Energía “Oceánica” en Puerto Rico
Retos y Oportunidades

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Objective – Determine a realistic and achievable estimate ofthe electricity that can be produced from renewable resources in Puerto Rico.

1. Biomass – including solid waste*,
2. micro hydro*
3. ocean – waves and thermal
    - (tides and underwater currents were estimated negligible in preliminary study)
4. solar - photovoltaic & solar thermal*,
5. wind – large and small,
6. fuel cells

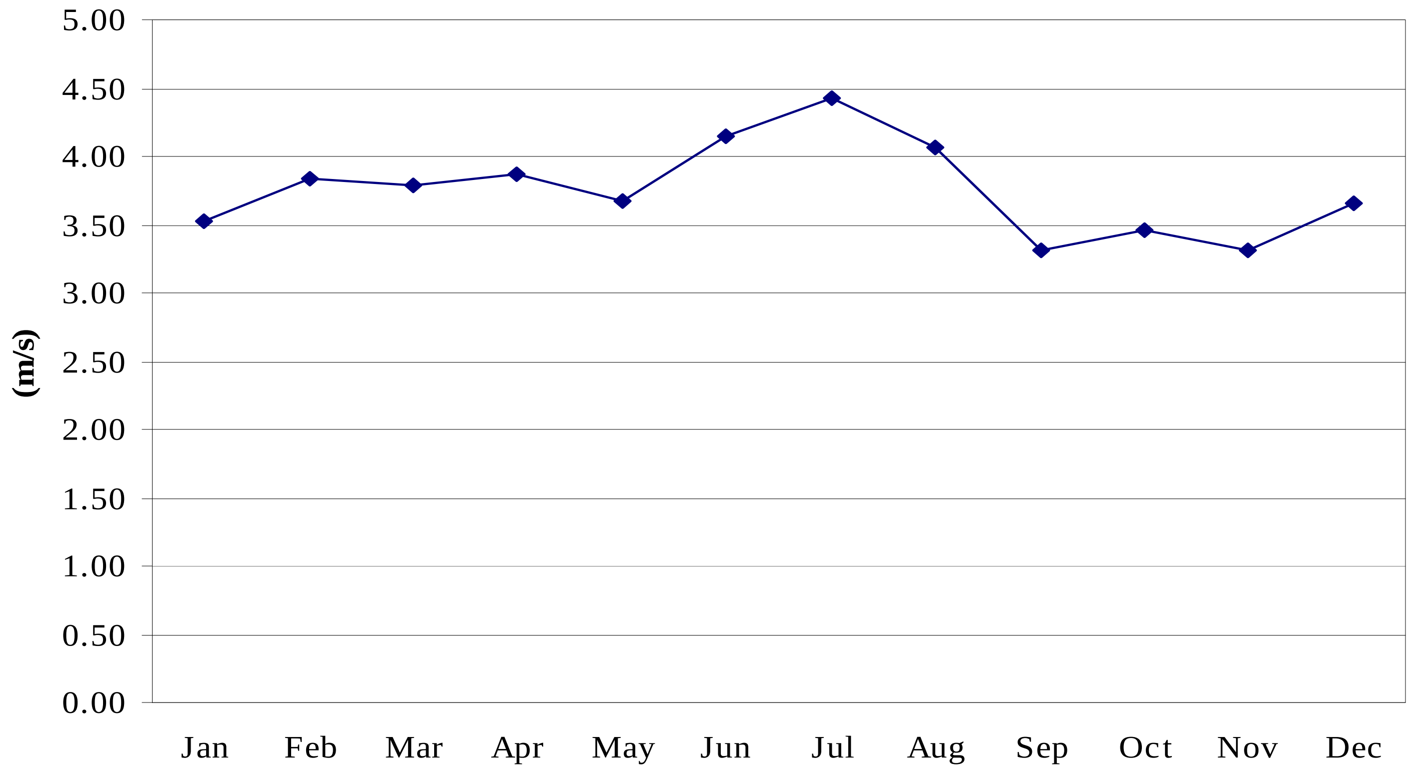
* Only in preliminary study

Detailed study.

WIND ENERGY

Variability of Wind by month

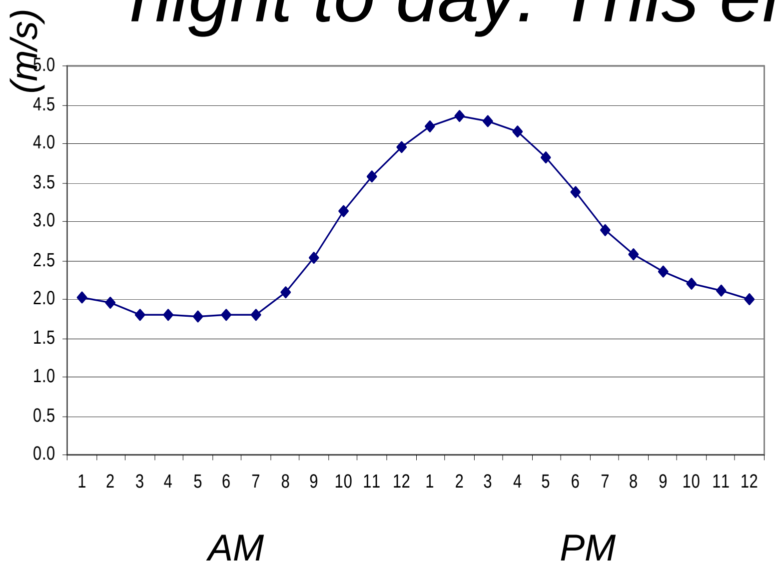
More wind in summer, based on "Monthly Distribution of mean wind velocity in (m/s)".



