) in many other regions. In 2007, the target (2015) for ethanol use in the U.S. was already 35 billion gallons/year; and the EU target for 2020 was using 20% of renewable in total primary energy. Brazilian ethanol from sugar cane is expected to grow to 40 Mm3 by 2015.

Public policies are essential to start biofuels programs anywhere. For instance, the modern Brazilian ethanol program started in 1975 with a mandate to blend 10% of ethanol in all gasoline (actually, mandatory use of ethanol as automotive fuel, blended in gasoline, begun in 1931). The government obligation to buy a specified amount, at a price based on an independent evaluation of the production cost; and low interest rates in loans, fostered the building ethanol plants. Large increases in the conversion efficiency and productivity led to strong cost reduction in the following years, so that when all subsidies were ended (gradually, till the 90’s) the ethanol production was competitive with gasoline at international prices.

The perspective for cellulosic ethanol technologies may boost the production worldwide during the next decade. Actually, the present technological constraints posed by some of the feedstock (low energy density and poor energy balance) indicate that sugar cane and cellulosic material may become the main biomass sources for ethanol, by 2020. Cellulosic ethanol development would also greatly add to sugarcane ethanol productivity and economics, since it would make possible to use efficiently the sugarcane trash and bagasse.

Sugar cane is produced in 100 countries worldwide; and it is present in all countries in the LAC region. Cane production technology is well known in the region; sugar is the main product everywhere (except in Brazil, where ethanol surpassed sugar production last season.). In all countries some ethanol is produced from molasses, and more recently from part of the cane juice. Increasing the production of ethanol from sugar cane has greatly promoted advances in the technologies, benefitting also the sugar production, leading to higher quality raw sugar.

iv. Co-generation. The most important perspective for the cane industry today is the availability of technology for full and efficient utilization of the sugar cane ligno-cellulosic fraction for energy, either bio-electricity or fuels. Even the implementation of large scale co-generation plants usually depends on government policies; not much for subsidies, but for changing the legal framework of the electricity sectors to allow more distributed energy sources. In Brazil, it is expected that the sugar cane industry could supply 10 -15% of the country’s electricity by 2020; the industry may increase its energy production / area by nearly 50% in the next decade, using the (today) residual biomass; the large variety of possibilities calls, in some cases, for strong R&D efforts.

v. Potentialities for production of energy from biomass. Production of biomass for energy purposes should not conflict with traditional uses of
biomass (namely food, fodder, fiber, forest and fiber). Modern agricultural products demands include flowers, fuel and feedstock for the chemical industry. The energy from biomass can be directed to the domestic consumption or exported to the international market. In both cases, there are five important considerations to establish the potentiality and the sustainability of the biomass production, as follow: a) land availability; b) water availability; c) climate; d) environmental restrictions; and e) present area of energy crops.

Although other feedstocks are very suitable and have large potential, like the sweet sorghum, for the larger part of the countries in LAC, sugar cane is the most efficient one for energy production purposes. The technology for sugar cane production was introduced centuries ago in the region; but the last 40 years have shown large advances, mainly in the cane breeding area, in many countries. In most cases the technology centers (institutes, cooperatives) were dedicated to the cane varieties program and some agronomic research. Agricultural engineering and almost all the industrial research / development were left to the equipment suppliers. With a few important exceptions, programs were developed in state owned institutions. The development of ethanol large scale production led to the need for more industrial research, but just a few countries were engaged in this area until now.

Some Technology Centers in the region are listed below (Table 7).
### Table 7 List of R&D institutions devoted to sugar cane in LAC.

<table>
<thead>
<tr>
<th>Country</th>
<th>Institution</th>
<th>Variety Development</th>
<th>Cultural Practices</th>
<th>Industrial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>Chacra Experimental Santa Rosa</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Estación Experimental Obispo Colombres</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>RIDESA (Network 7 federal universities)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>IAC – Inst. Agronomico de Campinas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>IPT – Inst. Pesquisa Tecnológica, S Paulo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Embrapa Tabuleiros Costeiros</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ESALQ/USP – Polo de biocombustíveis)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>UNICAMP (NIPE), USP (CENBIO)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>UNESP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CTC – Centro de Tecnologia Canavieira</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NATT (Tech Center, Cooperativa de Alagoas)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Votorantim (Allelyx, Canavialis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Petrobrás (Hydrolysis, Thermo-chemical processes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Oxiteno (alcohol chemistry)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Braskem (alcohol chemistry)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colombia</td>
<td>CENICANÁ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cuba</td>
<td>ICIDCA</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>ICINAZ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>INICA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ecuador</td>
<td>CINCAE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mexico</td>
<td>C. Híbridación Capachula</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CICTCAÑA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Universities (Veracruz, UNAM):</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Venezuela</td>
<td>Fundacaná Venezuela (V, A)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guatemala</td>
<td>ASAZGUA supports CENGICAÑA (A + I)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Costa Rica</td>
<td>LAICA supports technology transfer</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TOTAL** | 2,047,262 | 1,028,473 | 743,243 | 36
Revision of Priorities

For etanol production, the proposed priorities include:

1. Agronomic Technology: Sugar cane genetic modification; precision agriculture; and trash recovery and conditioning

2. Industrial technology: biomass (cane bagasse and trash) gasification for electricity of fuels production; and biomass hydrolysis for fermentation to ethanol

3. Technology Transfer

In the case of other biomass sources is rather difficult to review priorities, as there are different degrees of technological development, because biomass can be obtained from forest species to animal residues and wastes and due to the need to identify novel species with special attributes of energy interest. Technological development of plant species had been done looking at the food industry rather than energy production. As a general overview, priority on vegetable biomass production has encompassed variety development aiming improved yield and pest resistance; plant nutrition; pest control and harvesting procedures.

R & D institutions are mainly Agronomic investigations institutes (broadly known as INIA - Institutos Nacionales de Investigación Agrícola) and Universities.

Specific Research Areas

a. General biomass

1. Biomass Productivity

   1.1 Plant biology

   **Prospection of new species** - includes identification of new plants with outstanding energy production per unit of area; identification of algae with desired traits for energy purposes;

   **Plant physiology** - includes identifying the pathways of photosynthesis and modes of enhancing solar energy capture; lignin and cellulosic metabolic pathways; metabolic pathways for plant resistance to biotic and abiotic stresses;

   **Molecular biology and breeding** - includes set up, characterize and maintain plant DNA banks; identify plant genes linked to resistance or tolerance to major biotic or abiotic stresses and improved soil nutrients uptake and use; identify genes coding for chemicals of social and economic importance; introduction of the desired traits into cultivated plants;
Energy balance and carbon flow - includes optimizing the energy output/input for various target plants; identification of methods for altering carbon flows into higher energy compounds like lipids; establish the carbon flow and GHG emissions for different agroenergy feedstocks;

1.2 Agronomic practices

Plant nutrition - includes further understanding symbiotic plant bacteria associations for atmospheric nitrogen fixation and novel microorganisms able to associate to plants outside the Leguminosae family; investigate plant - microorganisms associations with growth promotion capabilities; deep understanding of phyto-hormones biochemical pathways and identification of substances acting as hormonal bio-activators; development of studies on plant / soil / water interactions

Environmental impacts - includes validation of soil carbon impact on crop residue removal; identification of potential environmental impacts of intensive agriculture;

Improvement of sustainable agronomic practices - includes the establishment of optimal agronomic practices for sustainable production, including existing residue removal; development of studies on plant / pest / predators relationships and biological control of pests; development of studies on the life cycle and energy balance of biomass feedstock, looking at reducing the energy consumption of the systems; identification of the most suitable soils and regions to grow energy intensive crops; and the intensive use of compost produced from cne filter-press mud;

Agroforestry - includes the development of basic studies on forestry parameters (spacing, fertilization, rotation, rate of growing, net photosynthesis, etc.); development of technologies to enable the establishment and management of energy forests in areas unsuitable for agriculture or degraded areas; identify requirements for establishing agro-forestry arrangements on the small scale

Precision Agriculture technologies and use of satellite images in cane production

Sugar cane trash recovery: integration with harvesting; trash conditioning

2. Processing biomass into energy carriers

2.1 Biomass for domestic cooking - includes optimizing biomass stoves; mitigating or eliminating health and environmental impact
of wood burning inside houses; studies for stabilizing cycles of wood demand; sustainable production and access to firewood;

2.2 Fueling Diesel cycle engines with biofuels - includes improving existing processes or develop new processes for substituting vegetable oil or animal fat as feedstocks for biodiesel production; develop adaptations on Diesel engines to run on bioethanol; developing studies on the catalysts and reagents used in industrial processes; improving oil extraction methods, especially adapted to small and medium size plants; improving oil extraction methods, especially adapted to small and medium size plants. However, biodiesel derived from conventional petrol or from oilseeds or animal fat cannot meet realistic need, and can only be used for a small fraction of existing demand for transport fuels. In addition, expensive large acreages for sufficient production of oilseed crops or cost to feed animals are needed for raw oil production. Therefore, oleaginous microorganisms are available for substituting conventional oil in biodiesel production. Most of the oleaginous microorganisms like microalgae, bacillus, fungi and yeast are all available for biodiesel production. Regulation mechanism of oil accumulation in microorganism and approach of making microbial diesel economically competitive with petrodiesel should be understood and be transformed into innovative processes;

