Renewable Energy: Challenges and Opportunities
Universidad Nacional Autónoma de México
Mexico City, Mexico
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Where is Puerto Rico?
Puerto Rico
Population: 3.9 Million
Area: 10,200 Km²

Mexico
Population: 113,910,608
Area: 1,973,000 km²
Old San Juan, Historic Area in Puerto Rico

Puerto Rico Convention Center
Puerto Rico
Recreation / Tourism

Flamenco Beach, Culebra, Island

Coquí, (
*Eleutherodactylus coqui*),
National Puerto Rican frog

“Flor de Maga”, Maga
Flower, Puerto Rican Flower

El Yunque Rainforest
Ana G. Mendez
University System
Total 2010 AGMUS Enrollment

(42,100 Students)

Number of Students

Turabo 16,600
UNE 11,500
UMET 12,800
FLORIDA 1,200

Campuses
UMET Campus
Universidad del Turabo
Campus
Universidad del Este Campus
Renewable Energy

- Renewable energy is fundamentally changing the electricity industry's strategic landscape.
- Active industry engagement in development and deployment of renewable energy for power generation has increased significantly, and continued engagement is more critical than ever before.
Renewable Energy

- Over the long term, renewable energy investment will depend on renewables' operating cost-effectively without mandates or subsidies.
- Renewable portfolio standards, financial incentives, concerns over energy security, and efforts to reduce greenhouse gas emissions will continue to drive renewable energy deployment.
What Causes Global Change?
'No doubt about it... an asteroid killed the dinosaurs!'
What Causes Global Change?

65 Million BC

5 kilometers
\( (5 \times 10^3 \text{ M}) \)

2007 AD

200 picometers
\( (200 \times 10^{-12} \text{ M}) \)
Concentration of Greenhouse Gases

- **Carbon Dioxide**
  - Year: 1000 to 2000
  - CO₂ (ppm)

- **Methane**
  - Year: 1000 to 2000
  - CH₄ (ppb)

- **Nitrous Oxide**
  - Year: 1000 to 2000
  - N₂O (ppb)

1750, the beginning of the industrial revolution
Future Energy Needs

The United Nations Framework Convention on Climate Change for “stabilization of greenhouse-gas concentration in the atmosphere at a level that would present dangerous anthropogenic interference with the climate system.....”

A standard baseline scenario that assumes no policy intervention to limited greenhouse-gas emission has 10 TW (10x10^{12} [W]) of carbon-emission-free power being produced by the year 2050, equivalent to the power provided by all of today’s energy sources combined.

M.I. Hoffert et.al., Nature 1998
The burning of fossils is producing dangerous levels of carbon dioxide in the atmosphere. Cheap coal produces the highest percentage of it.

Unfortunately, SOLAR is the most expensive source of energy, but is the cleanest.

Efficient technologies need to be developed to harvest the sun.
Energy Cost by Source

¢/kw=hr

(1) Coal  1-4 ¢
(2) Gas   2.3-5.0 ¢
(3) Oil   6.-8 ¢
(4) Wind  5-7 ¢
(5) Nuclear  6-7 ¢
(6) Solar  25-50 ¢

Fossil Fuel Reserves:

Oil  40-50 years
Gas  70-200 years
Coal > 600 years
Energy Cost by Source

Population in $[10^9 \text{ people}]$

- Coal: 4.43
- Gas: 5
- Oil: 6
- Wind: 6
- Nuclear: 7
- Solar: 25
Sources of Renewable Energy

- Hydroelectric
- Tide and Ocean Currents
- Geothermal
- Wind
- Biomass
- Solar
Possible Solutions to The TW Challenge

**Carbon Neutral Energy** (fossil fuel in conjunction with sequestration)
- Need to find secure storage for 25 billion metric tons of CO₂ produced annually (equal to the volume of 12500 km³ or volume of Lake Superior!)

**Nuclear Power**
- Requires construction of a new one-gigawatt-electric (1-GW) nuclear fission plant every day for the next 50 years

**Sustainable Energy Sources**
- Hydroelectric resource 0.5 TW
- From all tides & ocean currents 2 TW
- Geothermal integrated over all the land area 12 TW
- Globally extractable wind power 2-4 TW
- Biomass 5-7 TW
- Solar energy striking the earth 120,000 TW !!!
Water based energy

- A focus on renewable and noncarbon-emitting energy sources presents new opportunities for waterpower development, including conventional hydropower, pumped storage, and emerging hydrokinetic energy (ocean, tidal, and in-stream) development.