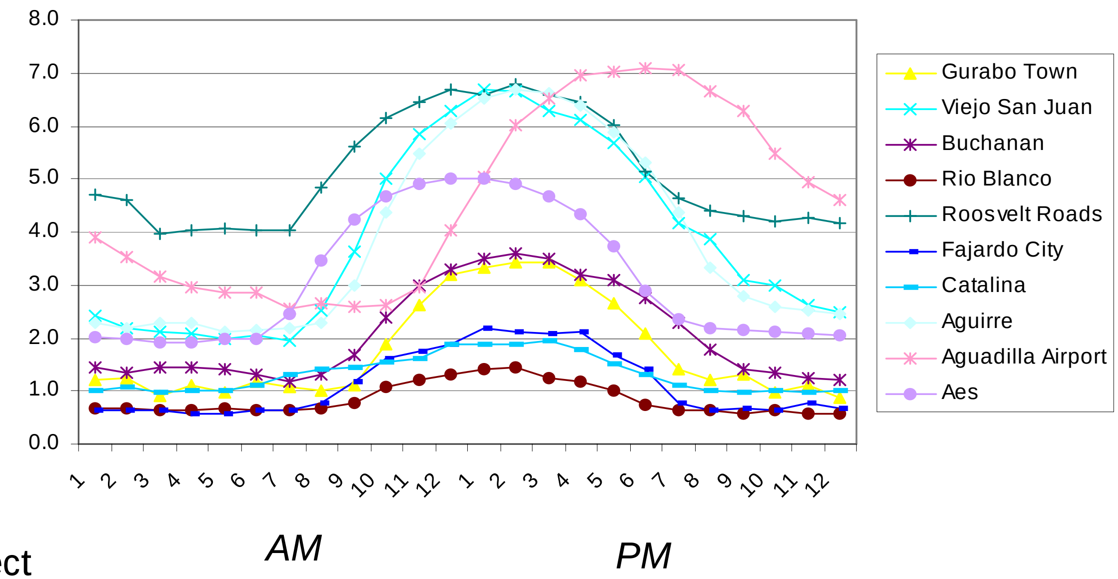
Average Monthly Wind Speed

Variability of Wind – day & night cycle

Diurnal effect is the change in wind speed from night to day. This effect is strong inland.



Puerto Rico Average Diurnal Wind Speed Effect



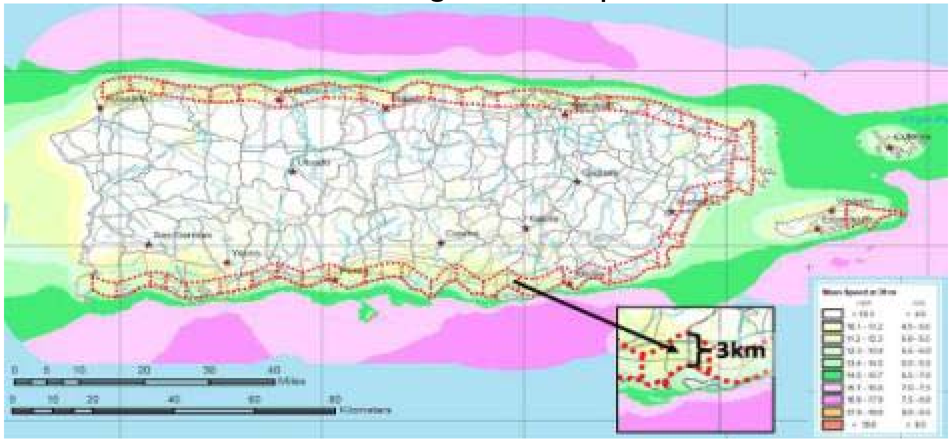
Hourly Average Wind Speed in Places with Diurnal Wind Effect ChangePuerto Rico Average

As the sun heats the ground during morning hours, the wind speed intensify. At sunset the wind return to the speed it had in the morning hours.

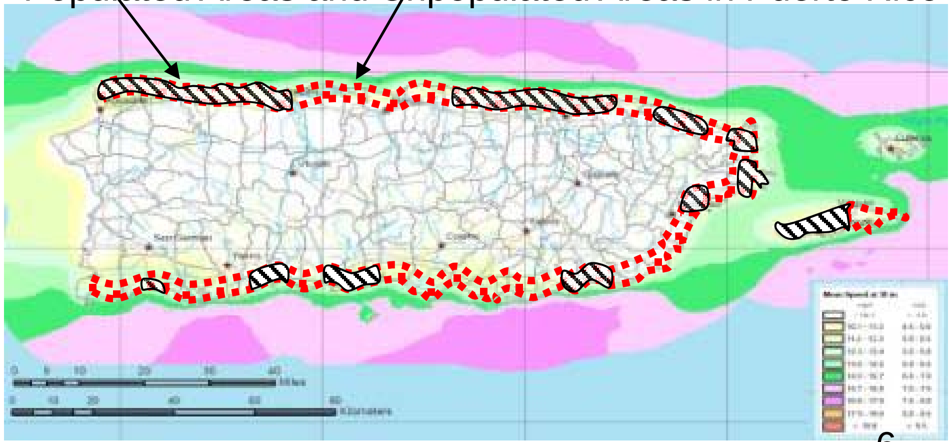
How many large turbines? Available land vs. best wind

- Puerto Rico's area = 8,960 km²
  - 160 km x 56 km
  - approx. 2.24 million cuerdas
- Best wind, and best access to infrastructure, in a 3 km wide band along the north, east, and south coast
  - 960 km² (240,000 cuerdas)
  - 10.7% of PR total area
  - 50%, 480 km², of this area is heavily populated (to be used for small wind) and 50% is not populated, we assume it can be used for wind farms, large wind turbines. Do not compete (it complements) with Biorefinery efforts.
- 12,000 small turbines (10 – 50 MW)