2.3 Biomass for heat and electricity production - includes research and develop reliable, fuel-flex, energy efficient, cost optimized gasification systems; generate technologies for the recovery of condensable gaseous products during the wood carbonization process; improve the energy use of black liquor; develop studies on the quality of charcoal to be used in blast furnaces, with emphasis on carbon fines studies; set up protocols, certification and technical standards for the technologies associated with the supply and use of energy from forest biomass;

2.4 Sugar cane biomass hydrolysis and fermentation to ethanol or other energy carriers. Advanced conversion technologies are needed to produce ethanol and ethanol derivatives from a wider range of resources, including lignocellulosic biomass. A wide range of lignocellulosic biomass wastes can be considered from agriculture (e.g. straw, corn stover, bagasse), forestry, wood industry, and pulp/paper processes. Cellulose and hemicellulose can be converted into alcohol, by first converting them into sugar, but the process need to be proven at an industrial scale. Lignin cannot be converted by such a biochemical process but can be via a thermochemical step. Today, there is little commercial production of ethanol and ethanol derivatives from cellulosic biomass, but R&D is ongoing in Canada, USA and also in Europe.
\textbf{2.5 Direct conversion from sugar to fuels}, Investigations are underway to transform common ethanol producing yeasts to produce linear chain hydrocarbon substances from saccharosisis, with fuel properties similar to diesel;

\textbf{2.6 Biogas} - includes developing domestic, multi-feedstock, modern high rate biomethanation systems; developing and evaluating the kinetics of anaerobic digestion in different biodigester models and systems for the final treatment of liquid biodigester wastes; evaluating the quantitative and qualitative characteristics of biogas as a function of climatic seasonality and type of animal production system; developing equipment for the use of biogas as heat source in swine and poultry production facilities; developing equipment to compress and transport biogas under low pressure; evaluating the use of bio-fertilizers, derived from biodigester residues; adapting Diesel and Otto cycle engines to run on biogas. Also, the use of innovative processes, like aerated and ferricyanide catholytes on the bioelectricity production via chambered microbial fuel cell (MFC) (mediatroless anode; graphite electrodes), employing selectively enriched H$_2$ producing mixed consortia as anodic inoculums, have a tremendous potential;

\textbf{2.7 Biorefineries} - includes identification of chemical substances present on biomass with interest to the chemical industry; identification of chemical substances presently extracted from fossil sources that can be obtained from biomass; identification of chemical routes for expansion of oil and ethanol chemistry; developing innovative uses for the glycerol generated on biodiesel plants and for residues or co-products of energy biomass; developing novel nutritional uses from residues of energy biomass.

\section*{B. Solar energy}

**Present status, potentialities and prospective scenarios**

The energy from the sun can be used directly to heat, cool or light buildings, to provide domestic hot water to meet basic thermal and hygienic requirements for the rich and poor alike, in both developed and developing nations. The sun radiant energy can also directly provide very hot water or steam for industrial processes, heat fluids through concentration to temperatures sufficient to produce electricity in thermal-electric generators or to run heat engines directly, and produce electricity through the photovoltaic effect.

The radiant energy from the sun can be used directly to enhance public safety, to bring light and the refrigeration of food and medicine to the 1.8 billion people of the world without electricity, and to provide communications to all LAC regions, as well as, to generate clean electricity through grid connected...
photovoltaic systems. It can also be used to produce fresh water from the seas, to pump water and power irrigation systems, and to detoxify contaminated waters, addressing perhaps the world’s most critical needs for clean water to drink and to grow food. It can even be used to cook food with solar box cookers, replacing the constant wood foraging that mostly falls on the shoulders of women, and which also denudes ecosystems and contaminates the air in poor shelters.

It is this diversity of opportunities that makes solar energy such an attractive option for so many applications and with critically important potential for all cultures, regions, economies and peoples of the world, particularly of the LAC countries. The LAC region is very reach in solar resource. In most of the territory the annual daily average insolation per square meter is above 4 Kilowatt-hrs/m²/day. But there are special areas with a very high value like the northern part of Mexico with values of 6 Kilowatt-hrs/m²/day or Honduras and some areas of Cuba, Dominican Republic, Peru, Bolivia and Brazil with insolations of 5 Kilowatt-hrs/m²/day or above. The highest value of insolation in the world is found in North Africa and Australia with a value of around 7 Kilowatt-hrs/m²/day. Solar radiation is the highest energy potential in LAC countries. Therefore, the LAC region in general is a very good region for the use of solar energy technologies (Figure 11).

However, even though the solar resources and its potential application are high, the use of solar energy technologies in the LAC region has been very limited, mainly it is restricted to solar water heating and photovoltaics. For example, in Mexico, there are some companies that produce flat plate solar water heating collectors for a local market and other companies that import those, mainly from China, and distribute in the country. The cumulative number of square meters installed in Mexico of flat plate solar collectors, by the year 2006, was about 840,000, but comparing with the installed in countries like Turkey or Israel is small. In the rest of the countries of LAC there is no information about the total amount of flat plate solar collectors used, but we presumed is very low.
With respect to the use of photovoltaic systems in the LAC countries, several national and international programs have been implemented to install PV systems for lighting and water pumping in small villages. One of those was the Mexican Renewable-Energy program, conducted by Sandia National Laboratories and sponsored by the Department of Energy and Agency for International Development of USA. This program has been a model to follow for the implementation of pumping systems and electrical generation using renewable energy sources; the model was used in other Latin-American countries. Under this program, more than 200 water-pumping systems in rural communities were installed, and intensive, professional training were provided to over 30 engineers, allowing them to become experts in renewable energy.

It is estimated that by the year 2006, 17,633 KWe of PV systems were installed in Mexico. Training has also been provided to dozens of Mexican professionals from the public and private sectors. Now, Mexico has a national program for the productive use of PV systems in rural areas supported by FIRCO, a federal grant agency. There are other examples of such programs in LAC but there are a few.

Other isolated applications like food drying, solar refrigeration for conservation of food or vaccine, solar stills have being implemented in the region, but with no replication and with lack of information.

The prospective scenarios of the use of solar energy in the LAC region are optimistic. It is expected that in the near term (5 years) and due to the implementation of adequate polices to promote renewable energy technologies, it will be a significant increase of the RE markets. Also, in the long term (10-15 years), as the research groups becomes stronger, national and international enterprises will born and grow and LAC RE technologies will be developed, it is expected the use of RE will be massive and cover at least the 20% of the primary energy consumption.

**Revision of priorities**

Solar thermal devices developments are of outmost importance in the LAC region. They can be used to heat water for domestic use saving a great amount of gas, to produce hot water or steam for industrial processes, to heat fluids through concentration to produce electricity in thermal-electric generators. They can be used in small villages to produce fresh water from the seas, to detoxify contaminated waters to drink and to grow food, to cook food with solar box cookers, to pump water and power irrigation systems relatively simple. Even, in small and big cities. Most of these technologies are capable of being developed and manufactured in the Region. The incipient industry in the LAC region on these solar devises should be supported through several actions, among them, the proper implementation of political issues that make grow the market and with specific support to the scientific and technological development to allow innovation in the sector.
Photovoltaic development is also of outmost importance because solar energy is the largest potential in the Region for electricity generation. An important characteristic of photovoltaic energy is that electricity can be produced where it is needed, especially in our region with a higher than average solar radiation intensity. Research towards making possible full-use of this potential is of primary importance. Not having to import solar-to-electricity converting technologies from the developed countries is fundamental to make the Region energy independent to satisfy its needs. On the other hand, modular character, ease of installation and very simple maintenance of PV systems make them ideal for the use in non-grid connected remote communities. At this respect, PV systems may play a very important role in contributing to bring education, culture and even health to those communities.

Creation of personnel and research facilities are badly needed in order to fulfill goals for photovoltaic systems development and production. Existing applications of PV systems in the Region are based on PV panel imported (with the exception of Cuba that produces panels using imported solar cells). Solar cells research is conducted in some universities in Mexico, Brazil, Cuba and Argentina. In all cases, these are small research groups that contribute with some to universal knowledge advancement through their publications, but these are not connected to industry.

Even though the use of Solar Energy in the LAC region has being low, since about 30 years have had some research groups, mainly in universities, that have done scientific and technological research in several topics of solar energy, like solar collector technology, thermal and chemical storage energy, photovoltaic, solar water heating, passive space heating and cooling, integration of solar collectors in buildings, solar systems for steam production, drying and desalination and mapping solar radiation and other resources and solar radiation models.

