Virginia Coastal Energy Research Consortium:
Offshore Wind Power and Marine Biofuels

Expanded Presentation

Virginia Coastal Zone Partners Workshop

Portsmouth, VA

07 December 2007

George Hagerman

VCERC Director of Research
Virginia Tech Advanced Research Institute

Aron Stubbins

VCERC Associate Director
Old Dominion University

Focus on Marine Renewable Energy Technologies with Large National Potential

Offshore wind and wind-wave hybrid technologies

could meet 20% of present US electricity demand using 8% of the Outer Continental Shelf (OCS) area between 5 and 20 nautical miles offshore and 17% of the OCS area between 20 and 50 nautical miles offshore

Algae cultivation and biofuel processing technologies

could meet 50% of present US transportation demand using less than 3% of available cropland

VCERC Created by 2006 General Assembly to Bring Together Universities, State Agencies, and Industry

Virginia Coastal Energy Research Consortium

Virginia Tech
- Mechanical, electrical, materials, civil, and ocean engineering
- Washington, DC area presence

Old Dominion University
- Physical, chemical, & geological ocean sciences

Virginia Institute of Marine Science (VIMS)
- Biological ocean sciences

James Madison University
- Wind energy engineering
- Renewable energy curriculum development

Norfolk State University (NSU)
- High-tech workforce training
- Entrepreneurship development

Non-University VCERC Directors

Virginia Department of Mines Minerals and Energy (DMME)
- Integration of marine renewables into Virginia Energy Plan

Virginia Marine Resources Commission
- Ensuring compatibility with other marine uses and coastal resources

Virginia Manufacturers Association (VMA)
- Identification of manufacturing job creation opportunities and industry benefits of long-term, price-stable energy supply

Hampton Roads Maritime Association (Incorporated 1920)
- Identification of waterfront development opportunities

Three Additional Universities and Two New Industry Representatives Added in 2007

Virginia Coastal Energy Research Consortium

Rice Center for Environmental Life Sciences expertise on natural algal blooms

Integration of GIS tool into Coastal GEMS

Virginia Coast Reserve Long-Term Ecological Research Project

Chemical Engineering Department
-- fuels testing and characterization

Research and development of alternative marine biofuels and bioproducts

Non-University VCERC Directors

Interface with local high-tech industry, including advanced manufacturing, sensors, and control systems

Virginia Clean Cities and the Hampton Roads Clean Cities Coalition identify regional transportation needs and opportunities for fuels from algae and integration of offshore wind with plug-in hybrid electric vehicles

Legislative Budget Amendment Funding Four Initial VCERC Projects in FY 2008

1. **Feasibility-level design and economic assessment**
   for a reference baseline offshore wind power project

2. **Preliminary mapping of offshore areas**
   suitable for offshore wind power development, with identification of military training areas, shipping lanes, commercial fishing grounds, and marine and avian habitats

3. **Evaluation of economic development potential**
   of commercial offshore wind power development and associated workforce training needs, and preliminary planning for ocean test bed

4. **Feasibility-level design and economic assessment**
   for an algae-to-biodiesel culture and processing system

FY 2008 Budget Distribution

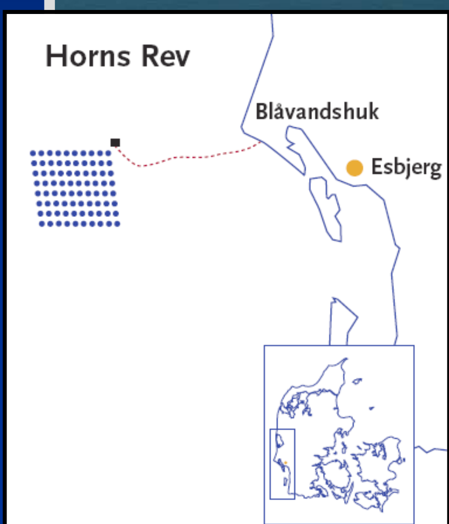
Project	VT-ARI	ODU	ODU (Industry)	JMU	NSU	VIMS	Total
1	$200K	$150K	$50K	$15K	$0K	$0K*	$425K
2	$30K	$64K	$0K	$120K	$0K	$50K	$244K
3	$20K	$0K	$100K	$15K	$75K	$0K	$195K
4	$0K	$511K	$0K	$0K	$0K	$100K	$636K
Total	**$250K**	**$725K**	**$150K**	**$150K**	**$75K**	**$150K**	**$1,500K**

* VIMS anticipates being able to support Project 1 through its normal Sea Grant activities and with a subset of the GIS data produced under Project 2.

Higher-education budget cut of 10.6% to VCERC budget amendment has been applied uniformly across all projects and universities

OFFSHORE WIND POWER

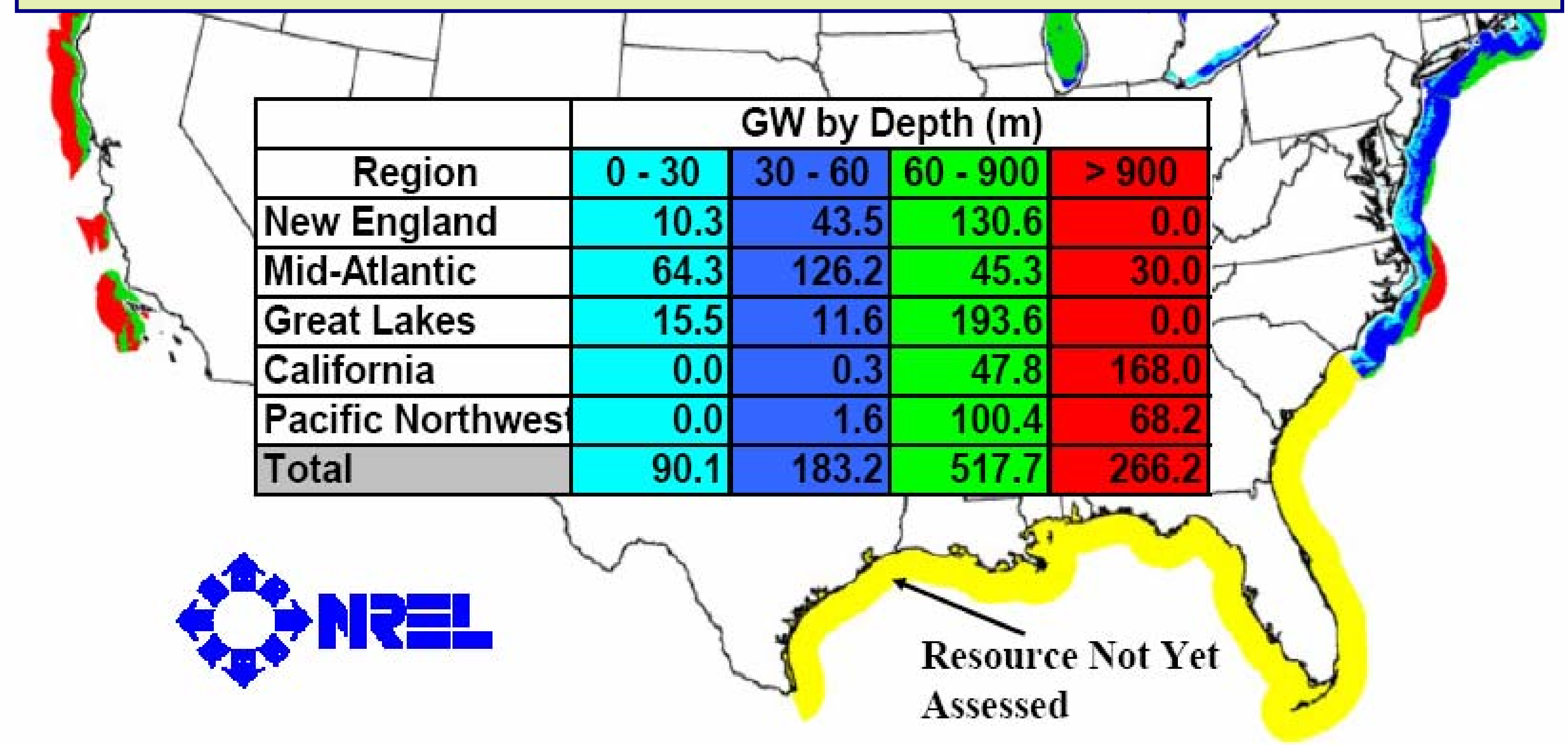
Project capacity = 160 MW (80 turbines), occupying 5.0 km x 3.9 km area (~ 8 MW per sq.km)
Mean wind speed = 9.7 m/s at 70-m hub height (Class 6)
Annual energy output = 600 GWh (43% capacity factor)
Capital investment = 270 million Euro ($248 million → $1,550/kW)



US Offshore Wind Energy Potential Between 5 and 50 Nautical Miles Offshore

Assumes turbine spacing density of 5 MW per km^2. To account for exclusions due to other ocean uses (e.g., military, shipping, and fisheries), NREL researchers assumed that only one-third of the available resource could be developed between 5 and 20 n.mi. offshore (67% exclusion), while two-thirds of the available resource could be developed between 20 and 50 n.mi offshore (33% exclusion).

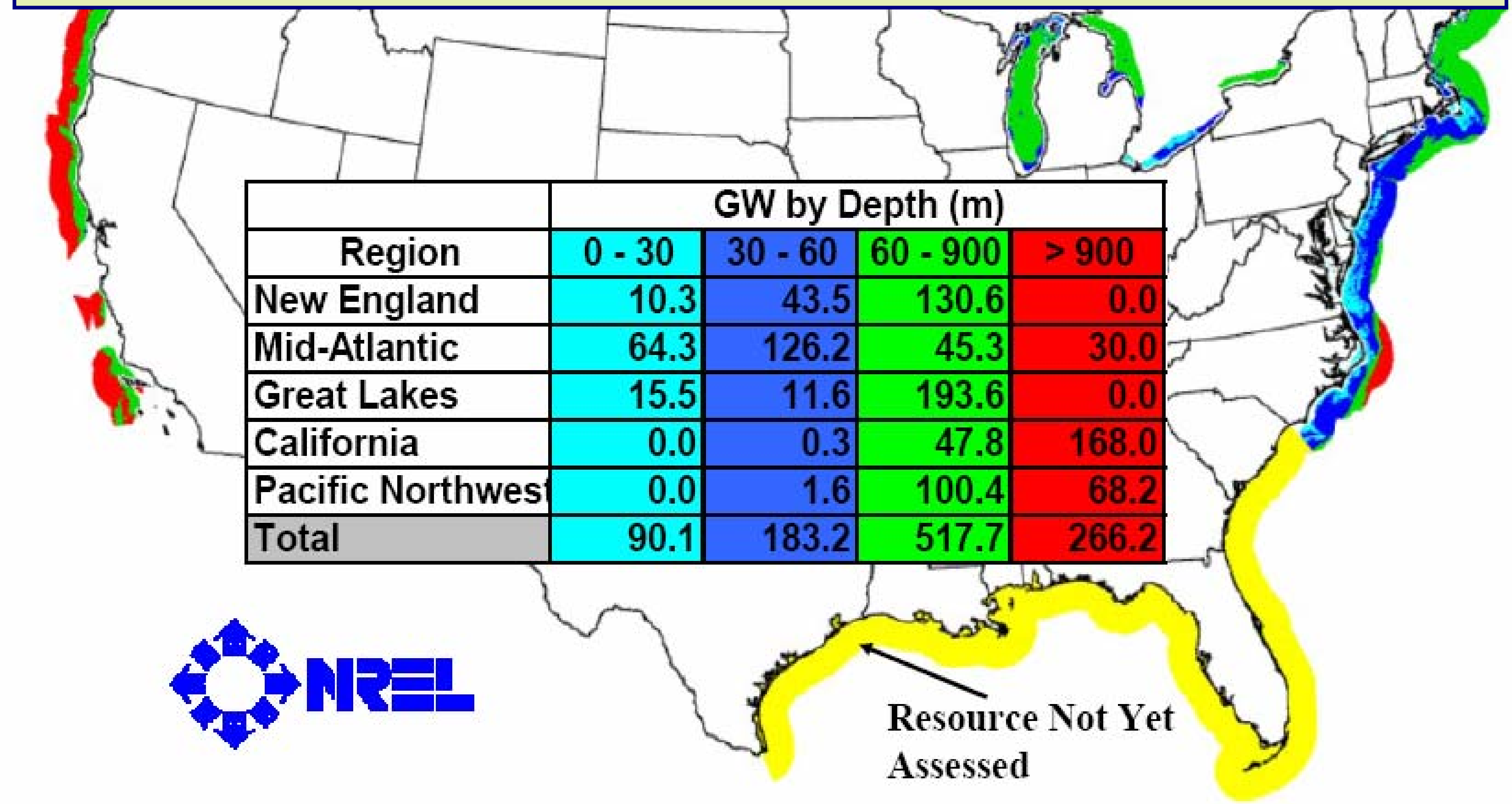
	GW by Depth (m)			
Region	0 - 30	30 - 60	60 - 900	> 900
New England	10.3	43.5	130.6	0.0
Mid-Atlantic	64.3	126.2	45.3	30.0
Great Lakes	15.5	11.6	193.6	0.0
California	0.0	0.3	47.8	168.0
Pacific Northwest	0.0	1.6	100.4	68.2
Total	90.1	183.2	517.7	266.2