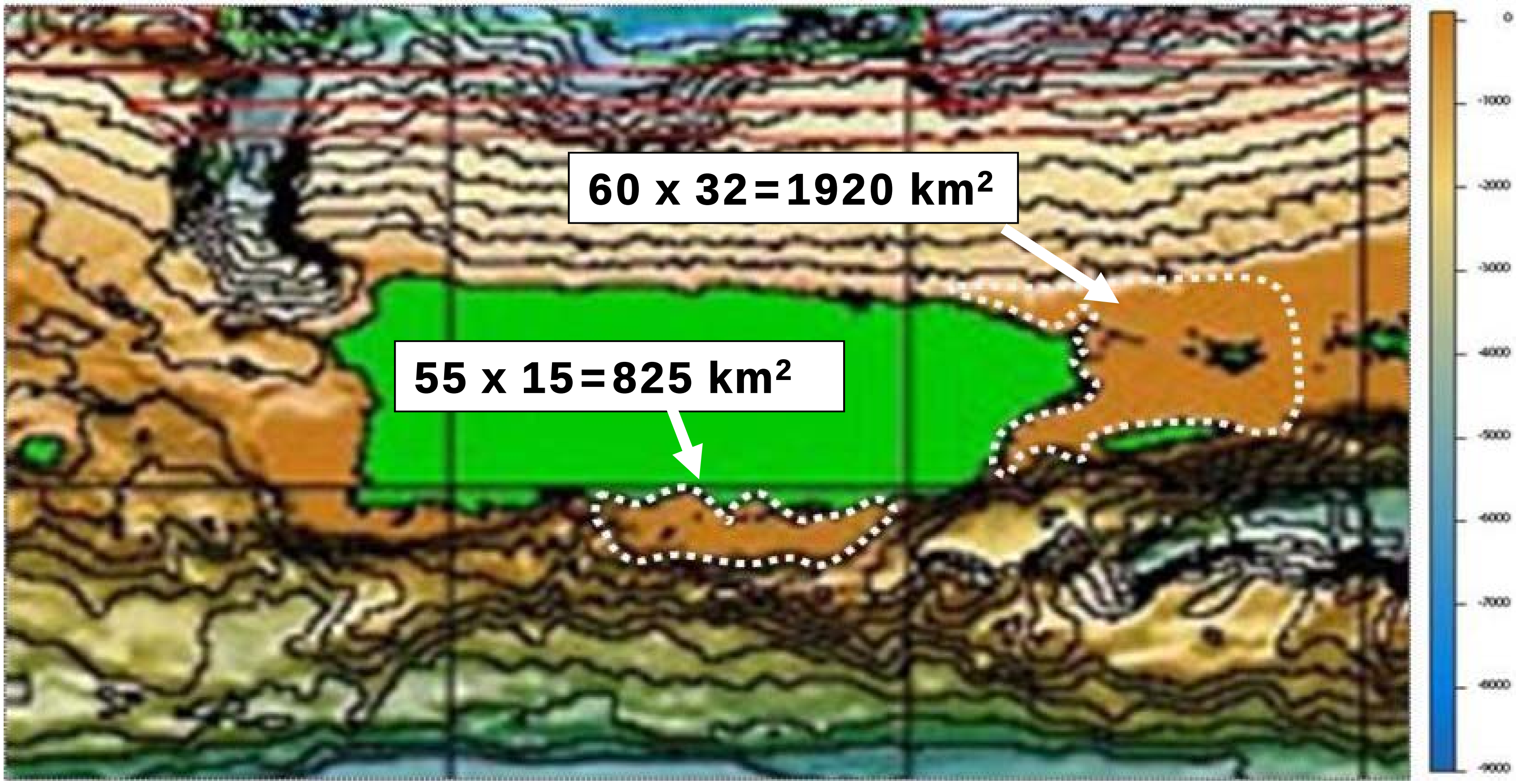
Selected Area with High Wind Speed Resources



Populated Areas and Unpopulated Areas in Puerto Rico



Off-shore wind turbines



With a density of 5 MW/km^2 the 2,745 km^2 can accommodate 13,725 MW of installed wind capacity. If only 10% is used we still have 1,372 MW.

Current State of Offshore Wind Offshore wind farms operating in Europe

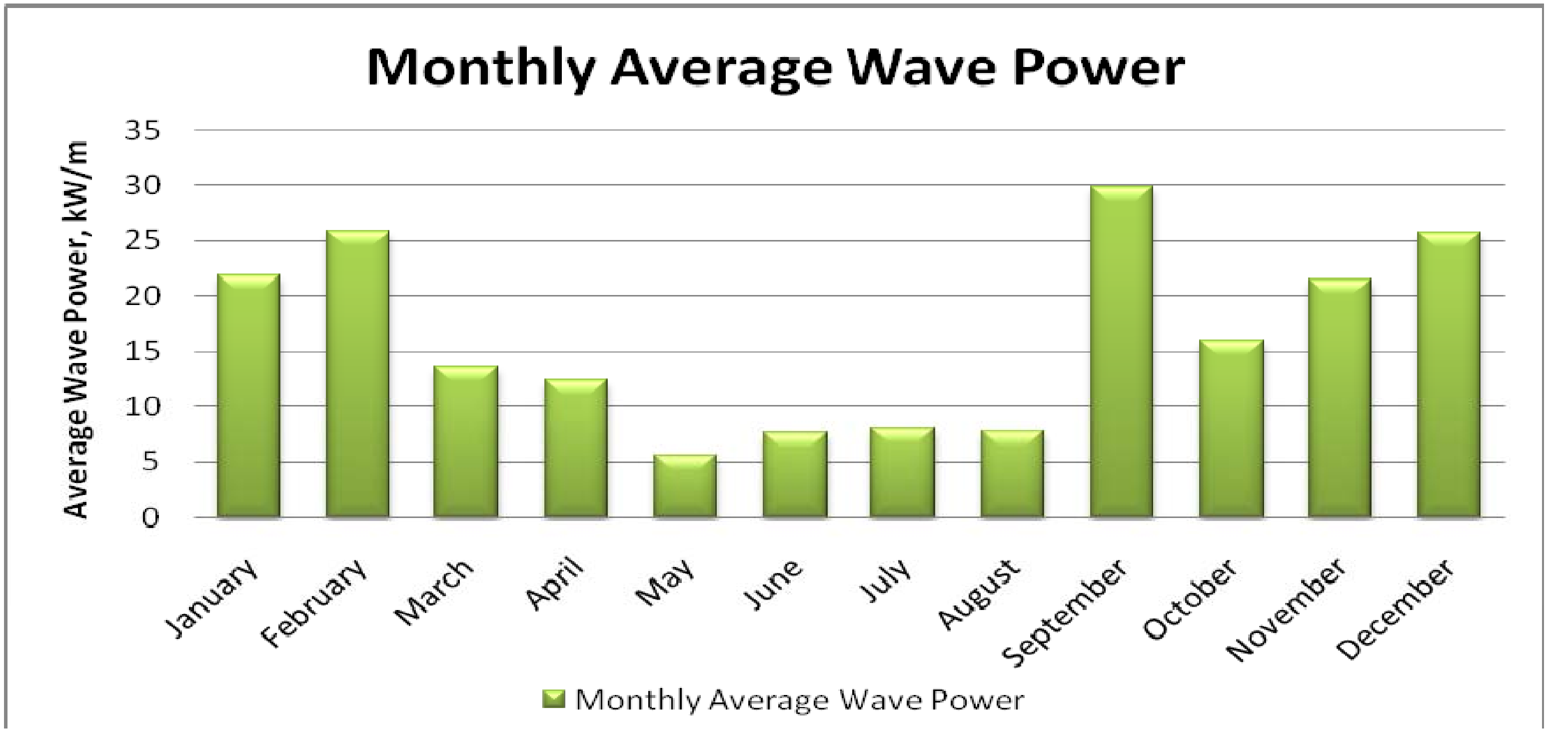
1. (~2GW total capacity)
2. Largest wind farm, 300 MW
   - 3-MW upwind turbines
3. Operating almost exclusively in shallow water (depth < 30m)
4. Wind farms generally under performing with high cost factors
5. Frequent unexpected failures and substantial downtime
6. Serious concerns about O&M, reliability, and system life