- Waterpower is challenged, however, by technology development and concerns related to fish passage restrictions, turbine mortality on downstream migrating fish, and other environmental and aquatic species impacts.
Hydroelectric Energy Potential

Globally

- Gross theoretical potential: 4.6 TW
- Technically feasible potential: 1.5 TW
- Economically feasible potential: 0.9 TW
- Installed capacity in 1997: 0.6 TW
- Production in 1997: 0.3 TW

Source: WEA 2000
Geo-Thermal Energy

- Geothermal holds the promise of underpinning a robust future renewable energy-based electric portfolio because of its potential as a baseloaded generation source.
- Currently, for geothermal power to be not only feasible but cost-effective, a unique set of subsurface conditions needs to be present: a fractured/porous rock medium, heat, and water (geofluid) in the proper proportions such that enough energy can be extracted from the system to sustainably operate a power plant for 30+ years.
Ring of Fire
Geothermal Energy

1.3 GW capacity in 1985

Hydrothermal systems
Hot dry rock (igneous systems)
Normal geothermal heat (200 C at 10 km depth)
Geothermal Energy Potential

• Mean terrestrial geothermal flux at earth’s surface 0.057 W/m²
• Total continental geothermal energy potential 11.6 TW
• Oceanic geothermal energy potential 30 TW
• Wells “run out of steam” in 5 years
• Power from a good geothermal well (pair) 5 MW
• Power from typical Saudi oil well 500 MW
• Needs drilling technology breakthrough (from exponential $/m to linear $/m) to become economical
Geothermal Power Plant at The Geysers
725MW

Eruption of a Geyser
Cerro Prieto, Mexico

- One of the world's largest geothermal complexes.
- Cerro Prieto is the name of a volcanic feature in far northern Baja not far from the U.S. line.
- Over 150 production and injection wells have been drilled at Cerro Prieto.
- Other infrastructure includes 170km of pipeline for steam and condensate and 60km of brine channels.
- It has a capacity of 720MW with plans for expansion up to 820 MW by 2012.
Wind

- Wind power generation meets an increasing share of electricity demand in the United States and worldwide, and with rising regulatory and legislative pressure, no fuel requirements, a low CO2 footprint and large regional on-shore and off-shore potential, wind power is expected to play a significant role in future electricity production.

- In the next 20 years, central station wind is expected to increase the renewable component of generation more than tenfold. Even though wind power technologies have advanced significantly in recent years, major obstacles continue to stand in the way of widespread deployment, effective integration within the electricity grid, and sustainable long-term performance.
Electric Potential of Wind

In 1999, U.S consumed 3.45 trillion kW-hr of Electricity = 0.39 TW

Relatively mature field

http://www.nrel.gov/wind/potential.html
Future Potential of Wind

- Significant potential in US Great Plains, inner Mongolia and northwest China

- U.S.:
  Uses 6% of land suitable for wind energy development; practical electrical generation potential of \( \approx 0.5 \) TW

- Globally:
  Theoretical: 27% of earth’s land surface is class 3 (250-300 W/m\(^2\) at 50 m) or greater, electricity generation of 50 TW
  Practical: 2 TW electrical generation potential (4% utilization of ≥class 3 land area)

  Off-shore potential is larger but must be close to grid to be interesting; (no installation > 20 km offshore now)
Bio-Mass

- Power produced from biomass offers a renewable, low-carbon-emitting option for dispatchable energy. Additionally, biopower can provide local economic support, coproduct opportunities, and environmental benefits, including restoration.

- Despite the abundant benefits of biomass-based power, overall development has been somewhat hindered by two critical issues: developing a reliable, sustainable supply chain, and producing cost-effective power with high efficiency.
Biomass Energy Potential

Global: Top Down

• Requires large areas because Inefficient (0.3%)
• 3 TW requires $\approx 6\times10^{12} \text{ m}^2$
• 20 TW requires $\approx 4\times10^{13} \text{ m}^2$
• Total land area of earth: $1.3\times10^{14} \text{ m}^2$
• Hence requires $4/13 = 31\%$ of total land area
Biomass Energy Potential

Global: Bottom Up

- Land with Crop Production Potential, 1990: \(2.45 \times 10^{13} \text{ m}^2\)
- Cultivated Land, 1990: \(0.897 \times 10^{13} \text{ m}^2\)
- Additional Land needed to support 9 billion people in 2050: \(0.416 \times 10^{13} \text{ m}^2\)
- Remaining land available for biomass energy: \(1.28 \times 10^{13} \text{ m}^2\)
- At 8.5-15 oven dry tonnes/hectare/year and 20 GJ higher heating value per dry tonne, energy potential is 7-12 TW
- Perhaps 5-7 TW by 2050 through biomass (recall: $1.5-4/GJ)
- Possible/likely that this is water resource limited
- Challenges: cellulose to ethanol; ethanol fuel cells
Solar Energy

- The U.S. Department of Energy estimates that solar power will represent approximately 1% of worldwide electric generation capacity in less than five years, and trends suggest that double-digit percentages could be achieved well within the next few decades.