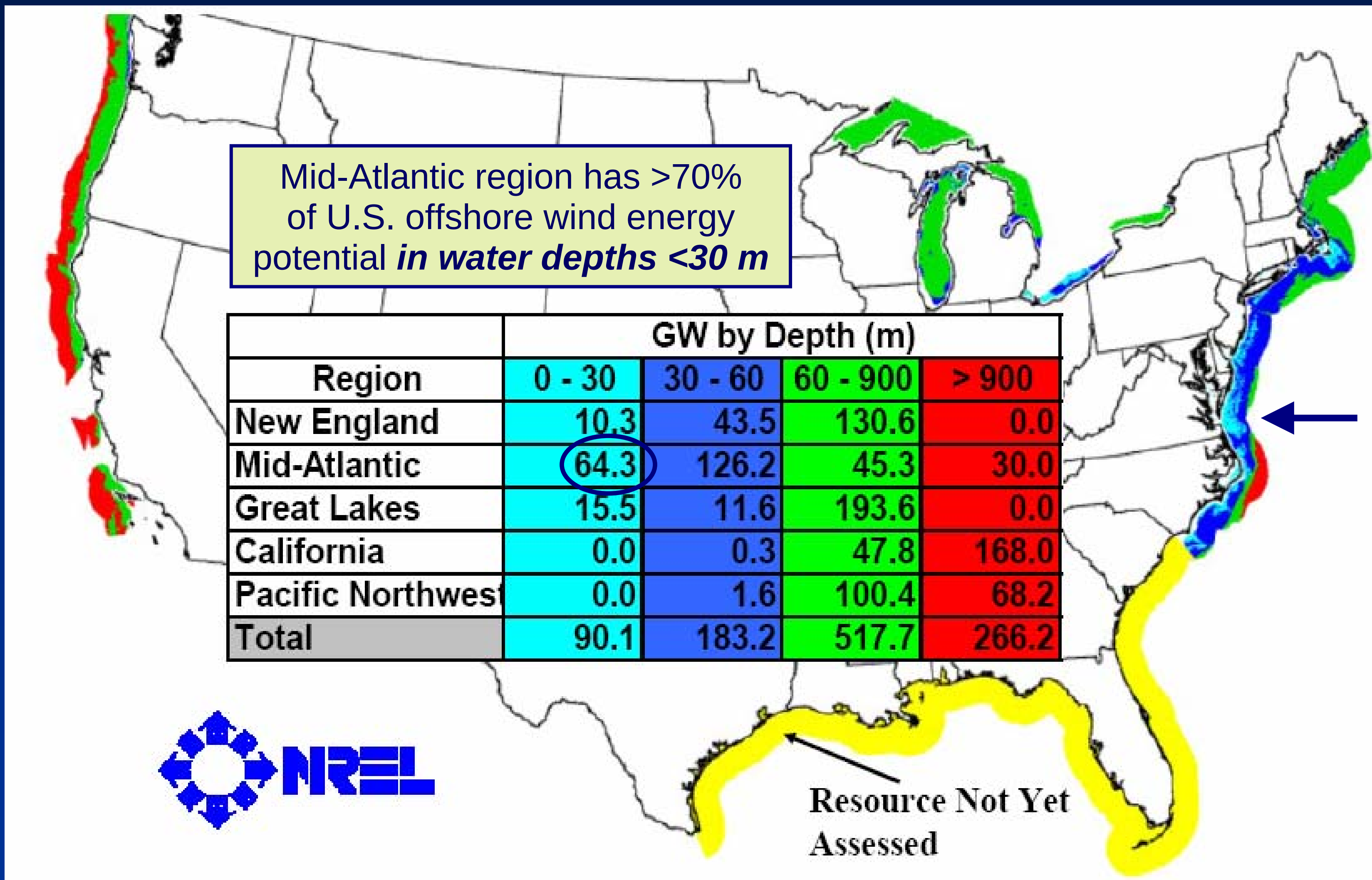
US Offshore Wind Energy Potential Between 5 and 50 Nautical Miles Offshore

Total potential installed capacity is 1,057.2 GW. Assuming an average capacity factor of 30%, total electrical energy output would be 2,780 TWh per year. This would equal 70% of all US electrical generation in 2004.

	GW by Depth (m)			
Region	0 - 30	30 - 60	60 - 900	> 900
New England	10.3	43.5	130.6	0.0
Mid-Atlantic	64.3	126.2	45.3	30.0
Great Lakes	15.5	11.6	193.6	0.0
California	0.0	0.3	47.8	168.0
Pacific Northwest	0.0	1.6	100.4	68.2
Total	90.1	183.2	517.7	266.2

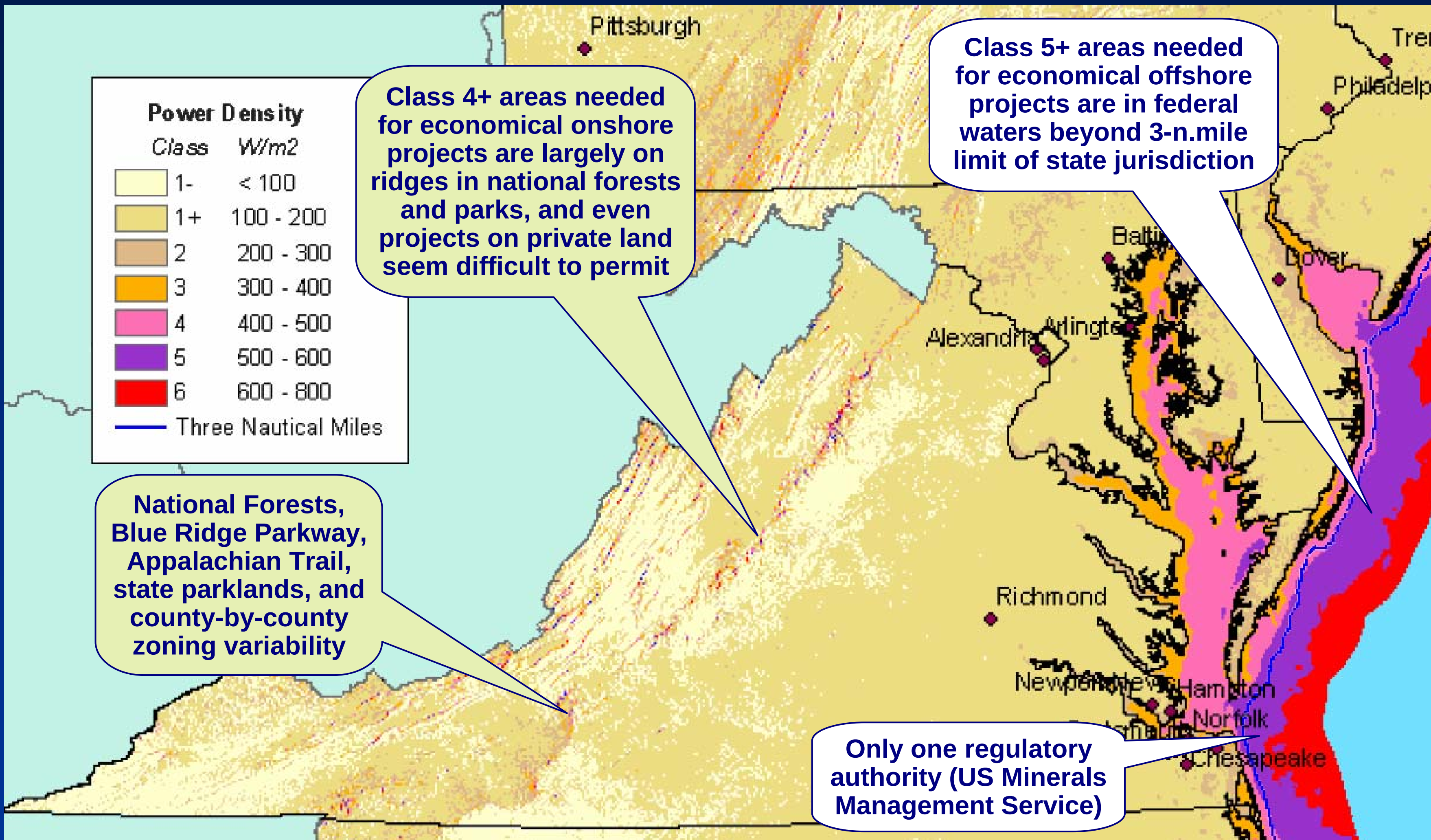


Most of the Shallow Mid-Atlantic Offshore Wind Resources are off Virginia's Coastline



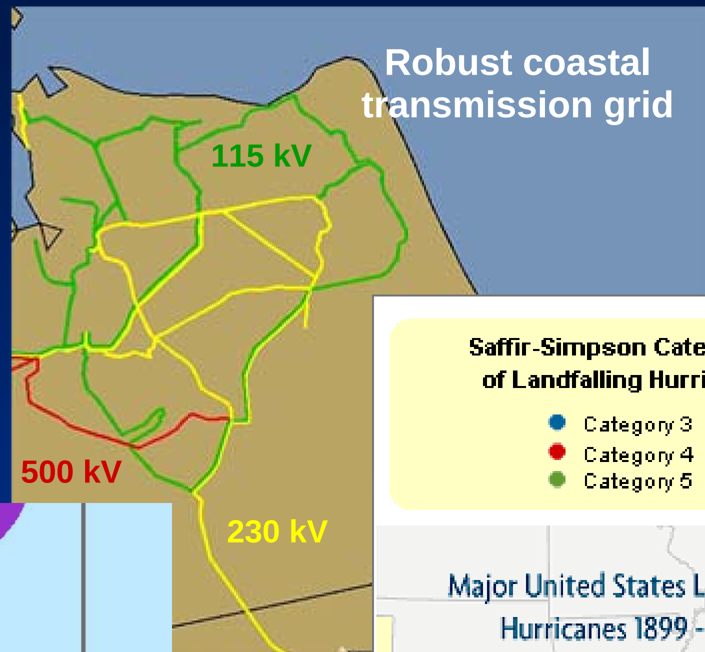
	GW by Depth (m)			
Region	0 - 30	30 - 60	60 - 900	> 900
New England	10.3	43.5	130.6	0.0
Mid-Atlantic	64.3	126.2	45.3	30.0
Great Lakes	15.5	11.6	193.6	0.0
California	0.0	0.3	47.8	168.0
Pacific Northwest	0.0	1.6	100.4	68.2
Total	90.1	183.2	517.7	266.2