Knowledge & Technology Gaps

1. Current designs based on extrapolation from experience of land-based wind energy and offshore structures (e.g., oil and gas) independently
2. Inadequacy of translating existing knowledge & technologies to offshore wind energy systems
   - Scaling issues of offshore wind different & unsolved from offshore oil and gas
   - Manufacturing, testing, control, and reliability of multi-megawatt machines
3. Aerodynamic and subsea interactions in offshore wind farm systems

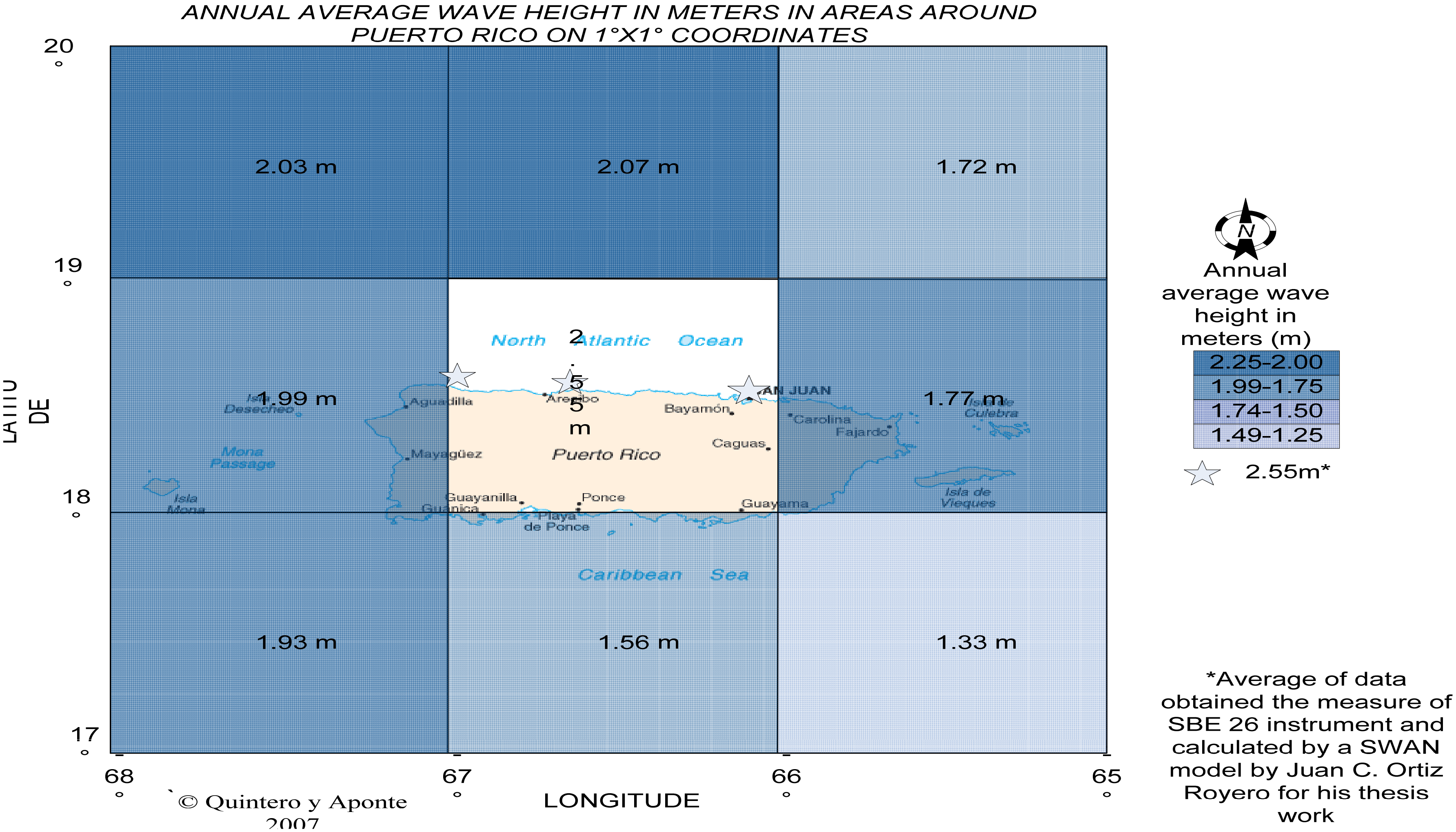
OCEAN ENERGY

Variability of Ocean Wave Energy



This graph shows the average wave power for station L1-9 during 1999.