The main institutions of different countries of LAC that have being working in research on solar energy are the following:

i. In Mexico, the main institutions with groups working in solar energy are:

1. Center for Energy Research (CIE) of the National University of Mexico. This is the only one institution in Mexico dedicated to research in renewable energy, mainly in solar energy. They have worked in solar refrigeration systems, heat pumps for solar heating and cooling, solar drying of agricultural products, solar concentration: low and high concentration ratios, desalination, passive solar space heating and cooling, components and system testing, solar water purification, solar detoxication, solar cooking, solar thermal electricity, solar photovoltaic electricity, energy storage, batteries, hydrogen production and storage, fuel cells, thin film technology and energy planning studies.
2. Institute of Engineering of the National University of Mexico. They have a small group that have worked mainly in the area of solar thermal: solar ponds, cylindrical-parabolic collector’s technology, direct steam generation, mirrors of first surface, desalination, passive solar space heating and cooling, energy planning studies and resource assessment.

3. Research and Advanced Studies Centre of the National Polytechnic Institute (CINVESTAV -IPN). They have worked mainly in solar photovoltaic materials, in the development of solar cells and solar panels, as well in photovoltaic solar systems and applications.

4. Electrical Research Institute. They have worked in photovoltaic solar systems, solar ponds, and more recently in hydrogen and solar concentration technology: cylindrical-parabolic collectors and dish/stirling.

5. National Association of Solar Energy ANES (ISES-Mexico). This association is 28 years old and through its annual congress allows the solar researchers meet and exchange technical information in all topics of renewable energy. It has been a catalyst for the solar research in Mexico.

ii. In Argentina, the main institutions with groups working in solar energy are:

1. Non-Conventional Energies Research Institute (INENCO) of the National University of Salta. This is the most active research center in solar energy in Argentina. They have worked in the area of resource assessment, solar drying of agricultural products, greenhouses, potable water production, water heating for domestic and industrial applications, flat plate solar collectors and solar ponds, solar cookers, solar architecture, daylighting, passive cooling.

2. Solar Energy Group of the National Atomic Energy Commission (SEG-CNEA). They have worked in the area of selective surface, concentrating collectors, photovoltaic cells and photovoltaic systems.

3. Human Environment and Housing Laboratory (LAHV) of the Science and Technology Research Regional Center (CRICYT). They have worked in the area of solar cookers, solar architecture, ecodesign, daylighting and passive cooling.

4. Solar Energy Argentina Association ASADES (ISES-Argentina). This association is also 28 years old. It has annual meetings in locations where there are research groups in renewable energies. It has been a catalyst for the solar research in Argentina.
iii. In **Brazil**, the main institutions with groups working in solar energy are:

1. Solar Energy Laboratory of the Santa Catarina Federal University (UFSC). They have worked in the area of resource assessment, refrigeration systems, passive solar space heating and cooling, solar photovoltaic electricity and energy efficiency in buildings.

2. Solar Energy Laboratory of the Paraiba Federal University (UFSC). This is a small group working in solar collectors of medium temperature, desalination, radiation in semitransparent materials, thermal characterization of materials and solar drying.

iv. In **Colombia**, the main institution with groups working in solar energy is the National University of Colombia. They have worked in the area of resource assessment, solar collectors of low and medium temperature, solar cookers, refrigeration systems and fuel cells.

v. In **Cuba**, the main institutions with groups working in solar energy are:

1. The Materials Science and Technology Institute (IMRE) and the Physics Faculty, both at the University of La Habana. They have worked in the area thin film technology by PLD, CSS y chemical bath, semiconductors devices for solar cells (silicon, dye sensitized solar cells, nanocrystalline solar cells).

2. The Center for Solar Energy Research (CIES) in Santiago de Cuba. They have worked in solar thermal (water heating, solar drying, applications, etc.), as well as, photovoltaic systems applications and demonstration projects.

3. The Center for Renewable Energy Technologies Studies (CETER) at the Higher Studies Polytechnic Institute “José Antonio Echevarría” in Havana. They work in solar thermal, as well as, photovoltaic applications.

4. The research center Cubaenergía, Ministry of Science, Technology and Environment (CITMA) working in solar thermal for water heating, air conditioning, water detoxification.

In Mexico, as in Argentina, Brazil, Colombia, Cuba, Guatemala and other LAC countries, there are several researchers in different institutions working in solar energy, but working alone or in small groups with few students and very low budget. The activities of research and development in solar energy in LAC region started in the early ’70s, gained increasing interest in the following years along with steady centralized government specific funding support for the area. After a certain decline in the late ’80s and early ’90s, today we see renewed interest.
The origin of the present funding for research has apparently shifted to national universities and non-specific national funding. The private sector, probably due to a stronger environmental conscience in the public and to the requirements of environmental impact analysis of projects in international loans and to harder economic competition due globalization of economy, as well as conscience of the depletion of fossil fuels, is showing increasing interest in the applications. We are going to a transition period in this sense.

**Specific research areas**

1. **Resource assessment**

   1.1 Provide standardization and benchmarking of international solar resource data sets for the LAC region, to ensure worldwide inter-comparability and acceptance.

   1.2 Provide improved data reliability, availability and accessibility in formats that address specific user needs, and

   1.3 Develop methods that improve the quality and spatial and temporal coverage, with customized solar resource products, including reliable solar radiation forecasts.

2. **Passive solar heating and daylighting of buildings**

   2.1 New limits for the design of constructions.

   2.2 New constructive methodologies.

   2.3 Develop of new technologies of components of encircling integrated to the design of the constructions (new materials with recyclable capacity and non pollutant, and advanced technologies of glasses, etc.).

   2.4 Develop of standards that determine the energy quality and level of emissions of the construction.

3. **Solar thermal for heating and cooling**

   3.1 Develop of new components that reduce the cost of the parabolic-cylinder collectors and increase their commercial competitiveness

   3.2 Develop of absorber tubes of low cost

   3.3 Develop of new coatings with application in solar concentration systems

   3.4 Develop of structure lighter and easier of installing in field
3.5 Manufactured concentrators with innovative materials

3.6 Characterization of components under real conditions, using specific experimental facilities

3.7 Evaluation of absorber tubes in vacuum chambers

3.8 Evaluation of new mirrors and solar tracking systems in real conditions, using specific experimental facilities

3.9 Development of industrial applications and processes with a good potential of use of the solar energy in the range of temperatures: 125°C-450°C (electricity generation, process heat and industrial air conditioning)

3.10 Develop of standards that determine the energy efficiencies of the components and systems

3.11 Develop of software to design and simulate solar systems

4. Solar thermal electric energy generation

1.1 Develop innovative and cost-effective components for solar collectors, systems, plants and competitive technologies for the use of the solar energy in the range of the stocking temperature (250°C - 1500°C).

1.2 Develop large solar thermal power plants having at least units of equivalent solar capacities of 10 MWe

5. Solar photovoltaic electric energy production

1.1 New developments in cells, modules and systems, that allow speed up the actual tendency of costs reduction

1.2 Reduction of the thickness and production cost, as well as the increment in efficiency of crystalline silicon cells.

1.3 Cost reduction and surface increased in the material production of thin film and heterounion devises.

1.4 New concept as organic cells, polymeric cells or cells with solar concentration III-IV.

1.5 Design of new integrated PV systems with ease installation, low cost and high durability (25-30 years).
C. Wind Energy

Present status, potentialities and prospective scenarios

Modern commercial wind energy started in the early 1980s following the oil crises of the 1970s when issues of security and diversity of energy supply and, to a lesser extent, long-term sustainability, generated interest in renewable energy sources. Significant consolidation of design has taken place since the 1980s, although new types of electrical generators have also introduced further diversification. Many developments and improvements have taken place since commercialisation of wind technology in the early 1980s, but the basic architecture of the mainstream design is little changed. Most wind turbines (WTs) have upwind rotors and are actively yawed to preserve alignment with wind direction. The three-bladed rotor proliferates and, typically, has a separate front bearing with a low speed shaft connected to a gearbox, which provides an output speed suitable for a four-pole generator. Commonly, with the largest WTs, the blade pitch will be varied continuously under active control to regulate power at the higher operational wind speeds. For future large machines there appears to be a consensus that pitch regulation will be adopted.

The vast majority of WT blades are made from glass polyester or glass epoxy. Although there is some automation involved in the process it is labour intensive with the procedures still traced back to their boat building origins. Support structures are most commonly tubular steel towers tapering in some way, both in metal wall thickness and in diameter from tower base to tower top. Concrete towers, concrete bases with steel upper sections and lattice towers are also used but are much less prevalent. Tower height is rather site-specific and turbines are commonly available with three or more tower height options.

Considering the range of wind turbine sizes, the increase in diameter to rating ratio of the latest turbines has been a consistent trend. This parameter is important because as the turbine increases in diameter it also increases in height. There is a relationship between diameter and rating as wind shear causes wind speed to increase with height. The drive train shows the rotor attached to a main shaft driving the generator through the gearbox. It is in the area of the gearbox that significant developments in basic design architecture are now appearing, in the form of direct drive generators. The gearbox is removed and the aerodynamic rotor drives the generator directly. Hybrid arrangements involving a single stage gearbox and multipole generator are also appearing.