Virginia's Wind Energy Resources Offshore are Much Larger than on Land

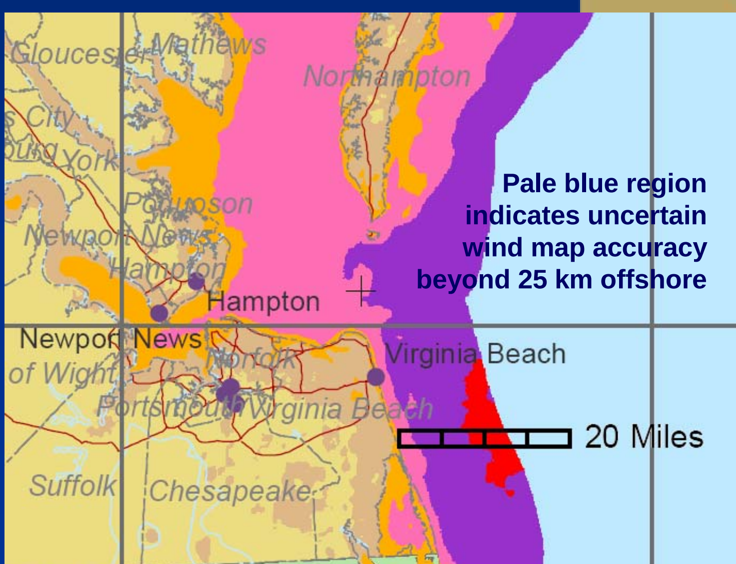


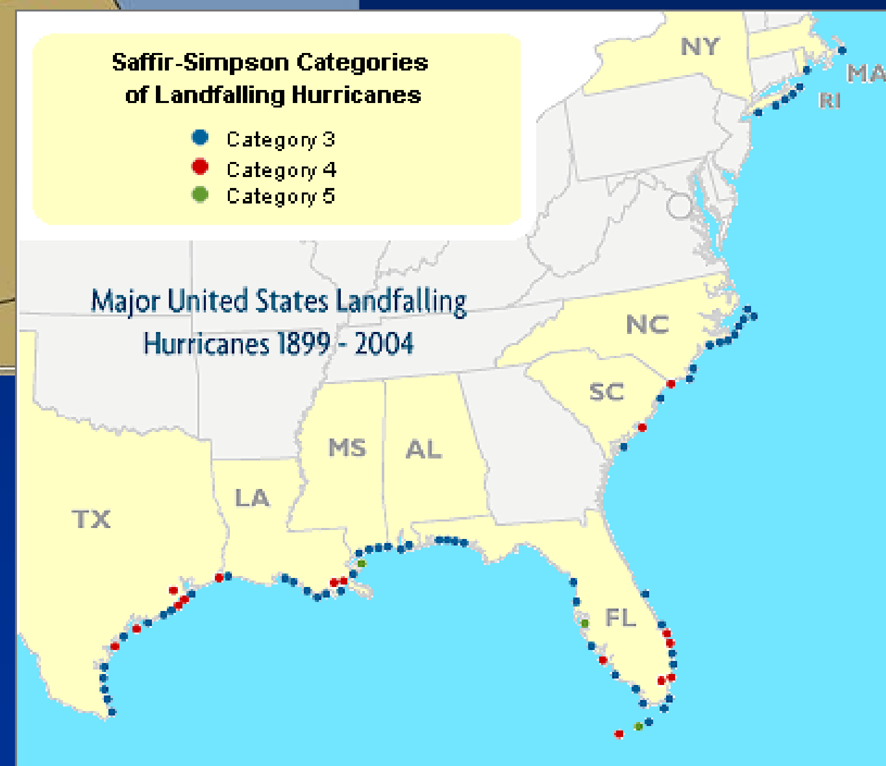
Hampton Roads Area has Unique Features Favorable for Offshore Wind Power Development

Class 6 (red) wind energy resource located within 10-15 miles (16-24 km) of shoreline and close to major, growing centers of power demand

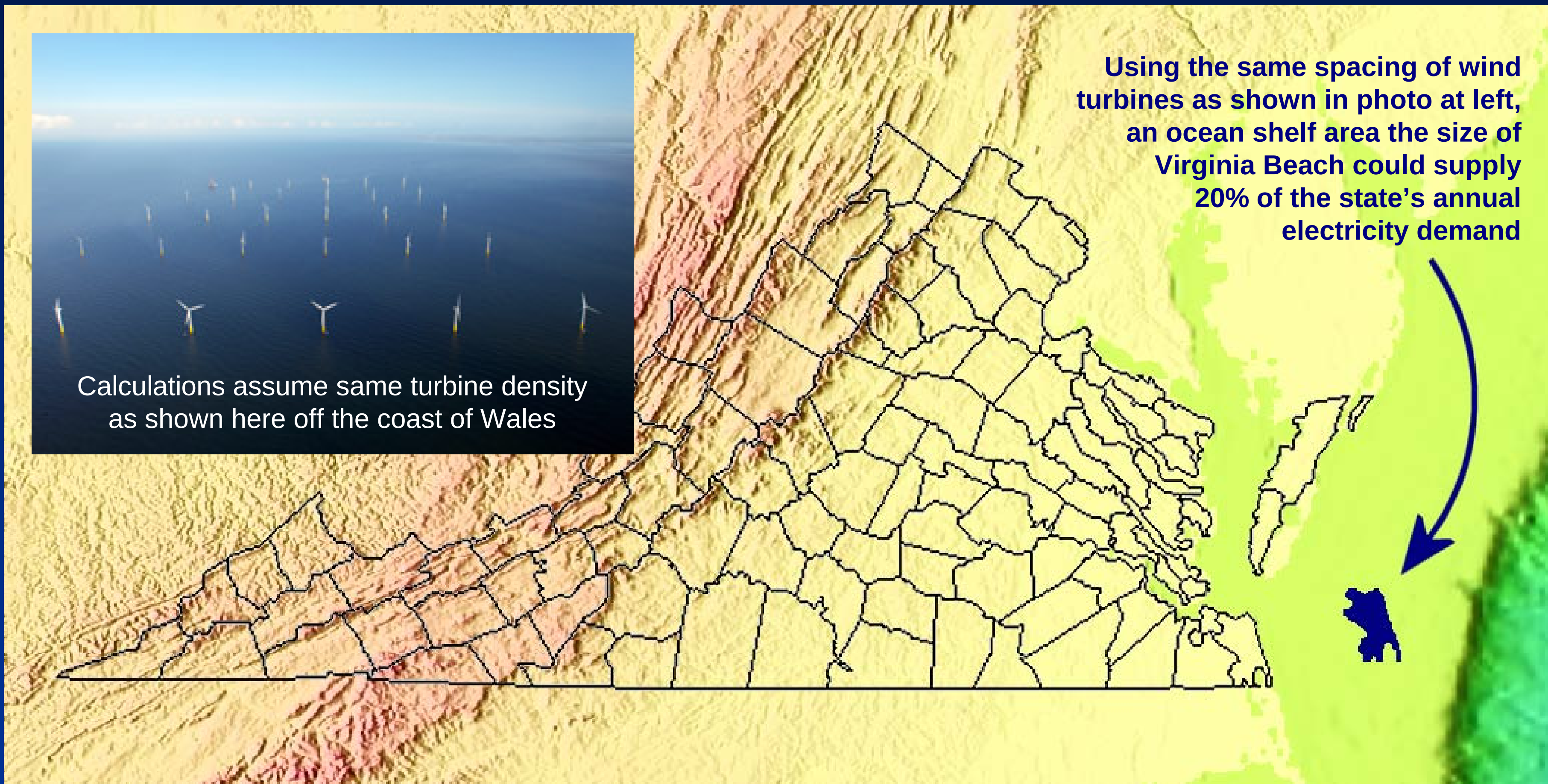


Minimal probability of major hurricane strike (Categories 3 through 5)





Offshore Wind Can Meet a Large Portion of Virginia's Energy Demand



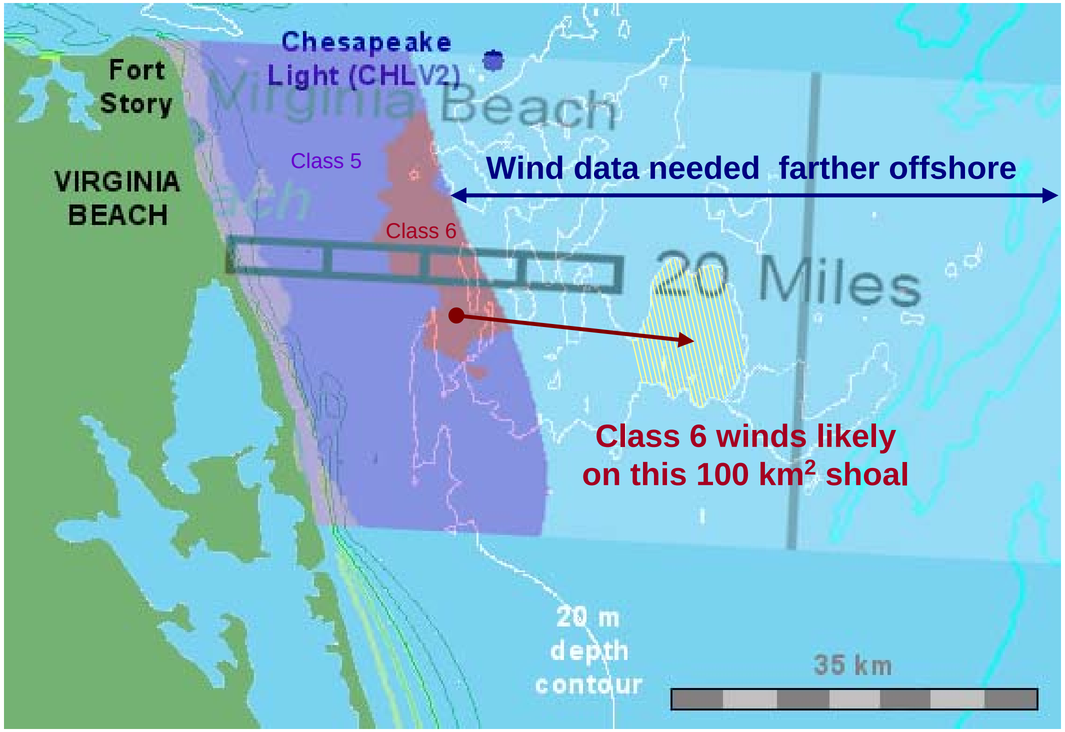
With wind turbines installed at a density of 10 MW per sq.km, an ocean area of 640 sq.km could produce 21,000 GWh/yr, compared with state consumption of 104,200 GWh/yr in 2005