Availability of Ocean Wave Energy



Highest wave energy concentrates in the north coast.

Offshore Wave to Electricity (Pelamis)

Pelamis Wave Energy Conversion Absorption Performance (kW) in Each Sea State

Hs (m) \ Tp (s)	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	20
10	750	750	750	750	750	750	750	750	750	750	750	750	711	750	750	738	734
9.5	750	750	750	750	750	750	750	750	750	750	750	750	691	750	710	694	662
9	750	750	750	750	750	750	750	750	750	750	750	750	670	746	668	650	592
8.5	750	750	750	750	750	750	750	750	750	750	750	750	650	699	626	606	551
8	750	750	750	750	750	750	750	750	750	750	750	750	630	653	584	562	509
7.5	750	750	750	750	750	750	750	750	750	750	750	748	610	607	542	518	467
7	750	750	750	750	750	750	750	750	750	750	750	692	566	560	500	474	425
6.5	750	750	750	750	750	750	750	750	750	750	723	592	617	513	458	430	384
6	597	630	663	684	750	750	750	750	750	750	616	633	525	476	396	386	329
5.5	428	497	566	612	750	750	750	750	750	635	642	532	482	400	399	341	322
5	259	364	469	539	750	750	750	750	644	641	531	482	399	394	330	308	274
4.5	94	233	371	467	735	744	738	634	626	520	473	390	382	319	299	250	208
4	105	216	326	394	632	616	583	585	494	454	374	361	339	283	236	197	153
3.5	0	86	211	326	484	577	568	502	421	394	330	312	260	216	196	164	140
3	0	91	180	246	402	424	417	369	343	331	275	229	208	173	144	120	93
2.5	0	7	93	171	279	342	351	320	274	230	210	174	145	120	100	84	65
2	0	0	66	109	199	219	225	205	195	162	135	112	93	77	64	54	41
1.5	0	0	26	62	112	141	143	129	110	91	76	63	52	43	36	30	23
1	0	0	11	27	50	62	64	57	49	41	34	28	23	0	0	0	0
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Total annual energy density, per unit length of wave crest, in the north coast is approx. 59,520 kWh/m (~ 5 houses/m).

Total annual energy absorbed by a Pelamis device is approx. 1,463,800 kWh.

The space occupied one Pelamis is approx 552 m^2 of sea.

No reliable cost data is available to judge the economic feasibility of OTEC technology.

- Concept is well understood, resource is available in Puerto Rico but **no one has built a commercial OTEC plant**.
- Funds are required to install a prototype facility (Puerto Rico's south coast) to identify and try to overcome the technological challenges in construction and operation.
  - No evaluation of environmental impact of OTEC has been produced. The prototype will provide real data to evaluate the consequences to the marine environment of operating this technology.
- Private companies claim to have a complete design for an OTEC plant but are unwilling to commit to a purchase power agreement at a fixed kWh sales price.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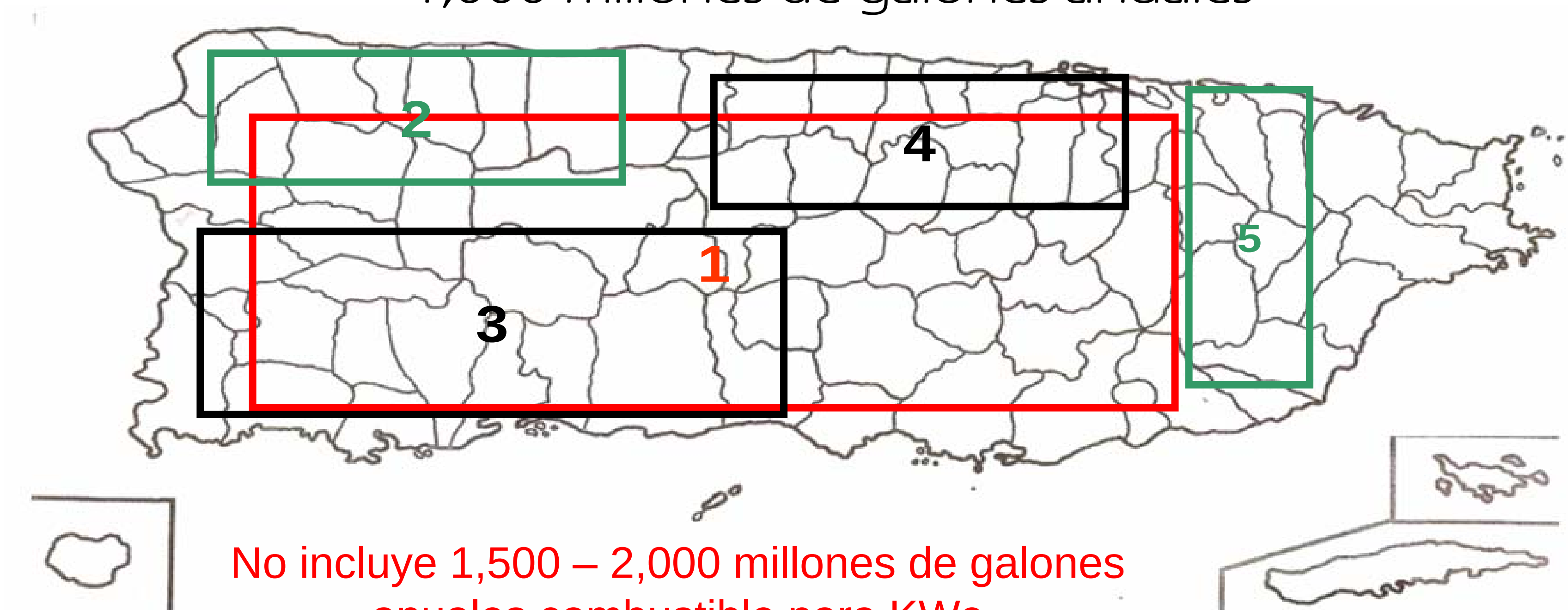
EN BIOREFINERIA