Direct drive transmission systems for WTs, avoiding the gearbox as a cost and maintenance item, are of increasing interest. Historically, gearboxes have presented challenges; hence their removal through the direct drive concept may seem desirable. It is, however, possible that mechanical difficulties are simply replaced by electrical ones. It is far from clear which of the configurations is optimum. The effort to minimise capital cost and maximise reliability continues; the ultimate goal is to minimise the cost of electricity generated from the wind.
Operation at variable speed offers the possibility of increased “grid friendliness”, load reduction and some minor energy benefits. It is thus an attractive option. Among wind turbines over 1 MW rating, out of 52 distinct models of 20 different manufacturers, only three were fixed speed, 12 had two speed systems and 37 employed variable speed. This shows that it is almost mandatory for MW-scale turbines to have some degree of speed variation and that continuously variable speed is the predominant choice.

The development of WTs is a remarkable success story, which is not yet complete. The wind industry is now poised at a stage where it is regarded by some as a mature technology and able to stand on its own commercially. While that status is a great achievement, it is important to realise the potential for greater growth that can best be furthered by continuing vigorous Research and Development efforts. The design drivers are always reduction in cost and increased reliability.

**Current and Prospective Scenarios**

The global wind energy industry has been growing at the staggering rate of nearly 30 % per year for the last 10 years, and experts predict that there is no end in sight for this boom. While a large proportion of this development is happening in Europe, other markets, especially Asia and North America are catching up fast. The success of wind energy worldwide and its tremendous growth has put unprecedented pressure on the manufacturers of the components of wind turbines, such as towers, rotor blades, gearboxes, bearings, generators, etc., and the industry has been struggling to keep up with the demand. At the moment, developers of wind farms have to wait for 12 months for the turbines required, and the trend shows that this may increase to 18 or even 24 months.

The booming wind energy markets around the world exceeded expectations in 2006, with the sector experiencing yet another record year with installations of 15,197 megawatts (MW). This takes the total installed wind energy capacity to 74,223 MW, up from 59,091 MW in 2005 (Figure 12).

Despite constraints facing supply chains for wind turbines, the annual market for wind continued to increase at the staggering rate of 32 % following the 2005 record year, in which the market grew by 41 %. This development shows that the global wind energy industry is responding fast to the challenge of
manufacturing at the required level, and manages to deliver sustained growth. In terms of economic value, the wind energy sector has now become firmly installed as one of the important players in the energy markets, with the total value of new generating equipment installed in 2006 reaching €18 billion, or US$23 billion.

The countries with the highest total installed capacity are Germany (20,622 MW), Spain (11,615 MW), the USA (11,603 MW), India (6,270 MW) and Denmark (3,136 MW). Thirteen countries around the world can now be counted among those with over 1,000 MW of wind capacity, with France and Canada reaching this threshold in 2006. In terms of new installed capacity in 2006, the US continued to lead with 2,454 MW, followed by Germany (2,233 MW), India (1,840 MW), Spain (1,587 MW), China (1,347 MW) and France (810 MW). This development shows that new players such as France and China are gaining ground (Figures 13 and 14).

The Latin American market is starting to show signs of healthy growth, mainly in Brazil and Mexico. Overall, Latin America saw 296 MW of new
installations in 2006, compared to only 6 MW in the previous year. In Brazil, the
government’s PROINFA programme is showing first signs of success, with new
installations of 208 MW, which brings the total capacity up to 237 MW, while
the infrastructure for another 220 MW is still being constructed. The Federal
Government is also expected to announce a 5,000 MW wind energy program to
be realized between 2009 and 2015 (see page 34 for a country report on Brazil).

In Mexico, which also has an excellent potential for wind energy, 85 MW
of new capacity were installed in 2006, bringing the total up to 88 MW. The
Mexican Wind Energy Association (AMDEE) estimates the development of
at least 3,000 MW by 2014. Figure 15 shows the wind energy share on the world
electricity generation.

Until the end of the current decade, the cumulative capacity of wind
energy installations is predicted to reach 149.5 GW, more than double of the
present installed capacity. The average annual cumulative growth rate during the
period 2006-2010 will be 19.1 %, compared with the 24.3 % of the period 2002-
2006. The annual installed capacity is predicted to reach the 21 GW in 2010, an
increase of 38 % from the15.2 GW installed in 2006. This implies an average
annual growth rate of 8.4 % for the global wind energy market. The growth
could be much bigger but, at least in the near future, is limited by the production
capacities of the manufacturers. In most markets, the current delivery time for
machines is around two years.
In 2006, first encouraging developments could be noted in Latin America and the Caribbean, with new installations of 296 MW. During the period 2007-2010 it is predicted that the market will take off starting with Brazil and followed to a lesser extent by Mexico. Smaller developments will also take place in some countries of Central America as well as in Argentina and Chile. Despite its large potential Latin America will remain a small market until the end of this decade, progressing towards significant development in the next decade.

Three different scenarios are outlined for the future growth of wind energy around the world (Figure 16). The most conservative “Reference” scenario is based on the projection in the (2004) World Energy Outlook report from the International Energy Agency (IEA). This projects the growth of all renewables, including wind power, up to 2030. The “Moderate” scenario takes into account all policy measures to support renewable energy either under way or planned around the world. It also assumes that the targets set by many countries for either renewables or wind energy are successfully implemented. The assumption here is that the success achieved in Europe in meeting the goals for wind energy implementation set by the European Union will be repeated globally.

The most ambitious scenario, the “Advanced” version, follows a similar development path to that outlined in the series of Wind Force 10 and 12 reports produced since 1999 by the European Wind Energy Association (EWEA), the Global Wind Energy Council (GWEC) and Greenpeace. These examined how feasible it would be for 10%, and later 12%, of the world’s electricity to come from wind power by 2020. The assumption here is that all policy options in favour of renewable energy, along the lines of this report’s recommendations, have been selected, and the political will is there to carry them out.

These three scenarios for the global wind energy market are then set against two trajectories for the future growth of electricity demand. Most importantly, these projections do not just assume that growing demand by consumers will inevitably need to be matched by supply options. On the basis that demand will have to be reduced if the threat of climate change is to be seriously tackled, they take into account an increasing element of energy efficiency. The more
conservative of the two global electricity demand projections is again based on data from the IEA's 2004 World Energy Outlook, extrapolated forwards to 2050. This is the “Reference” projection. It does not take into account any possible or likely future policy initiatives, and assumes, for instance, that there will be no change in national policies on nuclear power.

The IEA's assumption is that “in the absence of new government policies, the world's energy needs will rise inexorably”. Global demand would therefore almost double from the baseline 13,423 TWh in 2003 to reach 25,667 TWh by 2030 and continue to grow to 37,935 TWh by 2050. The IEA's expectations on rising energy demand are then set against the outcome of a study on the potential effect of energy efficiency savings developed by DLR and the Ecofys consultancy. This describes an ambitious development path for the exploitation of energy efficiency measures. It focuses on current best practice and available technologies in the future, and assumes that continuous innovation takes place. Under the “High energy efficiency” projection, input from the DLR/Ecofys models shows the effect of energy efficiency savings on the global electricity demand profile.

Although this assumes that a wide range of technologies and initiatives have been introduced, their extent is limited by the potential barriers of cost and other likely roadblocks. This still results in global demand increasing by less than 30 % to reach 17,786 TWh in 2030. By the end of the scenario period in 2050, demand is 39 % lower than under the Reference scenario .

The results of the Global Wind Energy Outlook scenarios show that even under the conservative IEA view of the potential for the global market, wind energy could be supplying 5 % of the world's electricity by 2030 and 6.6 % by 2050. This assumes that the “High Energy Efficiency” projection has been introduced. Under the Moderate wind energy growth projection, coupled with ambitious energy saving, wind power could be supplying 15.6 % of the world's electricity by 2030 and 17.7 % by 2050. Under the Advanced wind energy growth projection, coupled with ambitious energy saving, wind power could be supplying 29.1 % of the world's electricity by 2030 and 34.2 % by 2050.

Research priorities

The major priorities on wind energy Research and Development are related to wind resource estimation, wind turbines, wind farms, grid integration, environment and public support, standards and certification. The most important scientific institutions in Latin America dealing with Wind Energy are:

i. Brazilian Wind Center, CBEE, Brasil

ii. Instituto de Investigaciones Eléctricas, IIE, México

iii. Centro de Investigaciones de la Energía, Universidad Nacional Autónoma de México

iv. Center for the Study of Renewable Energy Technologies at the Technical University of Havana, CETER, Cuba
Other non-scientific institutions in Latin America dealing with wind energy are the Mexican Wind Energy Association (AMDEE), the Centro Regional de Energía Eólica, CREE, Chubut, Argentina and the IMPSA Wind, Argentina.

Specific research areas

1. Wind Resource estimation:

1.1 maximum availability of wind resource data, in the public domain where possible, to ensure that financiers, insurers and project developers can develop high quality projects efficiently, avoiding project failure through inaccurate data;

1.2 Resource mapping of areas with a high probability of high wind resource potential, but as yet unexplored;

1.3 Development of cost effective measuring units, including communications and processing, and which are easily transportable, for the assessment of wind resource characteristics, such as LIDAR, SODAR and satellite observation.