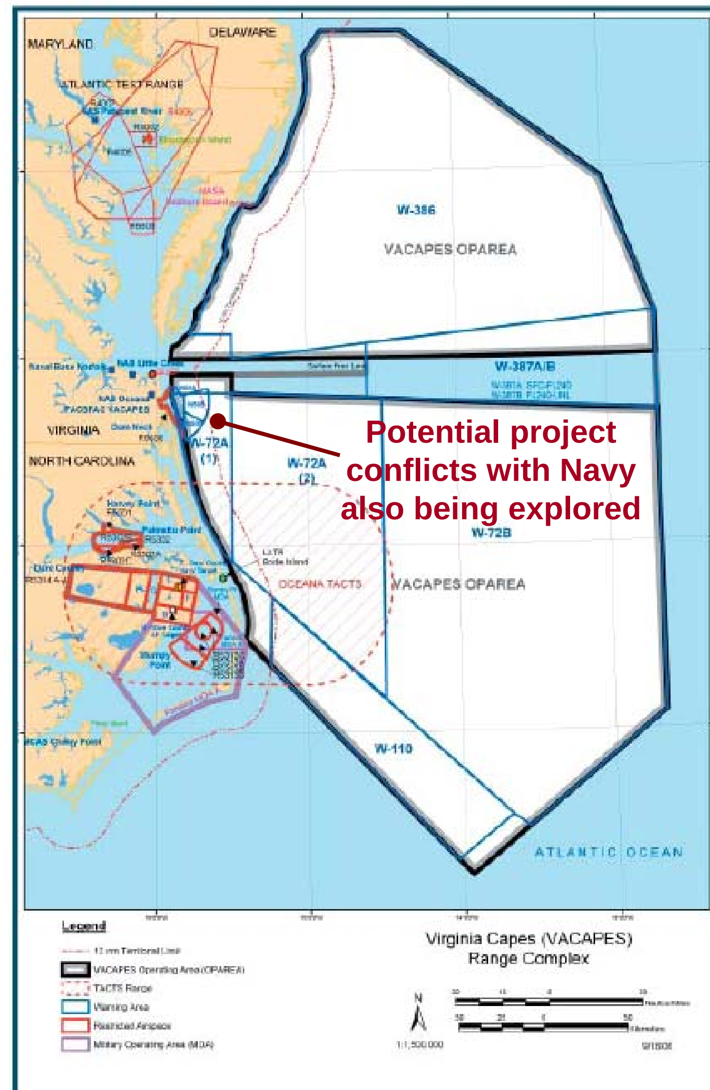
Offshore Wind Feasibility-Level Design

VT-ARI responsible for overall direction and preparation of final report

- *Which wind turbines models, foundations and hub heights are optimal for Virginia's offshore wind climate?*
- *For optimized, integrated design, what is cost of energy (COE) for different project financing scenarios?*
- *What is effect on COE of project size in range from 250 MW to 1,000 MW?*
- *What is effect on COE of distance offshore in the range from 10 km to 50 km for AC and DC transmission?*
- *How do seasonal and hourly output distributions match utility grid power demand?*

Reference Baseline Design Location



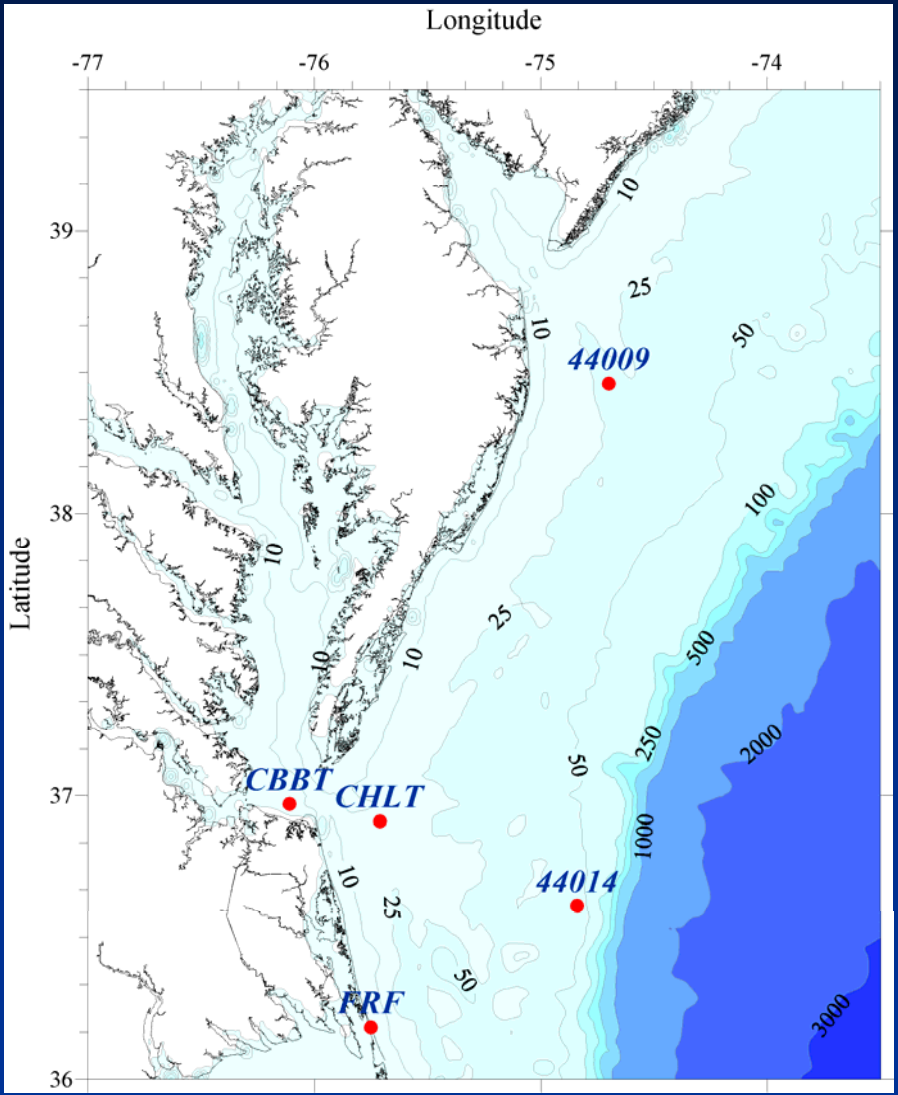


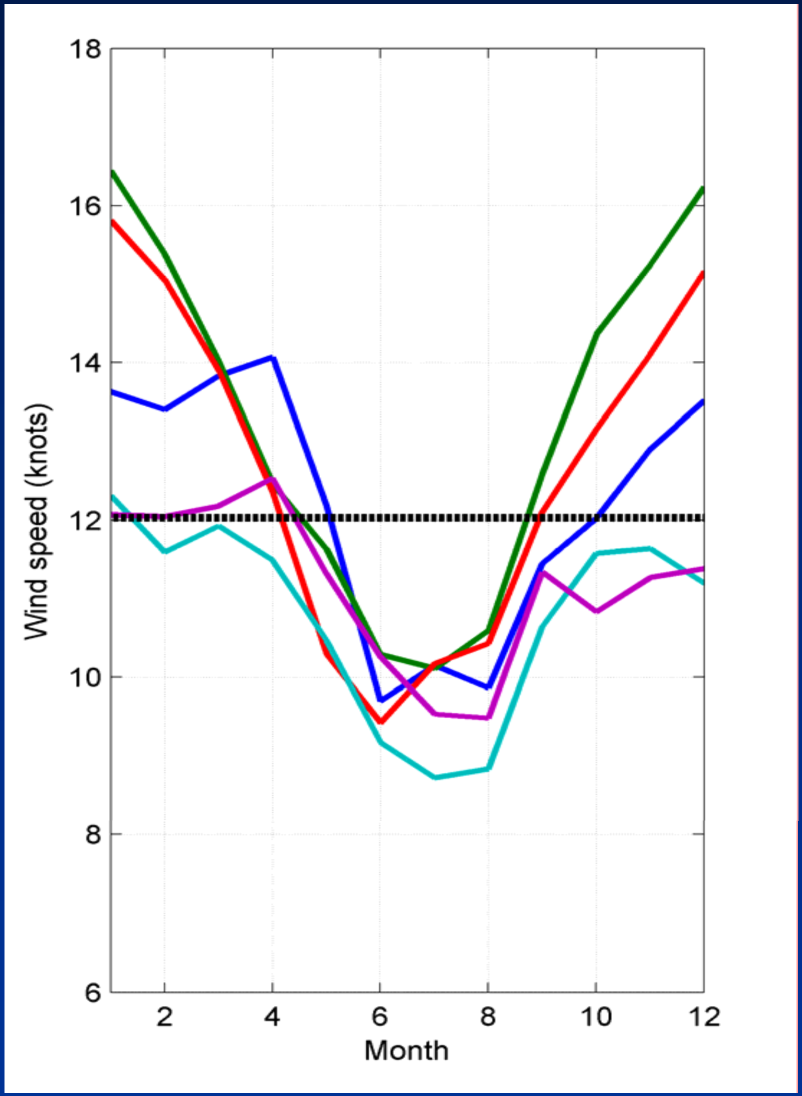
ODU's Center for Coastal Physical Oceanography is compiling data on offshore wind and wave climate.

ODU's Coastal Engineering Program is developing wind turbine tower foundation design alternatives.

ODU's Electrical Engineering Department is developing turbine electrical interconnection design alternatives.

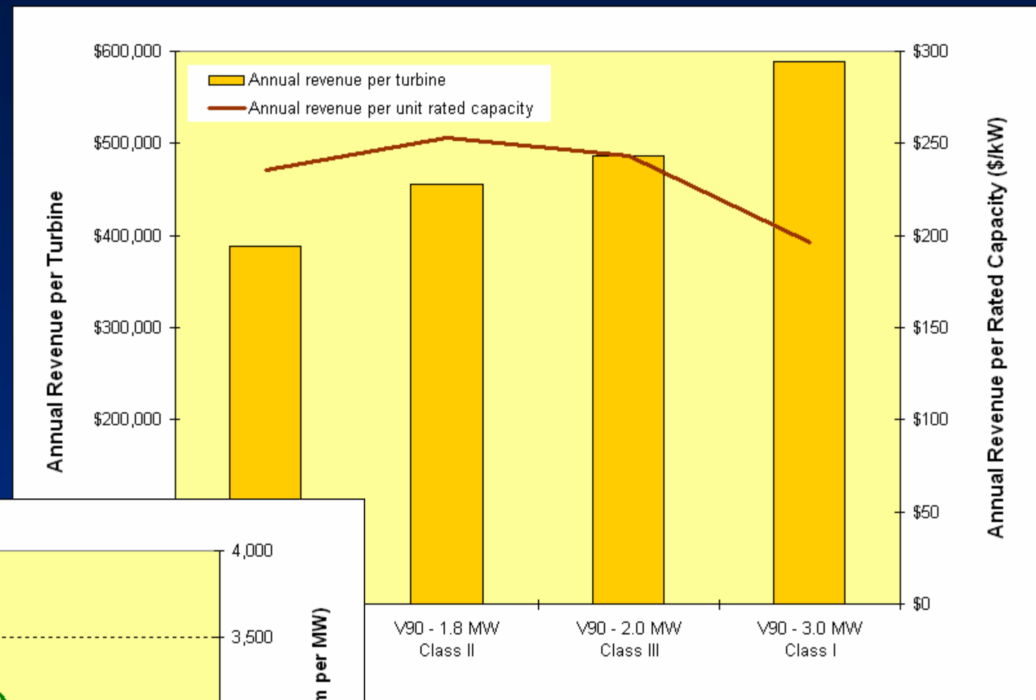
ODU Center for Coastal Physical Oceanography Evaluation of Coastal and Offshore Wind Data