BIOMASS

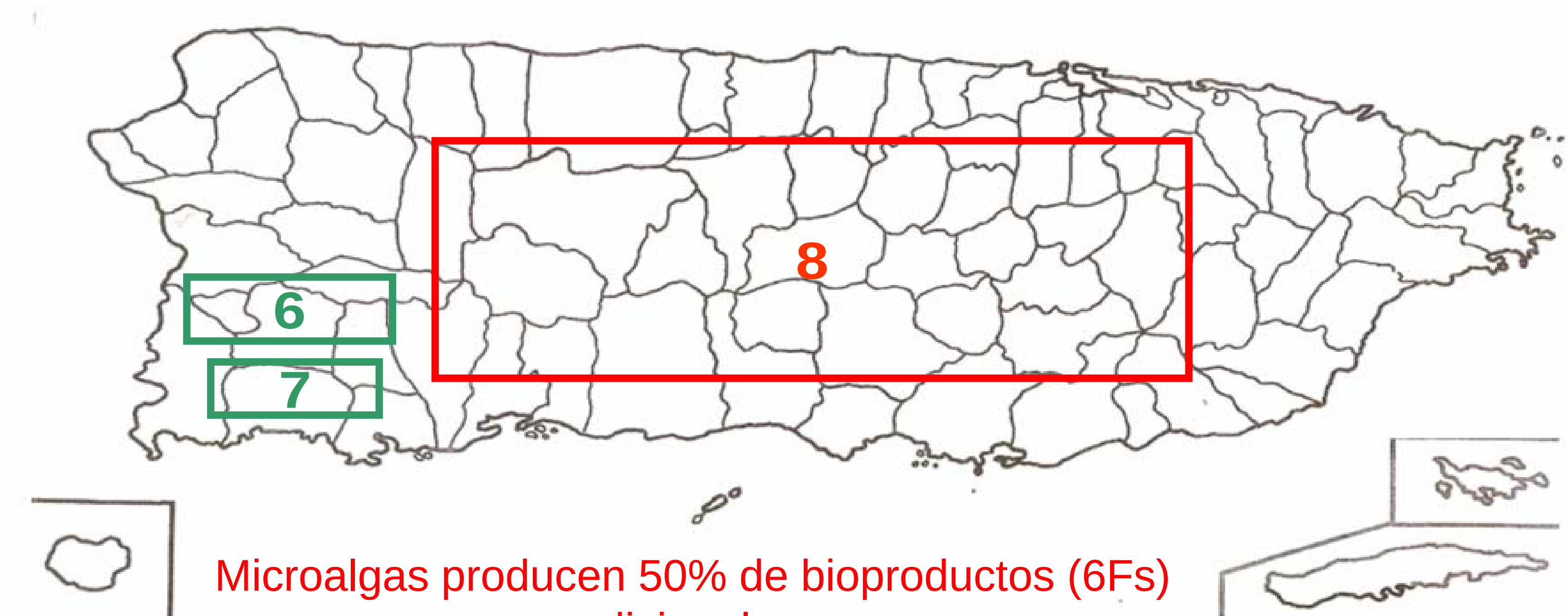
Area aprox. necesaria para la producción de Biogasolina
1,000 millones de galones anuales



No incluye 1,500 – 2,000 millones de galones anuales combustible para KWe

	Consumo de gasolina anual en PR	1,000,000,000	Unidades	Hectáreas de PR	Und.	% Hectáreas de PR
	Biomasa	Productividad por hectárea	gal *año	906,500	gal	100%
1	Bioetanol de almidón	2,000	gal / ha*año	500,000	ha	55.2%
2	Bioetanol de lignocelulosa (agresivo)	10,000	gal / ha*año	100,000	ha	11.0%
3	Bioetanol de lignocelulosa (moderado)	5,000	gal / ha*año	200,000	ha	22.1%
4	Gasolina de microalgas en charcas por Fisher Tropsch (+50% de productos adicionales)	10,000	gal / ha*año	100,000	ha	11.0%
5	Gasolina de microalgas en biofotoreactores por Fisher Tropsch (+50% de productos adicionales)	15,000	gal / ha*año	66,667	ha	7.4%

Area aprox. necesaria para la producción de Biodiesel
500 millones de galones anuales