2. Wind turbines

2.1 Integrated design tools for very large wind turbines operating in extreme climates, such cold / hot climates and complex terrain;

2.2 State of the art laboratories for accelerated testing of large components under realistic external (climatological) conditions;

2.3 Development of component level design tools and multiparameter control strategies.
3. Wind farms

3.1 Research and development of wind farm level storage systems; Understanding the flow in and around large wind farms;

3.2 Control systems to optimize power output and load factor at wind farm level;

3.3 Development of risk assessment methodologies

4. Environment and public support

4.1 Research on the effects of large-scale wind power plants on ecological systems, targeted at the general public and policy makers;

4.2 Include specific recommendations for wind park design and planning practices;

4.3 Effects on ecology adjacent to wind energy developments;

4.4 Development of automatic equipment to monitor in particular bird collisions;

4.5 Economic evaluation of externalities; International exchange and communication of results of R&D into ecological impacts

D. Small and micro hydro facilities

Present status, potentialities and prospective scenarios

This is an old proven technology that needs to be fully integrated into the Latin American energy matrix. The hydro potential in Latin America is over 659,531 MW of which we are currently using around 21%; in Central America the potential is 23,625 MW, of which the region is using 17% of the total available. Therefore, it is very important to the region to develop its hydro potential for several reasons:

i. Hydro electricity is an indigenous natural renewable resource that has myriad of sites that can be developed using environmentally sound technologies.

ii. Developing hydro facilities can induce environmental services recognition of the watershed that in turn can be sustained by forest management and integrated water resources techniques.

iii. By developing hydro sites, and thus inducing watershed management, it is possible to reduce the vulnerability to extreme weather phenomena.
iv. The technology is labor intensive and can create several employment opportunities, both at the technical services on skilled labor contribution, non-skilled massive local labor, equipment vendors participation and so on.

v. Most of the untapped hydro potential is located at the end of the national interconnected system thus making distributed electricity generation a sound energy policy, while at the same time introducing renewable energy into the national energy matrix.

vi. Renewable energy avoids or displaces the fossil fuel generation projects, therefore they are eligible for the CDM or other voluntary carbon trading mechanisms.

vii. Small scale hydro facilities are compatible with indigenous people cosmovision since it's based on the cyclical recreation of energy by tapping natural resources without polluting or destroying them.

viii. Small and micro hydro can be both off-grid and grid connected, thus they can provide electricity to isolated communities or feed energy into National grids.

It is necessary to explore other small renewable energy technologies such hybrid projects: including sun, wind and water. In some locations, there is a mix of natural resources that vary depending on the season: when it rains, there is no wind, but in the dry season, wind blows. The same with photovoltaic energy, in the rainy season, sun is limited, so the use of hybrid projects using more than one technology can be a solution for off-grid and remote areas where the national grid is highly unlikely to serve the population in the coming years. In other areas, the geothermal resources that are close to the surface (low enthalpy) can be used for cottage industries and to produce heat for drying crops and heating homes.

**Revision of priorities**

From the standpoint of micro hydro, it should be considered

i. Improved component design based on world commission on dams best practices, focus on lowering cost of the kWh installed capacity from the current US$4,000.00 - US$3,000.00 to US$2,500.00 - US$2,000.00 by increasing efficiency on the turbine (new materials) better automatization equipment and inducing a load factor based on productive uses of electricity (PUE).

ii. Research on multipurpose afforestation including firewood species in watershed management, focus on native species to promote ecosystem and germplasm protection.

iii. Improved small hydro components design and integration for key components, such as: derivation and intake, compensation chamber,
penstock, turbine, generator, controlling and protection. It is very important to take into account the experience of China, India and the European, but also it is necessary to learn from experiences in Perú and Cuba.

iv. The key milestone will be to lower the current price for install kW from US$4,000 - US$3,000 to arrange between US$2,500 - US$2,000. Most of the work will be concentrated on new materials for turbine manufacture.

v. The research will involve practitioners, Latin American manufactures and experts from other regions that will set an in service training process to generate improved blueprints on machinery such as Francis Banki, Pelton, and other models.

vi. Other specific milestones will be to set up synchronic equipment so small hydro facilities can be interconnected to National grids. This work will entail coordination between practitioner, vendors and manufactures of equipment, electricity regulation bodies that can set up the guidelines and threshold criteria for safe interconnection starting at capacities from 200KW.

vii. In order to make the research and development improvement feasible to implement it will be necessary to set up distributed energy by laws into the general electricity policy framework; therefore, it is expected to develop the protocol for distributed electricity generation market participation.

viii. Simultaneous to the development of improve less expensive, a more efficient hydro equipment it will be necessary to investigate the articulation of a productive uses of electricity program that incorporates high efficiency appliances and machinery into value added local production chains that also takes into account indigenous communities traditional knowledge.

ix. The main focus for this R&D is to put energy as a means to accomplish production ends that are environmentally friendly and culturally sensitive. For example, it will be necessary to perform R&D that integrates best practices of hydro facilities integrated to natural resources transformation that can improve the value of agroforestal products such as organic coffee, cardamom, certified woods, dairy products, handcrafts, vegetables canning and/or preservation and so on.
E. Related Technologies

Hydrogen

Present status, potentialities and prospective scenarios

The temporal variability of the renewable energy resources determines the necessity of energy storage in order to be able to match the utilization of those resources with the economic and social activities of our societies.

Thus, the primary energy from renewable resources, such as solar, wind, and biomass can be accumulated, transported and used whenever it is needed, independent of when the renewable resource is available.

Among energy storage and carriers, apart from fossil fuels, electric batteries are perhaps the most extended and common ones but the energy they can store per unit volume is very low. Nowadays biofuels are becoming very popular since they can replace hydrocarbons in transportation, though, because of the very low efficiency of photosynthesis, biomass cannot supply in the future all the energy needs. Hydrogen, which is the most common element on Earth obtainable from water, is foreseen to play a key role in the long term future once several issues such as cost, safety and storage are solved through research and development.

It is important to note that hydrogen is not a primary energy and requires primary energy to be produced.

Hydrogen can be obtained directly (photolysis) or with electricity derived from renewable energy (electrolysis). Its development will also be supported by its potential for transforming transportation and stationary energy systems worldwide. Remote sources of renewable energy in areas of attractive wind, solar or geothermal energy potential can become hydrogen factories. The transportation of that hydrogen for use in local, distributed fuel cells (which are also CHP devices) will then allow the original renewable energy to be delivered as electrical power and heat on demand.

Widespread and large-scale application of energy storage technologies will not be needed until after 2020, and perhaps not until 2030. The development of hydrogen fuel and applications will proceed independently of the renewable energy transition, pulled by the attractive economic benefits of the hydrogen transition, and pushed by aggressive government programs, so that by then the hydrogen technology and infrastructure can be expected to be sufficiently ready to support higher penetration levels of the renewable energy resources.

The corollary of this argument, though, is that the environmental success of the hydrogen transition will depend entirely on the utilization of renewable energy resources instead of the conventional energy sources to produce the hydrogen. A declared goal of the European Union is to achieve a fully integrated hydrogen economy base on renewable energy by the middle of the centura.
Revision of priorities

It is a priority to LAC countries be part of the research and development of hydrogen technologies, mainly as a part of the international effort that it is taking place. The synergy between hydrogen development and the application of the renewable energy technologies will be significant. Hydrogen, a clean energy when burned, will be produced by clean energy resources. And the energy from those clean resources will be converted to fuel for on-demand clean energy applications, fully decoupled from renewable energy source fluctuations. The economic and social values of both the hydrogen and the renewable energy resources will be enhanced by that synergy. The parallel renewable energy and hydrogen transitions will be mutually supportive.

Specific research and development areas

- characterization of material and devices adequate for production, storage and application of H₂, particularly in fuel cells.
- mathematical modeling of the processes in the fuel cell to improve design.
- fuel cells prototype and systems for the production of H₂ for practical applications.
- methodology to storage H₂ in solids.
- methodology for thermochemical processes at high temperatures with solar energy for the production of H₂.
- characterization of material and peripheral devices in related processes with the use of H₂ (batteries and supercapacitors).
- hydrogen norms and protocols related to all aspect of the technology.
- implementation of educational programs of H₂ technologies.
- prototype units to produce H₂ at high temperature

- planning and prospective studies related to the economy of hydrogen.
The integration of renewable energy resources and associated technologies into the present and future energy systems is a complex problem that is far from being solved, especially when the participation of renewable energy in the energy systems is relatively large.

This integration into energy supply systems such as electricity grids, heat distribution networks, gas distribution networks and liquid fuels requires research and development in areas such as:

- load management,
- grid management,
- energy transport,
- interactions with conventional systems,
- necessary back-up power systems.

R&D is also required to address the issue of distributed versus centralized deployment of renewables and its relation to energy efficiency.

In addition, the integration of renewable energy into current and future energy systems will require the creation of standards and protocols to be observed by both technologies and supporting normative to be developed.

**Grid integration**

Control strategies and requirements for wind farms to make them fully grid compatible and able to support and maintain a stable grid;

Development of electric and electronic components and technologies for grid connection.