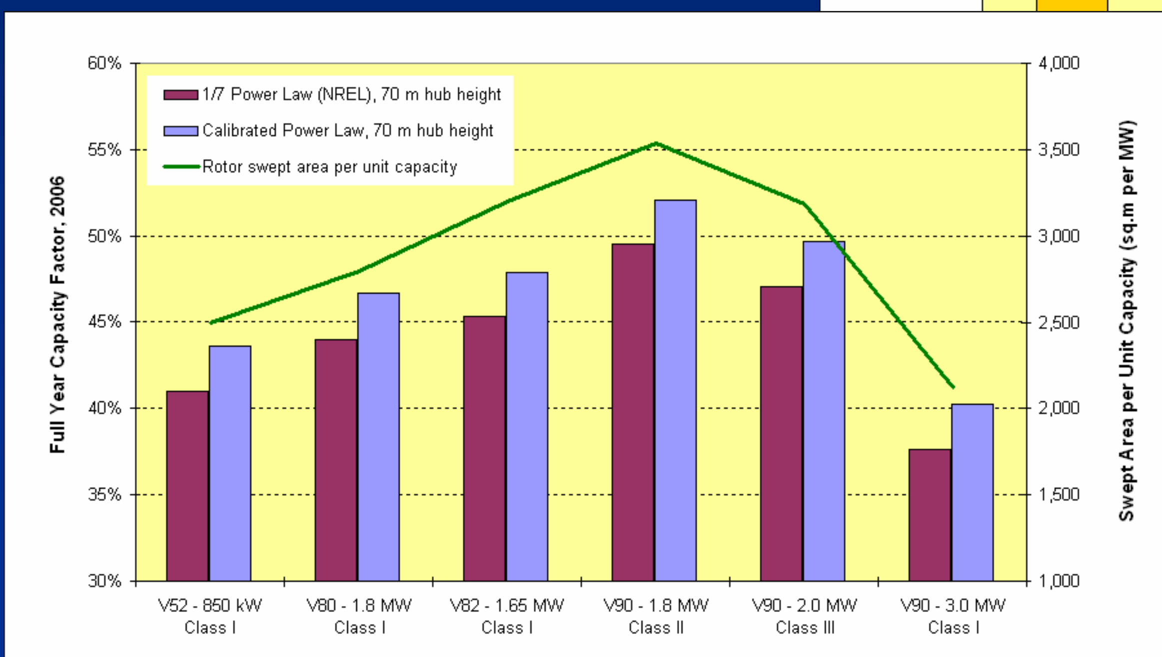




Virginia Tech Evaluation of Vestas Wind Turbine Performance Using CHLV2 Data

Virginia's offshore wind speeds are lower than those in the North Sea, such that smaller generators with larger rotor swept areas have more revenue per unit rated capacity than the V-90 3.0 MW turbine commonly used in European projects.





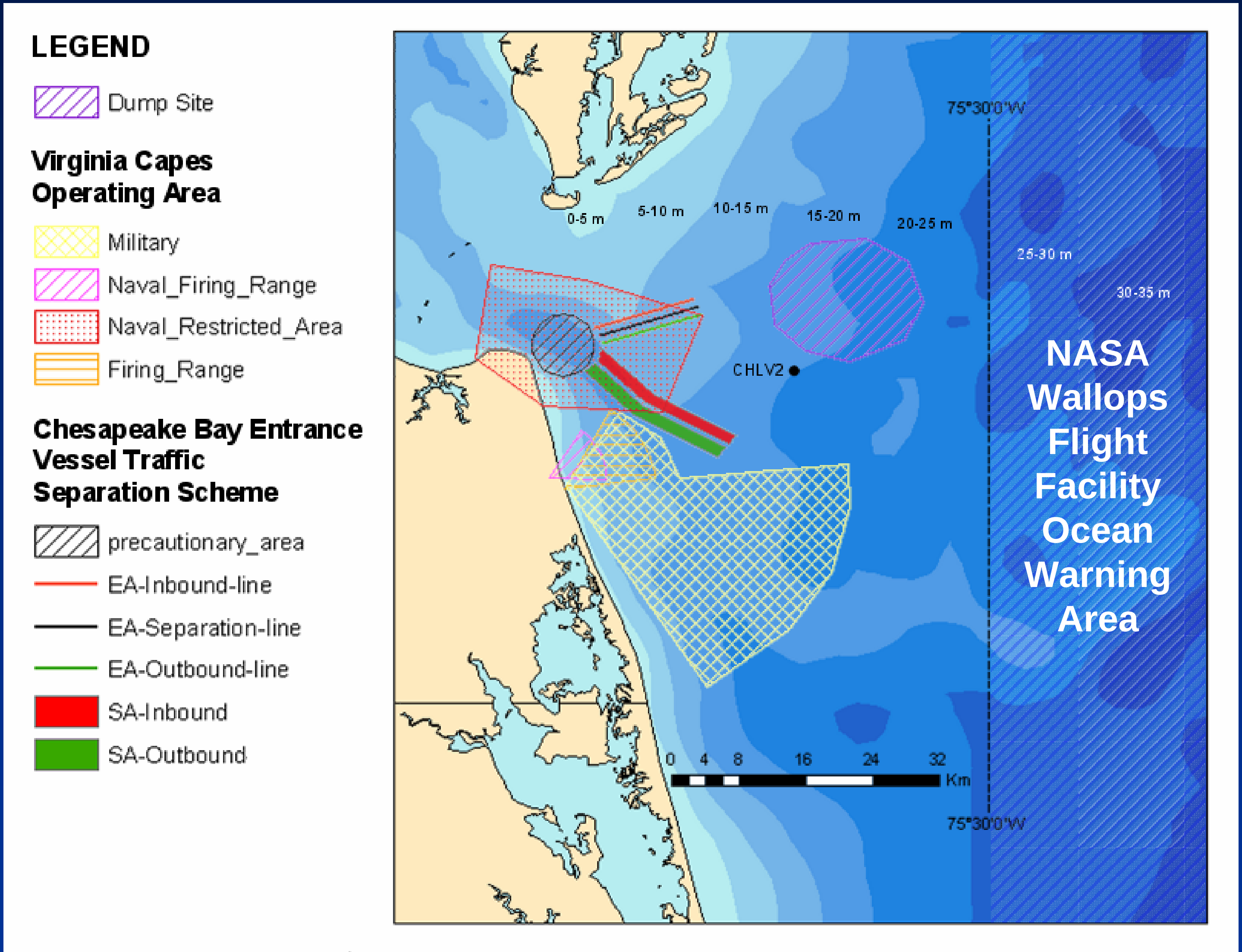
For wind turbines appropriately sized for Virginia's offshore wind climate, annual average capacity factors are in the range of 45-50%, which is much higher than typical land-based wind turbines in the Mid-Atlantic region, which have annual capacity factors of 30-40%.

Offshore Mapping and GIS Tool

JMU and VIMS responsible for overall direction and preparation of integrated GIS tool

- *Develop GIS layers for offshore wind resource, extreme survival conditions, bathymetry, and seabed geology, to characterize offshore area breakdown of potential installed offshore wind capacity by foundation type*
- *Develop GIS layers mapping other ocean uses (military and NASA operating areas, shipping, commercial fishing) to help avoid potential conflicts*
- *Develop GIS layers mapping offshore benthic and pelagic marine environments*
- *Develop GIS layers mapping shorebird migratory flyways and pelagic bird (e.g. sea ducks) population distributions*

Shipping Lanes and Military Operations Constrain Available Sea Space Near Shore



NASA Wallops Island Flight Facility (WFF) Operations Constrain Sea Space Farther Offshore

WFF owns restricted airspace to execute hazardous flight operations that reaches off shore to three miles, adjoining the off-shore Warning Areas (see Figure 1). Beyond this three-mile area, WFF flight activities occur in a sector from approximately due east to due south of Wallops Island, as shown in Figure 2. As is true within our Restricted Airspace, within this southeast sector, rocket motors and other flight hardware systems are routinely flown and expended safely into the ocean, and low-flying missiles and UAVs are frequently operated.