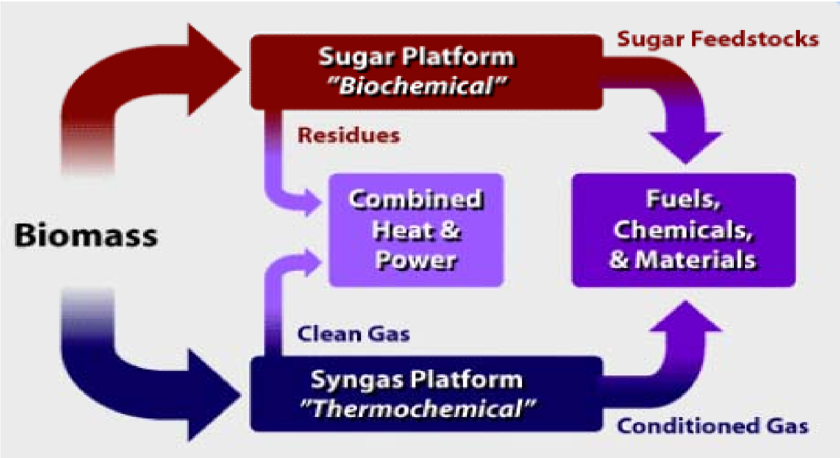


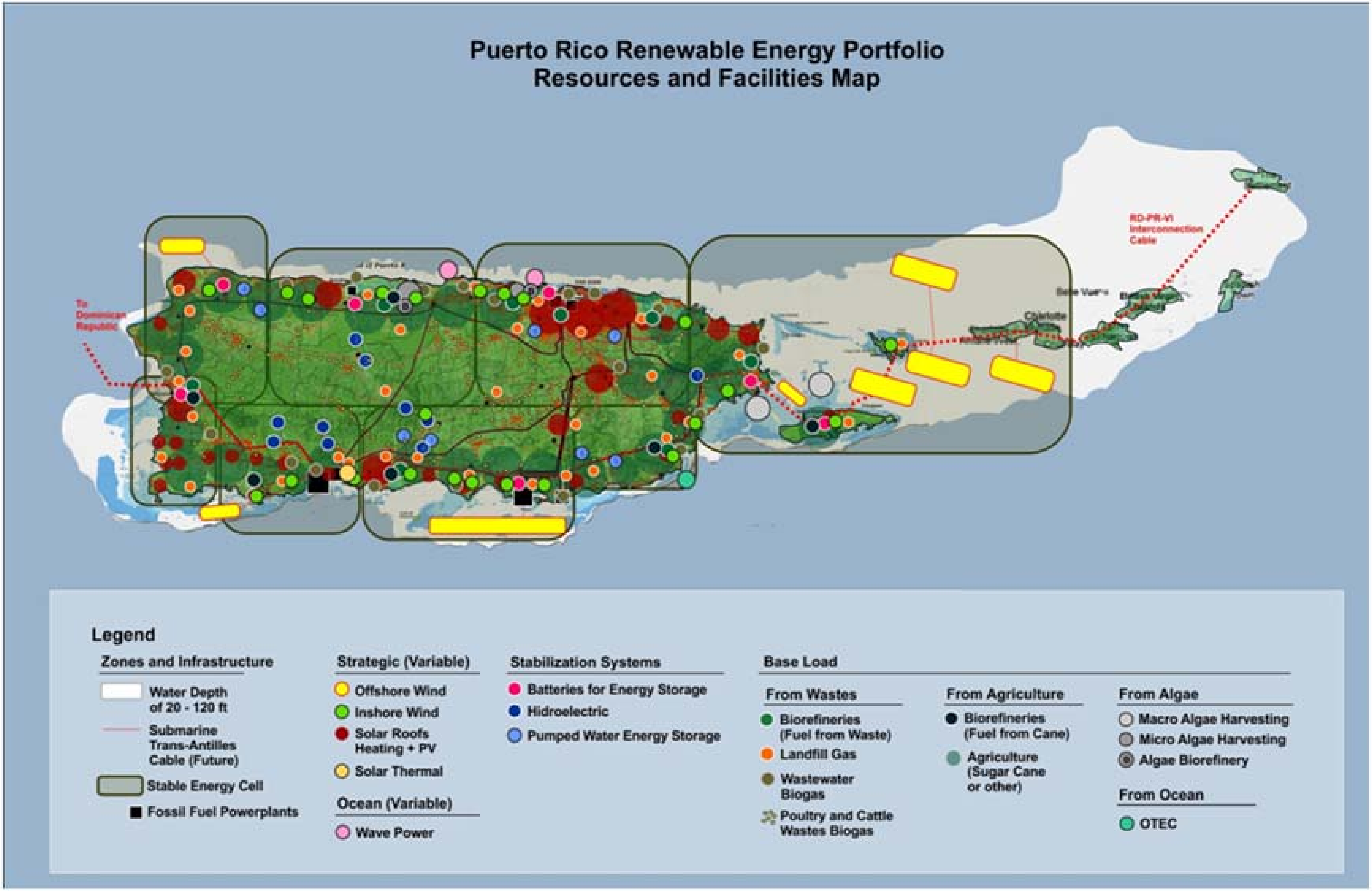
Microalgas producen 50% de bioproductos (6Fs) adicionales.

	Consumo de diesel anual en PR	500,000,000	Unidades	Hectáreas de PR	Und.	% Hectáreas de PR
	Biomasa	Productividad por hectárea	gal *año	906,500	gal	100%
6	Biodiesel de microalgas en charcas (+50% de productos adicionales)	20,000	gal / ha*año	25,000	ha	2.8%
7	Biodiesel de microalgas en biofotoreactores (+50% de productos adicionales)	30,000	gal / ha*año	16,667	ha	1.8%
8	Biodiesel terrestre	1,500	gal / ha*año	333,333	ha	36.8%

Bio-refinerías, ¿la industria del futuro?

- La bio-refinería puede ser una oportunidad más para el sector forestal
- La bio-refinería se define como:
  - "el uso eficiente del potencial total de la materia prima y en procesos del sector forestal para ampliar el rango del valor añadido de los productos (por cooperación en y entre cadenas)"
- Integra procesos y equipamiento de conversión de biomasa para producir combustible, electricidad, y productos químicos




Puerto Rico Renewable Energy Portfolio
Resources and Facilities Map
To Dominican Republic
RD-PR-VI Interconnection Cable
Legend
Zones and Infrastructure
Water Depth of 20 - 120 ft
Submarine Trans-Antilles Cable (Future)
Stable Energy Cell
Fossil Fuel Powerplants
Strategic (Variable)
Offshore Wind
Inshore Wind
Solar Roofs Heating + PV
Solar Thermal
Ocean (Variable)
Wave Power
Stabilization Systems
Batteries for Energy Storage
Hidroelectric
Pumped Water Energy Storage
Base Load
From Wastes
Biorefineries (Fuel from Waste)
Landfill Gas
Wastewater Biogas
Poultry and Cattle Wastes Biogas
From Agriculture
Biorefineries (Fuel from Cane)
Agriculture (Sugar Cane or other)
From Algae
Macro Algae Harvesting
Micro Algae Harvesting
Algae Biorefinery
From Ocean
OTEC

Dr. Agustín Irizarry Rivera, PE

Education:

- B.S.E.E. (Magna Cum Laude), UPRM
- M.S.E.E., University of Michigan
- Ph.D., Iowa State University

Areas of interest: renewable energy resources such as eolic and solar thermal and electric power systems dynamics and operation

Honors: ECE Professor of the Year, CIAPR EE of the Year, Iowa State Progress in Engineering Award

Professional experience: Led projects totalling over $2M. Expert witness in civil court cases involving electric hazard, shock and/or electrocution. Consultant to the Puerto Rico Energy Affairs Administration on eolic generation projects.