**Standards and certification**

Energy yield calculation;

Grid connection protocols and procedures; Risk assessment methodology;

Design criteria for components and materials;

Standardization of O&M mechanisms

Accelerated finalization of ongoing standards development activities (certification processes and test procedures, design criteria for offshore wind turbines, project certification).
5. Economic and Socio-Cultural Issues

At the beginning of the XXI century we are far from achieving an intergenerational and transtemporal dynamic equilibrium between humanity, other life forms and the planet itself. On the contrary, we have created an unbalanced sustained economic growth, based on profit maximization that relays on negative economic externalities there are not being incorporated in the full cost of transforming natural resources for human requirement and needs. What we experienced in the world is a sustained economic growth based on fossil fuel consumption and intensive mining activities. The economic globalization process is based on a linear mindset that accumulates capital through time, based on natural resources exploitation leading to pollution, and human and ecological stress.

In terms of energy consumption there are over two billion people in the world without access to modern energy supply. On the other hand it seems that humanity is addicted to oil, showed by the fact that the barrel of petroleum has increased its price three fold in one year. One good result is that consumers are starting to get worried about costs and are starting to set the pressure on automotive change. The time is very short for a measurable result, but indicators as demand for fuel efficient cars have skyrocketed, and multiple solutions are sprouting worldwide.

Even though, there is an increase in the participation of renewable energy technology investment for electric generation, the main energy projects being built in the world are based on burning fossil fuels such as petroleum and coal. Furthermore, the money allocated for energy research and development its being focus primarily on nuclear energy (56%), fossil fuels (32%) and only 12% are allocated for developing renewable energy technology. With this amount of subsidies skewed towards business as usual energy technology development it is going to be very difficult to level the field in order to have a fare shake of renewable energy participation. Still, change is in the air: in President Bush’s address to the World International renewable Energy Conference in Washington DC in March 2008, he pledged a sizeable portion of financing to start up research for greener fuels.

The economics of wind energy show that the capital costs, O&M costs, taxes, insurance and other costs, along with the expected profit, comprise the price of a kWh of electricity. Depending on the market situation and, perhaps, additional promitional measures, wind energy may or may not be competitive. It is generally appreciated that although wind energy and other renewable energy sources have environmental benefits compared to conventional electricity generation, these benefits may not be fully reflected in electricity market prices.
The externalities of energy generation deal with these questions in order to estimate the hidden benefits/damages of electricity production not accounted for in the existing pricing system. The costs are “external” because they are paid for by third parties and by future generations. In order to establish a fair comparison of the different electricity production activities, all costs to society, both internal and external, need to be taken into account.

For instance, employment in WT manufacturing includes both direct as well as indirect employment. Employment throughout the manufacturing sector has been increasing considerably in the EU since the beginning of the 1990s. Direct and indirect employment related to WT manufacture in Europe for 1998-2002 grew 185% for home market, and WT installation and 268% for WT maintenance, reaching 72,275 employment positions.

Despite the uncertainties and debates about externalities, it can be stated that with the exemption of nuclear power and long-term impacts of GHGs on climate change, the results of the different research groups converge and can be used as a basis for developing policy measures aimed at a further internalisation of the different external costs of electricity generation.

The use of the new solar energy technologies in the LAC countries is starting, and even though the market is very limited, as it increases, it will develop new factories and therefore new jobs. The fact that the solar energy is a low density source of energy implies that, to satisfy the same energy load that conventional energy systems do, it is needed a great amount of collector area. Thus, it is needed to manufacture a great amount of solar collectors. From the develop of new enterprises to produce thermal solar collectors, photovoltaic solar collectors, to design new power plants and new building, even new cities with and integral concept of sustainability, LAC countries are capable of being part of this revolution. A political vision and action is needed for that to happen.

It will be needed to transform the way our society think about energy as an infinity source to a more realistic way, where the energy is finite and its use must be sustainable. This will require the implementations of strong programs for saving energy with a great effort in education.

The simultaneous performing of technical R&D to improve the performance and efficiency of small and micro-hydro facilities that also reduce its final cost will require that the energy generated its used to create local employment by transforming the local natural resource based by blending traditional indigenous knowledge and high tech options in local businesses and agro industry to add value to local natural products. Socio economic R&D will be undertake setting up interdisciplinary teams of research including anthropology, gender studies, sociology, economics, business administration, and ecology in order to create specific case studies that illustrate high tech and traditional knowledge can be successfully implement.

It is today public policy and political leadership, rather than either technology or economics, that are required to move the widespread application of solar energy technologies and methodologies forward. The technologies and
economics will all improve with time, but they are sufficiently advanced at present to allow for major penetrations of solar energy into the mainstream energy and societal infrastructures. And significant goals can be now set with confidence for major percentage improvements in energy efficiency and increases in solar and renewable energy applications for the next 50 years, at which time the world should be receiving over 50% of all energy needs from locally available environmental resources, with most of these being from direct and indirect uses of solar energy. There are no resource limitations to this scenario.

**Actions with Social Impact**

To define concrete actions with a high social impact and visibility to be promoted by ICSU and its Regional Office and propose ways by which the ICSU family and its strategic partners can be involved in implementing the proposed actions.

i. Integrate with the other thematic areas

ii. Involvement of regional institutions (BID, OEA, CAN, Procisur, Proctropicos, etc)

iii. Involvement of national governments

iv. Integration with EU institutions / financing

v. Look for mechanisms like EU financing (involvement of different countries – networking)
6. Capacity building and other needs

Capacity building is required at different levels of renewable energy field. In the first place, capacity building is needed at governmental level to strengthen those institutions dealing with the energy sector, the industrial sector, and the trade and financing sectors. These institutions are key to create the enabling environments necessary to mobilize private capital and public resources for a full implementation of renewable energy in each country.

Capacity building may be needed for other actors, including engineers working in the academics or in the private sector, such project developers, etc. It may be realized by several means, including workshops, seminars, or full renewable energy courses. Capacity building and specific training may also be supported by planning visits to manufacture facilities and renewable energy installations.

The following aspects should receive higher priority

i. Network organization, implementation and operation, congregating LAC institutions, linked to other networks;

ii. Adaptation of universities disciplinary programs to cover RE and related disciplines;

iii. Incentives for undergraduate, specialization and graduate studies on renewable energy and related areas;

iv. Laboratory enhancement to provide adequate R&D conditions;

v. Financial incentives for prototyping, incubation and technological dissemination;

It is proposed deeply study the model of the International Consortium in Sugar Cane Biotechnology (ICSB), today involving 12 countries, in order to develop a LAC region “virtual” institution to promote specific studies and development in pre-commercial stage. The ICSB system is being used by Brazil, Argentina and Colombia, and a LAC region version could be very useful.

Communication and technology diffusion

Actions should be performed to involve the whole society on the discussion and adoption of renewable energy sources. Among others, the following actions are recommended:
i. Incentives for discussion and mass technological diffusion like congresses, seminars, workshops and technical meetings.

ii. Integration of the private and public sector to mass implementation of renewable energy generation and use;

iii. Prototyping and demonstration;

iv. Supporting high school Science Fairs for renewable energy demonstration;

v. Interact with the mass media to promote renewable energy;

vi. Prepare engineers and manpower to working with renewable energy generation, accumulation and distribution.

Extend and strengthen the BID initiative in Central America regarding sugar cane technology diffusion, including South American countries; to prepare a “virtual” technology information institution, also able to define and implement programs

**Fund Raising**

It is recommended to approach major donors, like JICA (the Japan International Cooperation Agency), Government supported financing agencies, private sector foundations like Bill & Melinda Gates, Rockefeller, Fulbright, which already are allocating funding for renewable energy and climate change R&D. Development agencies, like the Inter American Development Bank are also excellent options for program financing.

**Follow Up**

It is proposed to design a committee of renewed scientists on the renewable energy RD&I areas to follow up specific advances in the strategic plan, like organization of regional RD networks; adaptation of universities disciplines to renewable energy teaching; number of post graduation students linked to renewable energy areas; number of projects approved and amount of financial support conceded to renewable energy; number of communication and technological diffusion events completed; advance of the renewable energy generation and use on the national energy matrixes.
References