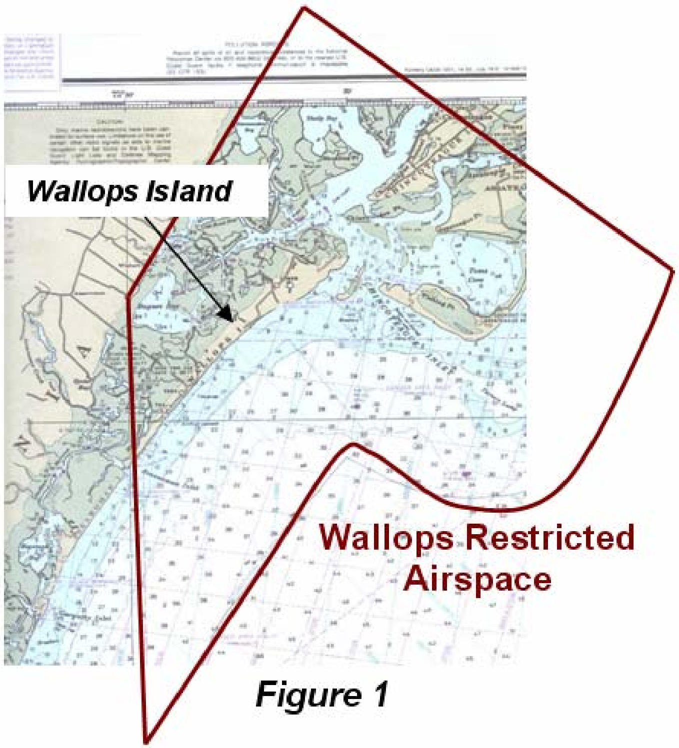


Figure 1

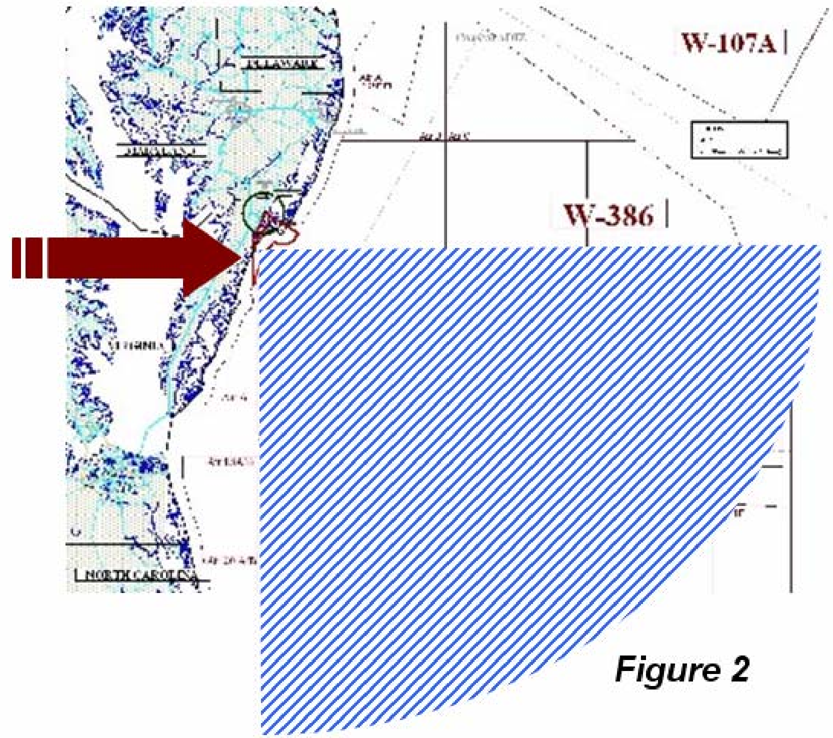
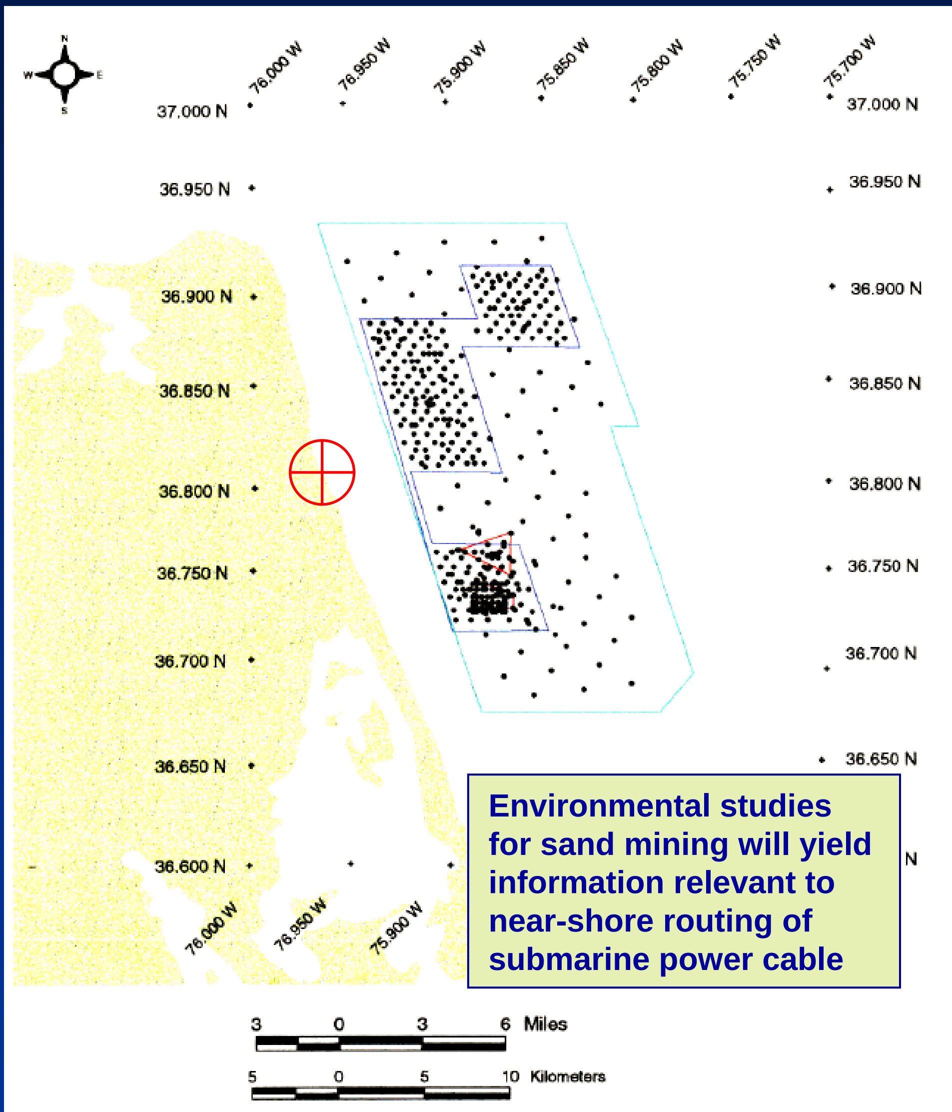


Figure 2

Compilation of Existing VIMS Data on Marine Benthic Communities and Biological Productivity



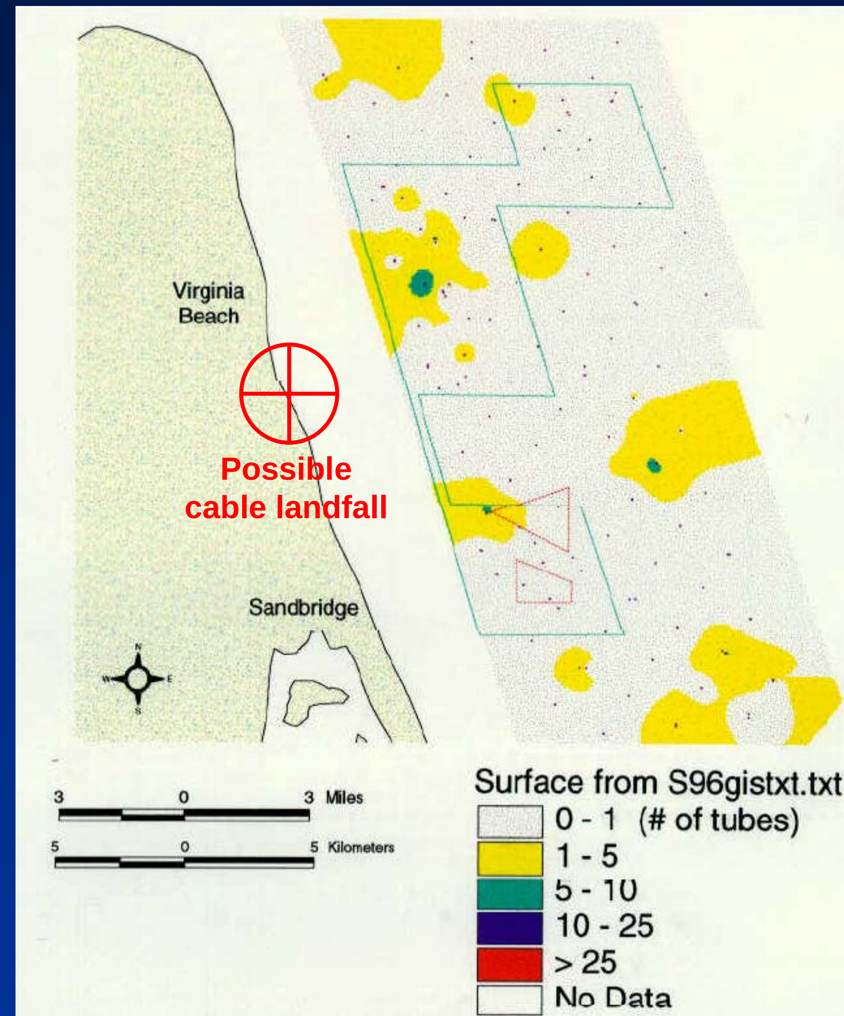
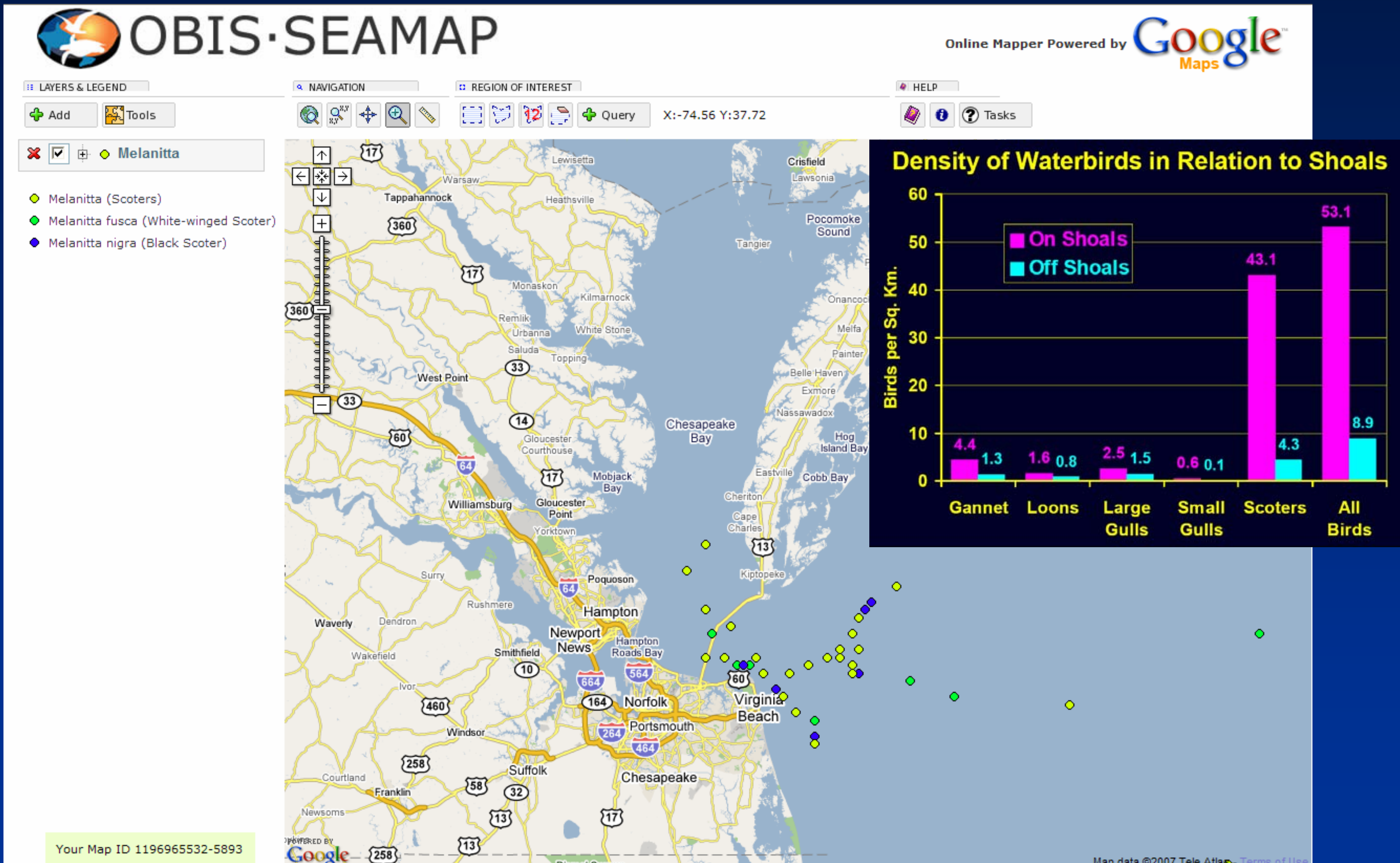


Figure 21. Spring 1997, number of infaunal tubes visible at the sediment-water interface.

Compilation of Existing Survey Data on Marine Mammals, Sea Turtles and Seabirds



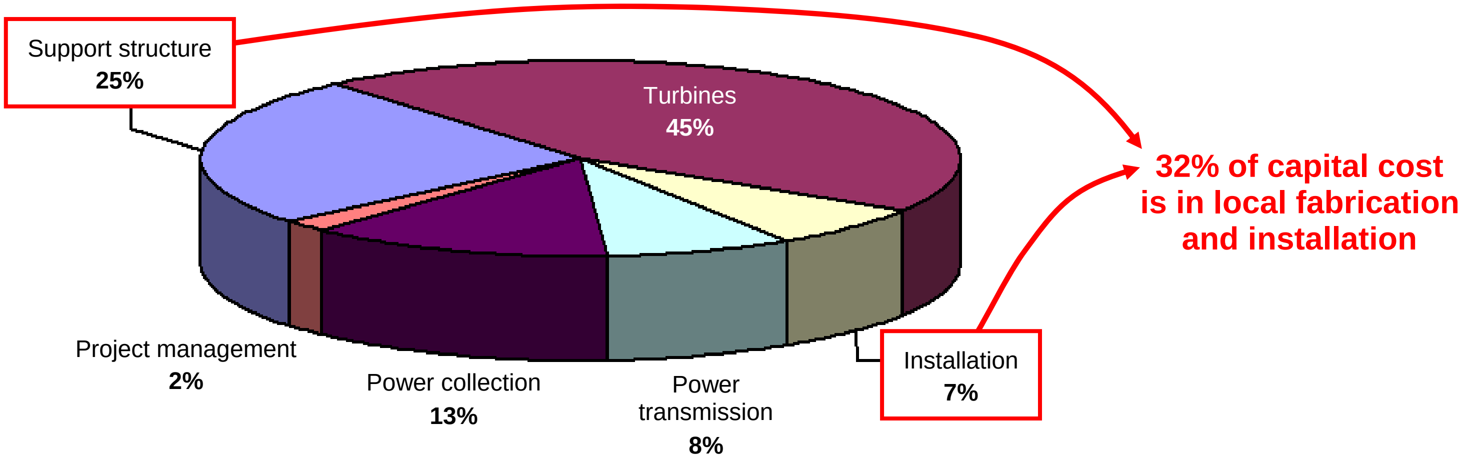
Economic Development Studies

Norfolk State University and Industry Partner (SAIC) responsible for overall direction and preparation of final report