Dr. Efraín O'Neill Carrillo, PE

Education:

- B.S.E.E. (Magna Cum Laude), UPRM
- M.S.E.E., Purdue University
- Ph.D., Arizona State University

Areas of interest: Power distribution systems, power quality, sustainable energy resources, load modeling and social implications of technology.

Honors: ECE Professor of the Year, CIAPR EE of the Year, IEEE/PES Walter Fee Outstanding Young Engineer Award

Professional experience: Led projects totalling over $4M, CPI del Caribe (Dorado, PR), TOR Engineering (Phoenix, AZ), Puerto Rico Electric Power Authority.

Dr. José A. Colucci Ríos, PE

Education:

- B.S.Ch.E. (Magna Cum Laude), UPRM
- Ph.D., University of Wisconsin-Madison

Areas of interest: Bio-refinery, biofuels, sustainable energy resources, fuel cells, nuclear engineering.

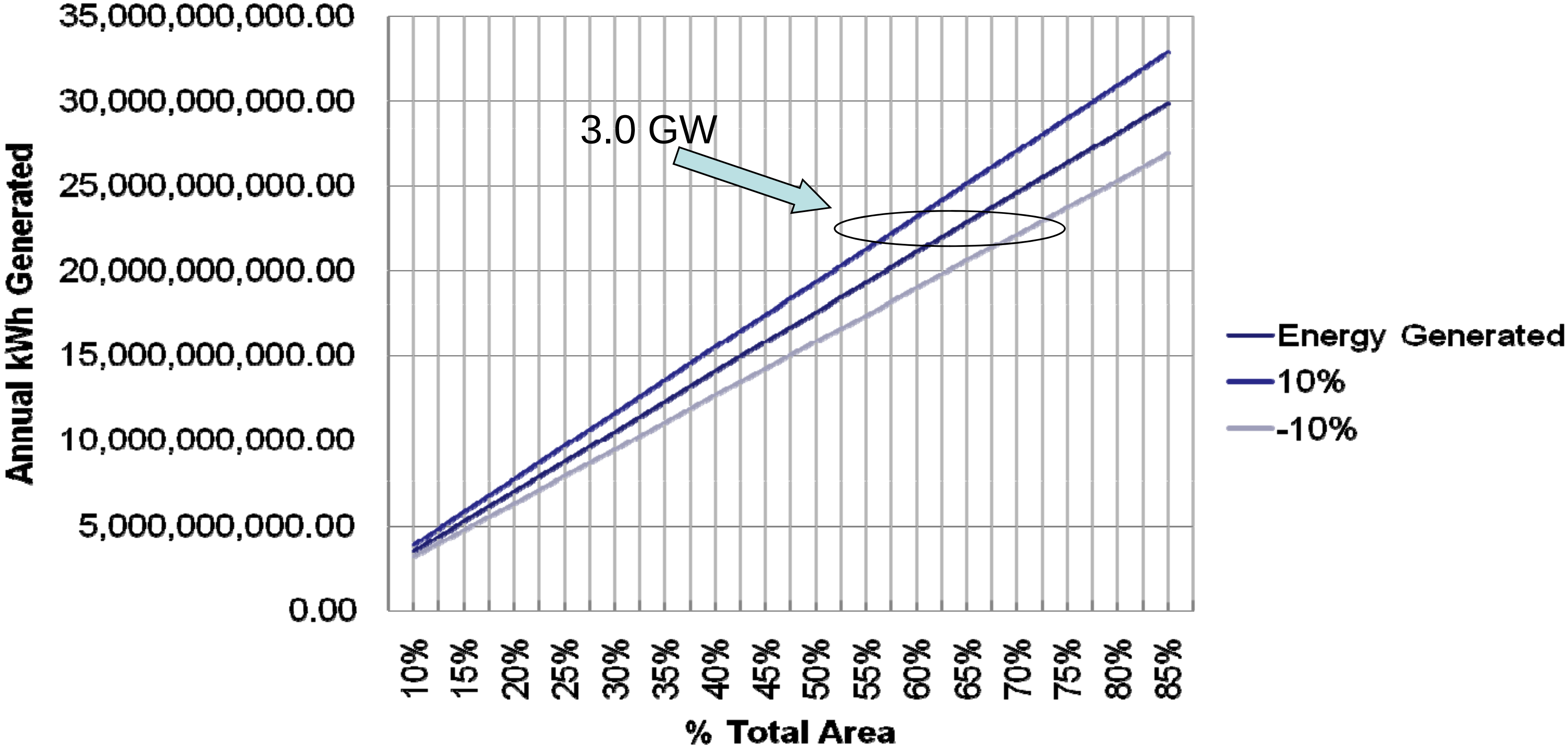
Honors: ChE Professor of the Year, UPR Distinguished Researcher, CIAPR ChE of the Year, 2008 EPA Environmental Award (Project Technical Director, *Caguas Fluoresce*)

Professional experience: Led projects totalling over $3M, Union Carbide, Chemical Industry Consultant, Associate Dean of Engineering, ChE Director.

Thanks

- AAE
- Miguel Ríos, Franchesca Aponte and Magaby Quintero, Arlene Sosa, Luisa Feliciano and Johana Dumeng, Hillmon Ladner, Liliana Martínez, Edy E. Jiménez

Estimate of potential electric energy residential contribution



Estimate of potential electric energy commercial contribution