## Glossary

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>WCS</td>
<td>World Conference on Science</td>
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<tr>
<td>UNESCO</td>
<td>United Nations Educational, Scientific, and Cultural Organization</td>
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<td>UNDP</td>
<td>United Nations Development Program</td>
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<tr>
<td>HDI</td>
<td>Human Development Index</td>
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<td>GW</td>
<td>Giga Watt</td>
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<tr>
<td>kW</td>
<td>Kilo Watt</td>
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<tr>
<td>GWh</td>
<td>Giga Watt per hour</td>
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<tr>
<td>kWh</td>
<td>Kilo Watt per hour</td>
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<tr>
<td>kgoe</td>
<td>Kilogram of oil equivalent</td>
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<tr>
<td>toe</td>
<td>Ton of oil equivalent</td>
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<td>EIA</td>
<td>Energy Information Agency</td>
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<td>GHG</td>
<td>Green House Gases</td>
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<td>MJ</td>
<td>Mega joule</td>
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<tr>
<td>PPP</td>
<td>Purchase Power Parity</td>
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<td>GDP</td>
<td>Gross Domestic Product</td>
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<tr>
<td>OECD</td>
<td>Organization for Economic Cooperation and Development</td>
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<tr>
<td>ECLAC</td>
<td>Economic Commission for Latin America and the Caribbean</td>
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<tr>
<td>FAO</td>
<td>Food and Agriculture Organization of the United Nations</td>
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<tr>
<td>WT</td>
<td>Wind Turbine</td>
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<tr>
<td>AMDEEE</td>
<td>Mexican Wind Energy Association</td>
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<td>IEA</td>
<td>International Energy Agency</td>
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<td>TW</td>
<td>Tera Watt</td>
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<tr>
<td>TWh</td>
<td>Tera Watt per hour</td>
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<tr>
<td>CHP</td>
<td>Compound Heat and Power</td>
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<tr>
<td>POL</td>
<td>Apparent sucrose content</td>
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<tr>
<td>PV</td>
<td>Photo voltaics</td>
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<tr>
<td>PLD</td>
<td>Pulsed laser deposition</td>
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<tr>
<td>CSS</td>
<td>Close-spaced sublimation</td>
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<tr>
<td>CPC</td>
<td>Compound Parabolic Concentrator</td>
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<tr>
<td>BID</td>
<td>Inter American Development Bank</td>
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<tr>
<td>OEA</td>
<td>Organization of American States</td>
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<tr>
<td>CAN</td>
<td>Andean Community</td>
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<tr>
<td>Procisur</td>
<td>Agricultural Cooperation Program for the Southern Cone</td>
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<tr>
<td>Procitropicos</td>
<td>Agricultural Cooperation Program for the Tropics</td>
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<tr>
<td>JICA</td>
<td>Japan International Cooperation Agency</td>
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Appendix

World and Regional Background

Fossil fuel use, especially crude oil, expanded very quickly throughout the world because of its portability, easiness of use, low cost and relative abundance. As a consequence, the world experienced very high rates of development during the XX century, in the sense of better standards of life based on more intense use of energy on transportation, heating, cooking, health, culture and educational services. At the same time, crude oil turned to be the basis of the chemistry, leading to new materials like plastics, polymers, pharmaceuticals, pesticides and fertilizers, among others.

Presently, a direct relation between Human Development Index and energy consumption is clearly observed. A study developed by the UNDP (UNDP, 2006) demonstrated that while the world averaged 0.741 on the HDI (2004), countries showing the highest HDI, between 0.9 and 1, presented also the highest electricity consumption, like Japan, France, Netherlands, Italy, United Kingdom, Germany, Israel and Republic of Korea (ca. 7GWh/person/yr), Australia (11GWh/person/yr), USA (14GWh/person/yr), Canada (18GWh/person/yr) and Norway (25GWh/person/yr). On the bottom HDI levels, Niger with 0.3 and Zambia with 0.4 showed per capita electricity consumption below 200kWh/person/yr. The best ranked Latin America countries, Brazil, Argentina and Mexico, presented HDI between 0.8 and 0.85, with electricity consumption below 2GWh/person/yr.

For understandable economical reasons, crude oil companies throughout the decades have focused on extracting the easy-to-reach cheap crude oil. At first, oil was extracted near the surface on land. This oil typically was of the “light and sweet” type or put more simply, refined into byproducts such as unleaded gas and heating oil very easily. As this process has continued for some time, land based crude oil has and will continue to become even harder to come by, therefore, production rates of crude oil will decrease substantially. Additionally, all oil fields will reach a point in their existence where they become economically unfit to continue to produce oil. If the costs associated with extracting a barrel of oil equates to the profit of producing energy from other sources equivalent to a barrel of crude oil it obviously becomes a fruitless

During the last three decades, the world has discovered less new oil wells than actual consumption. As for recent years, new proven reserves account for only 27% of actual consumption. At present, over 50 crude oil producing countries, such as Russia and the United States have produced less than they have in the past. Additionally, the North Sea region, a prolific oil region twenty years ago, has witnessed sharp crude oil production declines. Furthermore, many other crude oil producing nations may not be far off in witnessing a peak in
the crude production. Brazil, which has recently incorporated important new wells, is a global exception.

Energy consumption and efficiency vary dramatically in different parts of the world. In 2005, the global average annual per-capita consumption of modern energy (i.e., excluding traditional biomass and waste) was 1,519 kilograms of oil equivalent (kgoe). While the average in high-income countries is 5,228 kgoe, in low-income countries it is only 250 kgoe. Traditional biomass and waste account for 10.6 percent of total global primary energy supply. In low-income countries, these sources represent on average 49.4 percent of the supply, with some countries approaching 90 percent.

Energy consumption depends, primarily on population growth and per capita income increment. FAO estimations are that the world population will continue growing until 2050, in spite of progressively decreasing annual rates, when it is supposed to stabilize and even decrease towards the end of the century. On the economic ground, the world is experiencing a never-before steady period of high economic progress, especially on developing countries.

Latin America and Caribbean are presently growing close above the world average growth rate. If it is assumed that, on the medium range, current energy policies will not be strongly shifted, the world's energy needs would be well over 50% higher in 2030 than today, according to the EIA World Energy Outlook 2008 Basic Scenario. It is considered that China and India will account for 45% of the increase in demand. These trends lead to continued growth in energy-related emissions GHG and to increased reliance of consuming countries on imports of oil and gas – much of them from the Middle East and Russia. This scenario would heighten concerns about climate change and energy security.

Regarding the Global Climate Changes, the key conclusions of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), released in early 2007, were:

i. Warming of the climate system is unequivocal.

ii. Most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations.

iii. Anthropogenic warming and sea level rise would continue for centuries due to the timescales associated with climate processes and feedbacks, even if greenhouse gas concentrations were to be stabilized, although the likely amount of temperature and sea level rise varies greatly depending on the fossil intensity of human activity during the next century.

iv. The probability that this is caused by natural climatic processes alone is less than 5%. 
v. World temperatures could rise by between 1.1°C and 6.4 °C during the 21st century causing that:

1. Sea levels will probably rise by 18 to 59 cm.

2. There is a confidence level >90% that there will be more frequent warm spells, heat waves and heavy rainfall.

3. There is a confidence level >66% that there will be an increase in droughts, tropical cyclones and extreme high tides.

vi. Both past and future anthropogenic carbon dioxide emissions will continue to contribute to warming and sea level rise for more than a millennium.

vii. Global atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values over the past 650,000 years.

Most of the GHG (Greenhouse Gases) emissions are attributed to the use of fossil fuels, being coal the most dangerous one and natural gas the less aggressive to the environment. The challenge is to put in motion a transition to a more secure, lower-carbon energy system, without undermining economic and social development. Nowhere will this challenge be tougher, or of greater importance to the rest of the world, than in China and India. Vigorous, immediate and collective policy action by all governments is essential to move the world onto a more sustainable energy path. Measures to improve energy efficiency stand out as the cheapest and fastest way to curb demand and emissions growth in the near term. Considering the above mentioned aspects, the major threats facing the Humankind, derived from its dependence on fossil fuels, are:

i. **Reduction on the world oil reserves and climbing prices.** A wide international network called Association for the study of peak oil and gas (http://www.peakoil.net) has as a mission “to define and evaluate the world’s endowment of oil and gas; model depletion, taking due account of demand, economics, technology and politics and; raise awareness of the serious consequences for Mankind”. Calculations are annually made by the network to establish the number of years the proven reserves could supply the world at current demand. As for 2007, the reserves could supply the world for 39 years, against 43 years calculated in 2003. The problem with this calculation is that energy demand is increasing at high rates year after year, making the forecast somewhat unrealistic. According to Aleklett & Campbell (2003), for each 4 barrels produced each year, only one is incorporated to proven reserves. Prices forecast vary according to the source, but experts agree that never more will be oil at low prices like before 2005. In this scenario, two challenges are placed:

1. how to supplement the energy demand not attended by oil, in the case of reduced production;
2. second, how to avoid enlarging the gap between developed and poor countries, in terms of well being, progress, development, opportunities and income increment, considering a scenario of energy at very high prices.

ii. Uneven distribution of fossil energy reserves. The oil, coal and gas reserves are unevenly distributed in the world. According to Radler (2005), the world’s proven reserves of oil (crude oil, natural gas liquids, condensates and non-conventional oil) amounted to 1,293 billion barrels at the end of 2005 - an increase of 14.8 billion barrels, or 1.2%, over the previous year. Reserves are concentrated in the Middle East and North Africa, together accounting for 62% of the world total. Saudi Arabia, with the largest reserves of any country, holds a fifth. Of the twenty countries with the largest reserves, seven are in the MENA region. Among the LAC region, only Venezuela (5th), Brazil (10th) and Mexico (13th) appear in the list of the major oil producing countries. In the case of natural gas and coal, the concentration is even worst, as Russia, Iran and Qatar own 56% of the proven gas reserves, and 76% of the coal reserves are concentrated in 5 countries (China, Russia, United States, Australia and India). As a counterpart, land (biomass), wind and solar radiation are far more democratic and the LAC region is particularly favored by the presence of these natural resources.

iii. Global climate changes. According to the recent report of the UN/IPCC, serious actions are urged to mitigate the climate changes hitherto underway. One of the most urgent is the incentive to the use of renewable energy, in substitution to fossil fuels.