- *What are realistic timetables and magnitudes of economic development impact to build out offshore wind potential?*
- *What are workforce training needs and small business opportunities associated with this build-out?*
- *Develop budget and plan to seek federal funding for ocean test bed to host offshore wind or wind/wave hybrid systems*

New Sustainable Business Value of $150-200 Million per Year in Maritime Sector Alone

Typical capital cost breakdown for monopile-based offshore wind project



Estimated maritime industry value of fabrication, installation, and service contracts to supply 20% of Virginia's electricity:

- Based on total installed turbine capacity = 6,500 MW
- At $1,600 per installed kW, total capital investment = $10.4 billion
- Assuming an installation rate of 325 MW per year= $520 million per year over 20-year build-out
- Value of local fabrication and installation contracts = $166 million per year <u>until</u> fully built out
- Value of local offshore service contracts = $190 million per year <u>after</u> fully built out

Large Manufacturing Opportunities and New Waterfront Industries

Wind energy supply chain facilities exist in and around Virginia

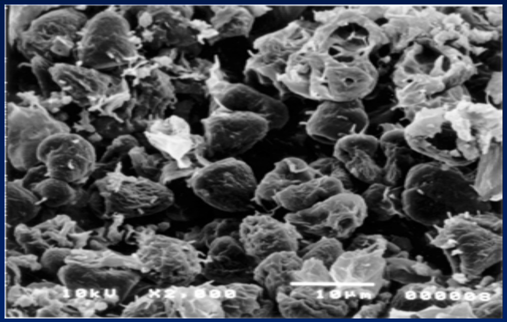
- *General Electric in Salem, VA produces wind turbine control system components*
- *General Electric in Greenville, SC has a wind turbine assembly plant*
- *Tower Logistics in Huntington, WV manufactures in-tower man-lifts for service crews*
- *Gamesa in Ebensburg, PA manufactures blades, nacelles (turbine and gearbox housing), and towers*

Early, Meaningful Engagement of Local Stakeholders Essential to Success

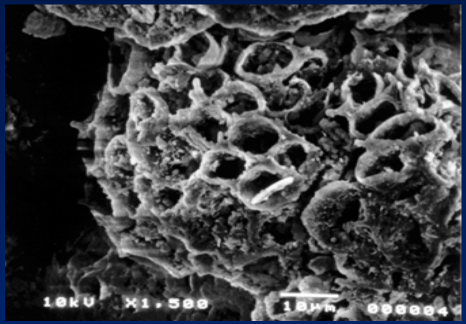
MARINE BIOFUELS

The algae *Botryococcus braunii* under magnification, showing many of the natural oil particles in the algal cells. The inset shows the particles under x500 magnification. Jian Qin/Flinders University

Geothermal Heating and Compression of Single-Celled Algae Naturally Produces Oil

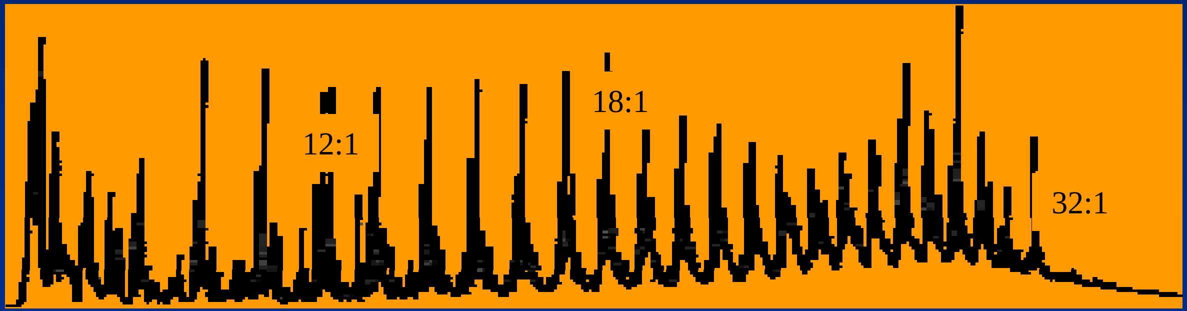


Scanning Electron Micrograph (SEM) Living Algal Cells



4-Million-Year-Old Fossilized Cell Walls

They look similar, and pyrolysis (slow heating in the absence of oxygen) of algae yields hydrocarbons that have a similar chemical composition to crude oil



Pyrolysis / GC / MS chromatogram of algae

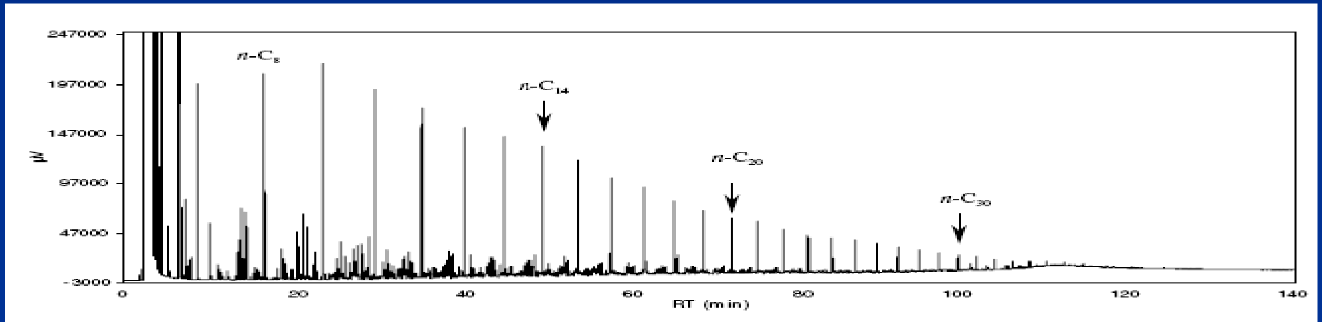


Fig. 1. GC trace of the total Safaniya oil.

GC / MS chromatogram of fossil crude oil

Single-Celled Algae are a Promising Feedstock for Biodiesel Production

Growth conditions for maximum biomass and oil yield:

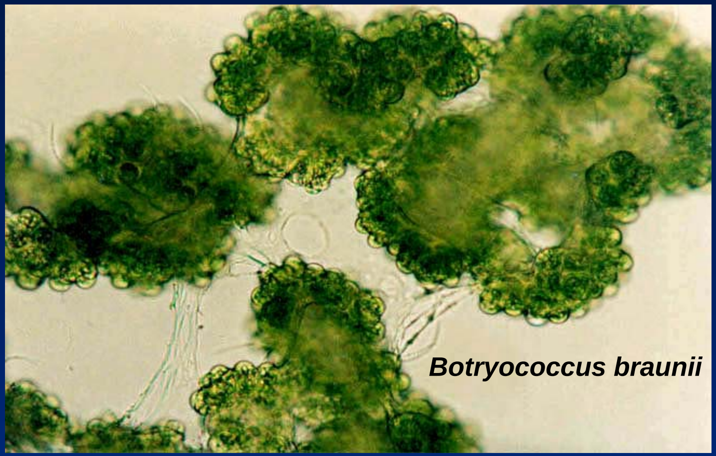
- *Ambient temperature of 22-25^{o}C (71-77^{o}F)*
- *Salinity of 8-10% (brackish)*
- *Light intensity of 30-60 W/m^2*
- *Photoperiod of 12 hours light and 12 hours dark*
- *Still has >30% oil content even when stressed*

Oil Content of Some Microalgae

Microalga	Oil Content (% dry wt)
Botryococcus braunii	25–75
Chlorella sp.	28–32
Crypthecodinium cohnii	20
Cylindrotheca sp.	16–37
Dunaliella primolecta	23
Isochrysis sp.	25–33
Monallanthus salina	>20
Nannochloris sp.	20–35
Nannochloropsis sp.	31–68
Neochloris oleoabundans	35–54
Nitzschia sp.	45–47
Phaeodactylum tricornutum	20–30
Schizochytrium sp.	50–77
Tetraselmis sueica	15–23

From : Chisti, Y. 2007. Biodiesel from microalgae. *Biotechnology Advances* **25** 294–306

"Fat Algae" Could Supply 50% of US Transport Fuel Needs on <3% of US Cropland



Comparison of some sources of biodiesel

Crop	Oil Yield (L/ha)	Land Area Needed (M ha)[a]	Percent of Existing US Cropping Area[a]
Corn	172	1540	846
Soybean	446	594	326
Canola	1190	223	122
Jatropha	1892	140	77
Coconut	2689	99	54
Oil Palm	5950	45	24
Microalgae[b]	136,900	2	1.1
Microalgae[c]	58,700	4.5	2.5

[a] For meeting 50% of all transport fuel needs of the United States.
[b] 70% oil (by weight) in biomass.
[c] 30% oil (by weight) in biomass.

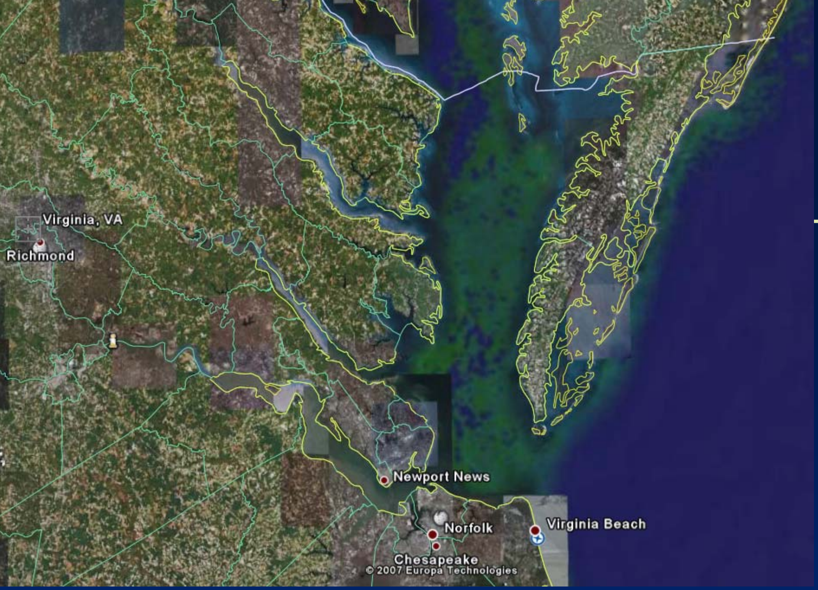
From : Chisti, Y. 2007. Biodiesel from microalgae. *Biotechnology Advances* **25** 294–306

Oil Content of Some Microalgae

Microalga	Oil Content (% dry wt)
Botryococcus braunii	25–75
Chlorella sp.	28–32
Crypthecodinium cohnii	20
Cylindrotheca sp.	16–37
Dunaliella primolecta	23
Isochrysis sp.	25–33
Monallanthus salina	>20
Nannochloris sp.	20–35
Nannochloropsis sp.	31–68
Neochloris oleoabundans	35–54
Nitzschia sp.	45–47
Phaeodactylum tricornutum	20–30
Schizochytrium sp.	50–77
Tetraselmis sueica	15–23

From : Chisti, Y. 2007. Biodiesel from microalgae. *Biotechnology Advances* **25** 294–306

Virginia Attractive as an "Early Adopter"