- The large gap between society’s current use of solar energy and its underdeveloped potential represents an enormous technical, economic, and political challenge.
Solar Energy

- Despite significant industry growth and technological progress, the need remains for advanced solar technologies that will provide cost-competitive power.
- Incremental cost reductions are being accomplished by steady improvements in materials, manufacturing processes, and scientific understanding.
- In addition, solar power remains a field in which breakthrough innovations are possible—and even anticipated.
Solar Energy Potential

• Theoretical: $1.2 \times 10^5$ TW solar energy potential
  $(1.76 \times 10^5$ TW striking Earth)

• Energy in 1 hr of sunlight $\leftrightarrow$ 14 TW for a year

• Practical: $\approx 600$ TW solar energy potential
  $(50$ TW - 1500 TW depending on land fraction etc.; WEA 2000)
  Onshore electricity generation potential of $\approx 60$ TW
Solar Energy Data

Theoretical: \(\sim 1.2 \times 10^5\) TW of solar energy strikes the earth surface

Practical: \(\sim 600\) TW of energy could be gathered

Average rate of consumption of energy in the USA \(\sim 3\) TW (1998)

Average rate of consumption of energy in the world \(\sim 13\) TW (2000)

Projection: \(\sim 28\) TW global energy demand in 2050

\[1\text{TW} = 10^{12} \text{[W]}\]
Global need. This map shows the amount of land needed to generate 20TW with 10% efficient solar cells.

Science 22 July 2005 page 548
## Nuclear Power Generations

<table>
<thead>
<tr>
<th>Country</th>
<th>% Electricity Generated</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>21</td>
</tr>
<tr>
<td>France</td>
<td>80</td>
</tr>
<tr>
<td>Japan</td>
<td>30</td>
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<td>Germany</td>
<td>31</td>
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<td>Russia</td>
<td>18</td>
</tr>
<tr>
<td>South Korea</td>
<td>37</td>
</tr>
</tbody>
</table>
World Population Projection

Fuente: Revista “The Economist” (Octubre 09)
Population in Dynamics and Fertility Rate

Fuente: Revista “The Economist” (Octubre 09)
Less is more....

Source: gapminder.org

Fuente: Revista “The Economist” (Octubre 09)
Projections, Population of the World:

- **Medium UN scenario**: fertility declining from 2.6 children per woman in 2004 to slightly over 2 children per woman in 2050. Source: Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat (2005).

- **Scenario assuming** that all fertile women are henceforth limited to 1 child. Source: Dr. Sergei Scherbov, research group leader, Vienna Institute of Demography, Austrian Academy of Sciences.

Fuente: Revista “The World with us”
Possible Solutions to the TW Challenge

Carbon Neutral Energy (fossil fuel in conjunction with sequestration)
• Need to find secure storage for 25 billion metric tons of CO₂ produced annually (equal to the volume of 12,500 km² or volume of Lake Superior)

Nuclear Power
• Requires construction of a new one-giga watt-electric (1-6W) nuclear fission plant everyday for the next 50 years.

Sustainable Energy Source
• Hydroelectric (0.5TW), Tides & Oceans (2TW), geothermal (12TW), wind power (2-4TW) biomass (5-7TW) and solar (120,000TW)
Conclusions

▪ The sun alone could meet the TW Challenge

▪ Challenges include:
  (1) Cheap Photovoltaics
  (2) New Chemistry to Create Fuels
  (3) System optimization to produce energy

▪ There exists a critical need for sustainable carbon-free-energy
Compounding Losses

Fuel energy input (coal): 100 units

- Power plant losses: 70 percent
- Transmission and distribution losses: 9 percent
- Motor losses: 10 percent
- Drivetrain losses: 2 percent
- Pump losses: 25 percent
- Throttle losses: 33 percent
- Pipe losses: 20 percent

Energy output: 9.5 units

Thanks to Amory Lovins, Sci Amer Sept 2005
La casa posible EXPO 2008
Carbon Capture & Storage

- Trapping and storing CO2 emissions could prevent the carbon cycle disruption caused by fossil fuel combustion.
- Lawrence Berkeley National Laboratory is developing new materials to capture CO2 and exploring the biogeochemical implications of carbon sequestration.
Energy Storage

- Batteries and other methods of storing energy are essential components of a carbon-free energy system.
- Lawrence Livermore National Laboratory is exploring next-generation vehicle battery technologies, as well as innovative grid-scale energy storage.
Artificial Photosynthesis

Lawrence Livermore National Laboratory is looking to the chemistry of photosynthesis for inspiration on how to convert sunlight into stored energy using earth-abundant, inexpensive materials—a potentially game-changing energy source for humanity.
Smart Grids
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