From the social standpoint, it should be stated that the substantive focus of much of the R&D needed to promote sustainable development will have to be on the complex, dynamic interactions between nature and society (socio-ecological systems), rather than on either the social or environmental sides of this interaction. Moreover, some of the most important interactions will occur in particular places, or particular enterprises and times. S&T for sustainable development therefore needs to be “place-based” or “enterprise-based”, embedded in the particular characteristics of distinct locations or contexts. This means that S&T will have to broaden where it looks for knowledge, reaching beyond the essential bodies of specialized scholarship to include endogenously generated knowledge, innovations and practices.

Devising approaches for evaluating which lessons can usefully be transferred from one setting to another is a major challenge facing the field. The scientific and technological community and society is committed to devising a new set of strategies to meet the challenges that lie ahead. Building on Chapter 31 of Agenda 21, the S&T Community proposes that these strategies be based on the following principles:

i. A New Contract – Addressing social equity, poverty reduction and other societal needs must be integral to scientific, engineering and technological endeavors.
ii. **Reorient and Invest** – Science and engineering must give higher priority to identifying solutions for pressing environmental and developmental challenges with enhanced support by society and government.

iii. **Build and Maintain** – Scientific and technological capacity, as an elaboration of knowledge and new tools, must be built up and maintained in all countries, but especially in countries that currently lack a minimum, critical mass of S&T capacity.

**LAC background**

Annual per capita consumption of energy varies significantly from country to country, being 300 GJ/capita in Trinidad and Tobago and only 10 GJ/capita in Haiti. Another indicator pointing to the highly diverse nature of the region is the energy intensity of the different countries, varying from 36 MJ/$(ppp) in Trinidad and Tobago (a large exporter of natural gas) to 4 MJ/$(ppp) in Barbados. The Latin America and the Caribbean region’s average value is around 11 MJ/$(ppp), slightly above the world average of about 10 MJ/$(ppp).

It is important to state that higher living conditions are required which means higher energy per capita consumption. The idea to achieve this is saving energy (=avoiding unnecessary waste of energy) and substituting fossil fuel by renewable sources rather than reducing the overall amount or per capita consumption of energy.

Population and income growth are key drivers for energy consumption in the world. Forecasts for population growth in the LAC region indicate that the peak of the annual population growth was achieved in the 60’s (2.8%) and future trend is a continuous slow from present 1.2% to estimated 0.25% in 2050. Studies indicated a direct and linear relationship between population growth and energy consumption. Under social and economic *ceteris paribus* conditions, each one point of population growth means one point on energy consumption indexes.

That is not the case for economic growth. Relationship of per capita income growth to energy consumption is more likely a logarithmic one, biased by inflation rates and income distribution equity (Gini index). PPP-based GDP figures indicate that the LAC economies account for 8% of the world economy as opposed to 5%percent based on GDP converted to US dollar using market exchange rates. Brazil and Mexico are the largest economies in the region and account for nearly two-thirds of LAC’s GDP and 61 percent of the population. The region’s average GDP per capita is US$9,064 in PPP terms. Chile, Mexico, and Argentina have the highest GDP per capita in the region and Paraguay and Bolivia the lowest. LAC’s actual individual consumption is above the world average. Country values range from the nearly one and one-half times the world average for Mexico to less than half the world average for Bolivia.

Regional GDP is expected to slow further in the years ahead, coming in at 4.5 percent in 2008 and at 4.3 percent in 2009. This estimation is supported by continued strong growth in Brazil and a rebound from a weak 2007 for Mexico. Growth in other countries—notably Argentina and the Bolivarian Republic
of Venezuela—is likely to slow. Excluding those two countries, regional GDP growth is expected to moderate only marginally from 4.4 percent in 2007 to 4.2 percent in 2008—because of weakness in the United States—before picking up to 4.3 percent in 2009.

Should these outturns be realized, they would represent the longest positive growth spell for Latin America since the 1960s. Despite a gradual worsening of current account balances due to increasing commodity prices and slower growth in global demand, this stronger growth is likely to persist, supported by continued expansion in consumption and investment and buoyed by an environment of low inflation (excluding Argentina and Venezuela); improved fiscal policy (particularly in Mexico); and continued strong capital inflows (especially to Brazil).

Between 1970 and 1980 the economic growth was accompanied by lower energy use per unit of output (lower energy intensity), pointing to efficiency gains and better use of energy resources. The trend was reversed, however, between 1980 and 1985 (per capita income contracted and energy intensity increased), and the same unfavorable pattern continued between 1987 and 1990. This suggests that there was no improvement in energy efficiency during the economic recession of the 1980s. In the first three years of the 1990s, income recovered but energy intensity remained high. There was scarcely any improvement in energy intensity between 1990 and 2000. The energy intensity indicator has followed fairly similar trends in the different sub-regions, but its absolute value varies considerably. Energy intensity is highest in the Caribbean countries, mainly because of the more frequent use of energy-intensive, low-efficiency equipment. The Southern Cone countries have the lowest absolute values, owing to the use of more advanced equipment and energy technologies in their production processes. The Andean countries showed no significant changes in the period considered.

This way, the LAC countries have made only modest advances in reducing energy intensity; in some periods, they have even experienced setbacks. After dropping 9% between 1970 and 1980, energy intensity trended upward in the 1980s. The region’s energy use per unit of output was 7% higher in 1999 than it had been in 1980. The countries of the OECD, on the other hand, have reduced their energy intensity by 20% over the past 20 years, through energy policies geared to diversifying the energy supply and enhancing energy efficiency by cutting down on waste and using energy more efficiently. LAC has significant potential to undertake efforts in this same vein, given appropriate technologies, support and policies.

Notwithstanding the region’s potential for progress, energy intensity projections up to 2015 are less than promising. According to OLADE, and barring any major structural changes such as the incorporation of more efficient technologies, the region is unlikely to show any appreciable improvement in its energy intensity. Some countries may achieve gains in this respect, but others are showing a tendency to increase their energy intensity.

The LAC region has 10% of the world’s oil reserves, 4.3% of the world’s natural gas reserves, and 1.6% of the world’s coal reserves. Moreover, 22.7% of the world’s hydroelectric potential is found in the LAC region. The energy
demands of Latin America and the Caribbean constitute approximately 6.6% of
the world energy market.

On the other hand, 10% renewable sources of energy, established as a
worldwide goal for 2010, is already a reality in Latin America, achieved mostly
through big hydroelectric dams. Nearly 26% of the LAC energy come from
renewable sources, being 15% hydroelectric, according to the Economic
Commission for Latin America and the Caribbean (ECLAC). Renewable does
not mean sustainable, say activists and experts who want to see fewer gigantic
dams and more regulation of the use of firewood (the source of 5.8 percent of
energy used in the region in 2002), and incentives for non-conventional sources

Argentina, highly dependent on natural gas, is the only country in the
region with under 10 percent renewable energy sources, but there are four others
in the critical zone of 10 to 20 percent: Mexico, Ecuador, Venezuela and Chile.
On the other extreme are Paraguay, Honduras, Haiti and El Salvador, with more
than 80 percent of renewable energy share on the country energy matrix. But
even in that group, all is not positive. Paraguay is almost totally dependent on
hydroelectric energy, while Honduras, Haiti and El Salvador, like its Central
American neighbors Nicaragua and Guatemala, rely heavily on firewood. Costa
Rica produces 99% of its electricity generation from renewable energy sources,
but total renewable energy share in the country matrix is ca. 25%.

In recent years, automotive companies have developed engines that use
gasoline or alcohol, or the two mixed, and are working on “trivalent” models that
could also run on natural gas. Brazil produces, annually, over 2,500,000 vehicles
under the concept of flex fuel (running on any proportion of ethanol and
gasoline). Today in Brazil there are 700,000 to 800,000 natural gas-run vehicles, a
figure that only Argentina surpasses.

In Cuba, the energy matrix is tending towards achieving sustainable energy
development. Cuba relied heavily on Soviet petroleum until the early 1990s. The
collapse of the Soviet Union led to an interruption in supplies and pushed Cuba
into crisis. Since then, Havana has been developing its own hydrocarbon resources,
energy conservation plans, and pursuing research of renewable energy sources. But
Cuba still depends on petroleum, which represents 56.1 percent of its TPES, while
renewable sources comprise 37.9 percent, and are mostly sugarcane by-products
(34.5 percent), which tend to use combustion processes that are not very efficient.

It should also be considered that the present skyrocketing prices of
crude would not only induce substitution of fossil by renewable energy sources in
LAC but worldwide. In this scenario, some countries will not have the conditions
for producing all the necessary energy – specially biofuels – to conveniently supply
its domestic market, needing to look for suppliers elsewhere, as well as, move
industries to places with cheaper energy. This way, the generation of renewable
energy in the LAC region would not only mean a more sustainable future but also
an important economic opportunity.

The energy discussion should always be conducted side to side to
environmental considerations, among them the emissions of Greenhouse Gases,
especially the carbon dioxide.