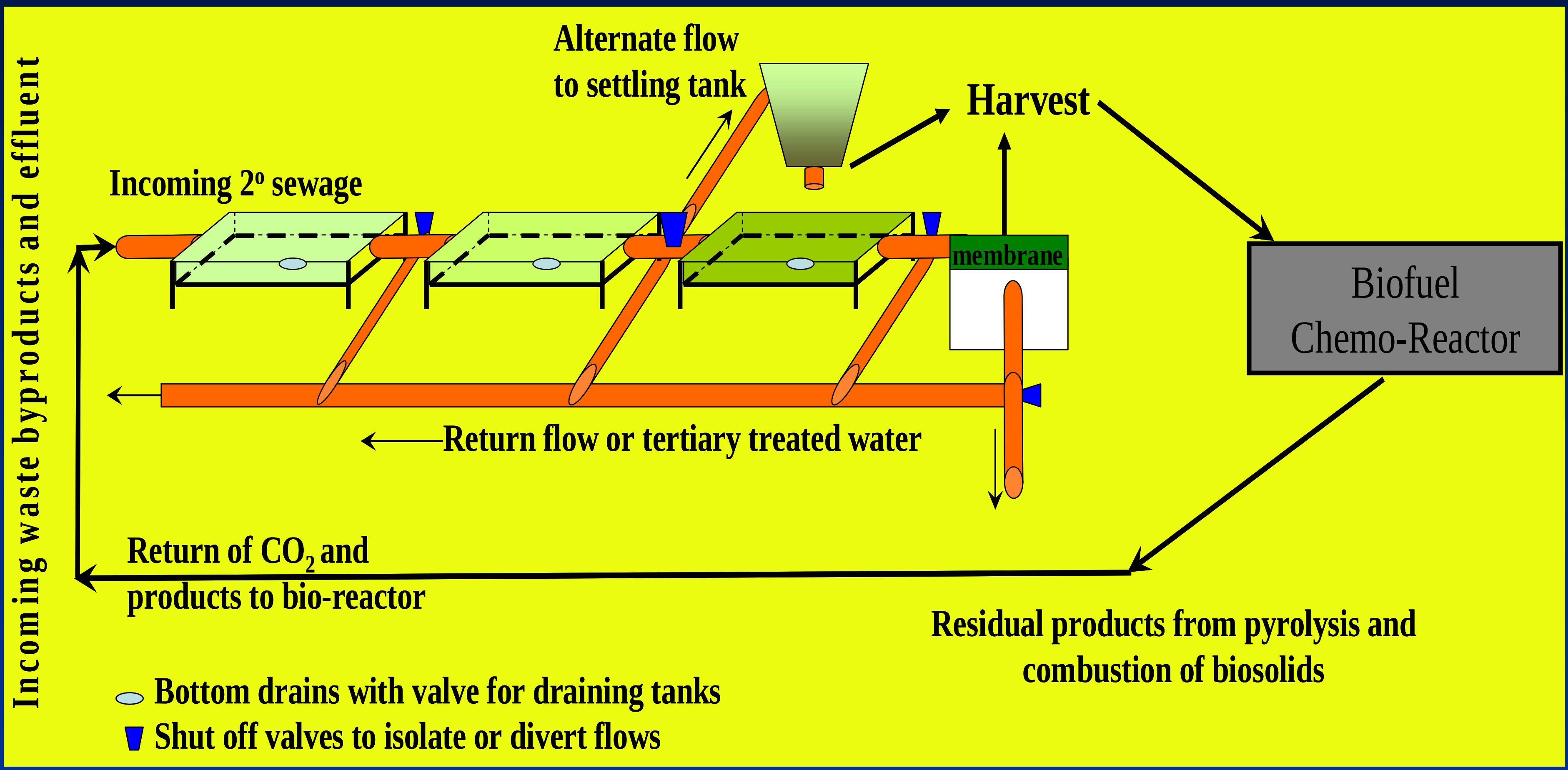
1. VA has plenty of sunshine on its coastal plain (east of the Fall Line)
2. VA has many coastal areas amenable to locating algal ponds on flat land and in close proximity to fossil-fueled power plants (CO_2 source) and municipal wastewater treatment facilities (nutrient source)
3. VA's coastal waterways are choked with algae blooms which could be harvested and used as an additional biodiesel feedstock, preventing their decay and de-oxygenation of our waterways
4. VA has the customers:
    a. *US and State government vehicle fleets*
    b. *Military installations with high liquid fuel needs*
    c. *Emerging biodiesel fueling infrastructure (Arlington, Harrisonburg)*

Biodiesel Algal Culture Research

ODU responsible for overall direction and preparation of final report

- *Which species and environmental conditions yield highest biodiesel yields?*
- *Which techniques for biomass harvest and conversion to biodiesel are most energy-efficient and cost-effective?*
- *Testing and improvement of biodiesel product using research engine, including emissions testing*
- *Coupling of biodiesel algal cultures to wastewater plant effluent for removal of N and P and enhanced algal growth*
- *Feasibility study and assessment of major research requirements to improve algal biodiesel production efficiency*

Bio-Reactor: Production of Algal Biomass



Wastewater Interfaces for Bioreactor

Free tertiary treatment

- *Alternative solution for meeting new nutrient discharge criteria*
- *Potential sale of biofuels produced*
- *Potential sale of nutrient credits generated through N and P removal*

Algal biomass from recycled nutrients, CO_2 and organic matter

- *Effluent nutrients stimulate algal growth*
- *Potential boost in lipid production from heterotrophic growth*

Use available/adaptable technologies

- *Take advantage of continuous high nutrient flow*
- *Harvesting technologies (e.g., flocculation)*

Test Facility: Virginia Initiative Plant, Hampton Roads Sanitation District

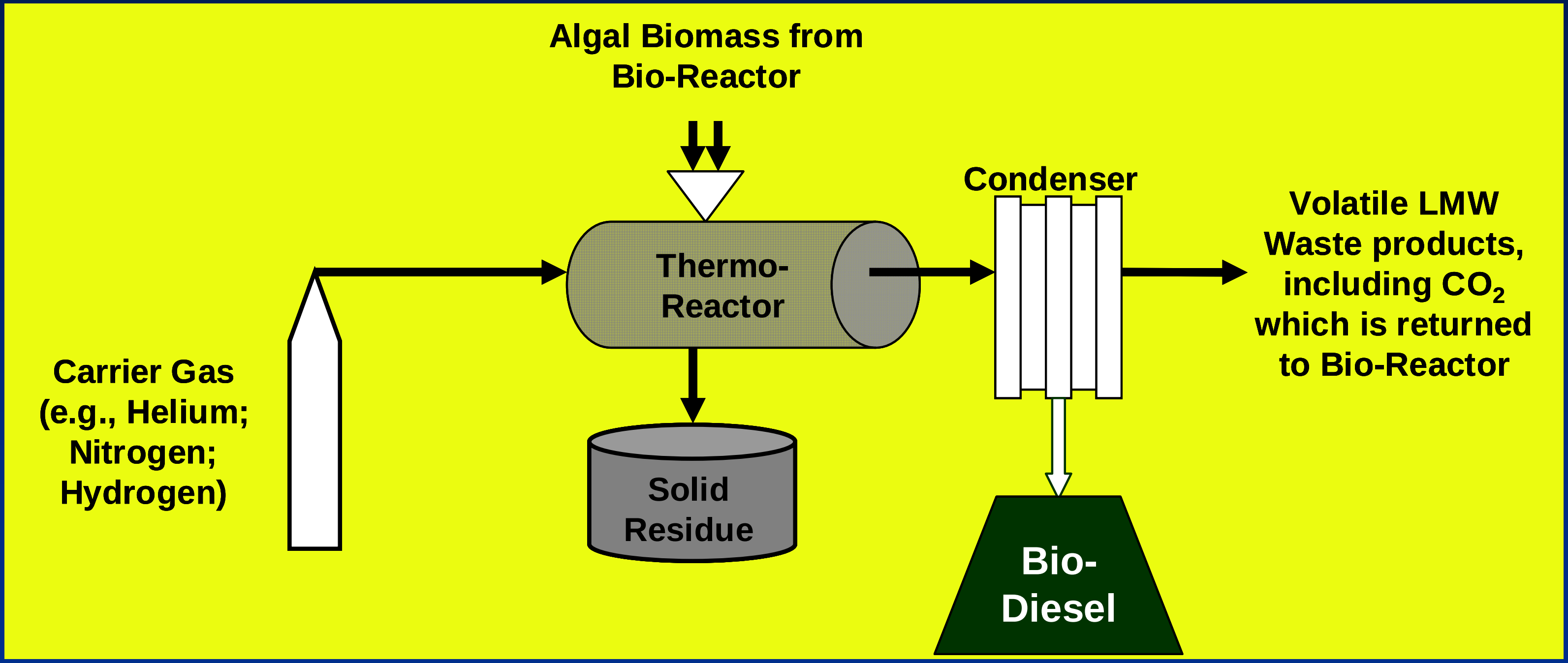
Research Plans for FY 2008 and beyond

1. Design a bench-scale and pilot-scale facility for converting various algae to diesel to provide proof of concept for the biological and chemical process being designed

2. Produce diesel fuels in sufficient amounts to test production efficiency and characteristics

3. Scale up to full-size facility in cooperation with industry partners

Chemo-Reactor: Conversion of Algal Biomass to Biodiesel



Recent Report about VCERC Algal BioDiesel

Story aired on the 5:30 edition of WVEC-TV News (Channel 13, ABC) on 6 Nov 2007, Craig Moeller reporting

www.wvec.com/video/index.html?nvid=190300&shu=1607_algae_to_fuel.1ddc1163a.html

Visit www.vcerc.org for More Information

Virginia Coastal Energy Research Consortium - Windows Internet Explorer

http://www.vcerc.org/

File Edit View Favorites Tools Help

Virginia Coastal Energy Research Consortium

Page Tools

Virginia Coastal Energy Research Consortium

Home | About VCERC | Research | Board Members | Symposium | News | Related Links |

University Partners

- Old Dominion University
- Virginia Institute of Marine Science
- Virginia Tech Advanced Research Institute
- James Madison University
- Norfolk State University
- Virginia Commonwealth University
- University of Virginia
- Hampton University

Government Partners

- Hampton Roads Clean Cities Coalition
- Hampton Roads Sanitation District - Virginia Initiative Plant
- Hampton Roads Technology Council
- Virginia Department of Mines, Minerals & Energy
- Virginia Marine Resources Commission

Industry Partners

- Science Applications International Corporation
- Virginia Manufacturers Association
- Virginia Maritime Association

In August 2006 an Act of the Virginia General Assembly passed the landmark "Virginia Energy Plan" which establishes a foundation for the research and development of future renewable energy resources.

The Virginia Coastal Energy Research Consortium (VCERC) was established in Chapter 6 of the Virginia Energy Plan. The VCERC was created to *"serve as an interdisciplinary study, research, and information resource for the Commonwealth on coastal energy issues"* with an initial focus on offshore winds, waves, and marine biomass.

The Consortium is charged with the following responsibilities:

- consult with the General Assembly, federal, state, and local agencies, nonprofit organizations, private industry and other potential users of coastal energy research;
- establish and administer agreements with other universities of the Commonwealth to carry out research projects relating to the feasibility of recovering fuel gases from methane hydrates and increasing the Commonwealth's reliance on other forms of coastal energy;
- disseminate new information and research results;
- apply for grants made available pursuant to federal legislation, including but not limited to research and development calls from the federal government and from other sources; and
- facilitate the application and transfer of new coastal energy technologies.

Further, the Consortium is governed by a board which consists of fourteen members - with representatives from each of the eight partner universities and six government and industry partners. The Consortium is located at Old Dominion University in Norfolk.

OFFSHORE WIND questions?
Email: hagerman@vt.edu

MARINE BIOFUELS questions?
Email: AStubbin@odu.edu