Mapping Operation & Maintenance Strategy for U.S. Offshore Wind Farms

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2nd US Offshore Wind Conference & Expo

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Overview of Collaboration

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Reference O&M Concepts for Near and Far Offshore Wind Farms

- Understand impacts of meteorological ocean (metocean) conditions on operation and maintenance (O&M) costs
- O&M study of five offshore wind plants in the North Sea
- Tool: ECN O&M Calculator
- December 2016

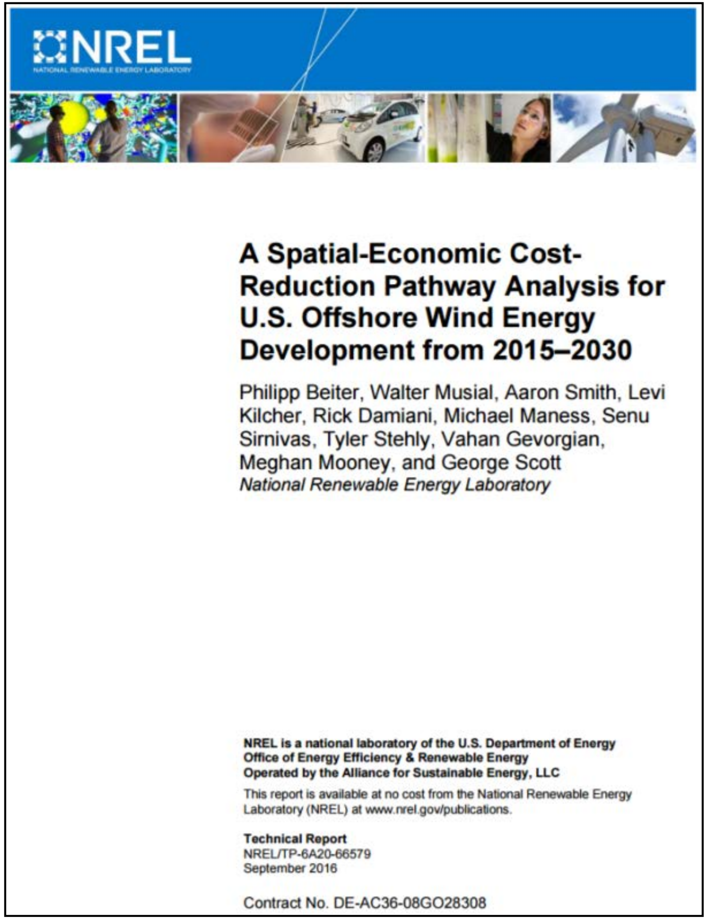
A Spatial-Economic Cost-Reduction Pathway Analysis for U.S. Offshore Wind Energy Development from 2015-2030

- Quantify the impact of spatial characteristics of the U.S. offshore wind resource area on levelized cost of energy (LCOE)
- O&M specific tool: ECN O&M Tool
- September 2016

Mapping O&M Strategy for U.S. Offshore Wind Farms

- Collaboration between ECN and NREL
- O&M study of six offshore wind plants in the United States
- Tool: ECN O&M Calculator
- Anticipated joint publication 2017

NREL's Spatial-Economic Analysis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A Spatial-Economic Cost-Reduction Pathway Analysis for U.S. Offshore Wind Energy Development from 2015–2030

Philipp Beiter, Walter Musial, Aaron Smith, Levi Kilcher, Rick Damiani, Michael Maness, Senu Sirnivas, Tyler Stehly, Vahan Gevorgian, Meghan Mooney, and George Scott
National Renewable Energy Laboratory

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Technical Report
NREL/TP-6A20-66579
September 2016

Contract No. DE-AC36-08GO28308

CAPEX: Capital expenditures
OPEX: Operations and maintenance expenditures

The analysis considers:

- Four access strategies
  - Close to shore
  - Advanced close to shore
  - Medium distance
  - Far shore
- Three types of large maintenance strategies
  - In situ
  - Tow to port
  - Tow to assembly area

Key variables:

1. Metocean conditions
2. Distance from O&M port

Representative Metocean Conditions

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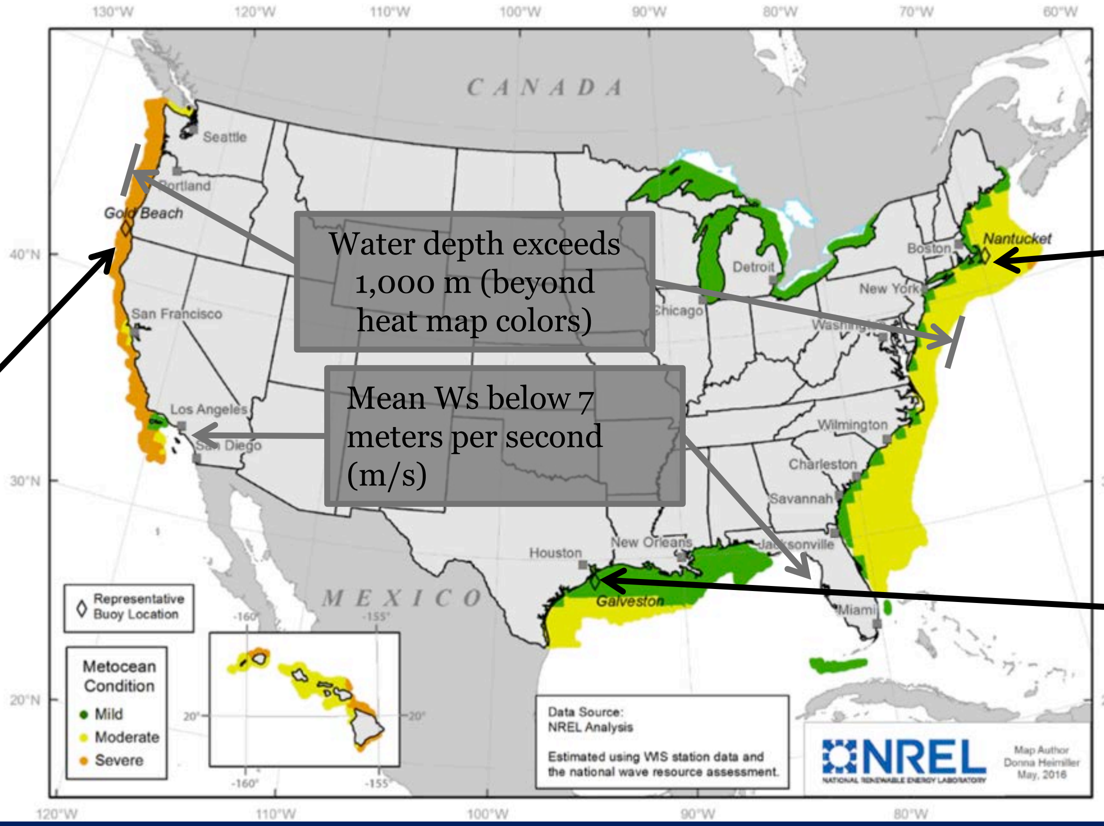

Severe:
- Hs ~2.5 meters (m)

Moderate:
- Hs ~1.39 m

Mild:
- Hs ~0.88 m

Representative metocean conditions do not consider extreme weather events (e.g., hurricanes) or site-specific features (e.g., ice)

Distance from O&M Port and Access Strategies

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Distance to O&M Port (km)	Metocean Conditions: "Mild" Site Mean Hs = 0.88 m Mean Wind Speed = 6.12 m/s[a]			"Moderate" Site Mean Hs = 1.39 m Mean Wind Speed = 7.32 m/s[a]			"Severe" Site Mean Hs = 2.50 m Mean Wind Speed = 6.61 m/s[a]		
10	CS[a]	MD[b]	FS[c]	CS+[d]	MD	FS	CS+	MD	FS
30	CS	MD	FS	CS+	MD	FS	CS+	MD	FS
50	CS	MD	FS	CS+	MD	FS	CS+	MD	FS
70	CS	MD	FS	CS+	MD	FS	CS+	MD	FS
90	***	MD	FS	***	MD	FS	***	MD	FS
110	***	MD	FS	***	MD	FS	***	MD	FS
150	***	MD	FS	***	MD	FS	***	MD	FS
200	***	***	FS	***	***	FS	***	***	FS
300	***	***	FS	***	***	FS	***	***	FS
400	***	***	FS	***	***	FS	***	***	FS
500	***	***	FS	***	***	FS	***	***	FS

[a] Mean wind speed at 10 m above mean sea level

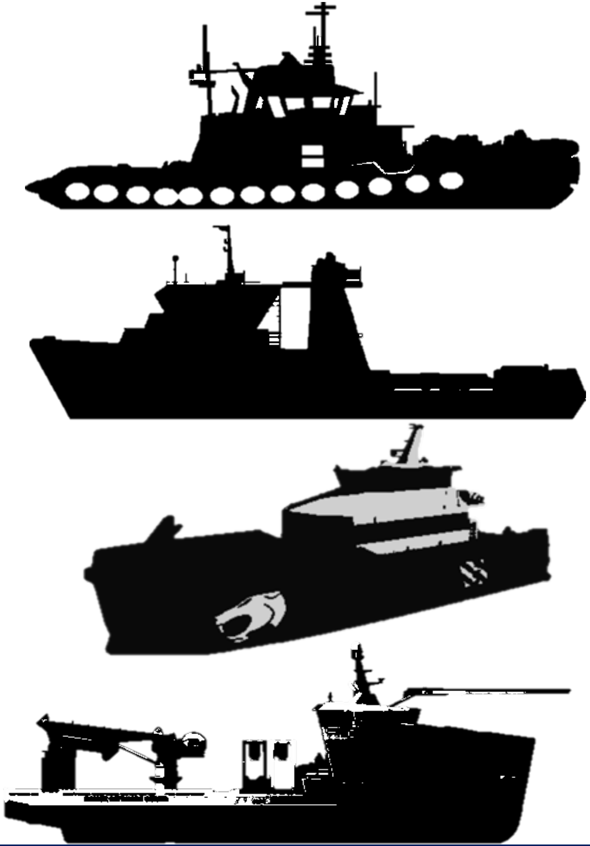
[a] Close to shore

[b] Medium distance

[c] Far shore

[d] Advanced close to shore

*** Distance exceeds the 2-hour limit for transporting technicians between the O&M port and the project



Crew Transfer Vessel (CTV)

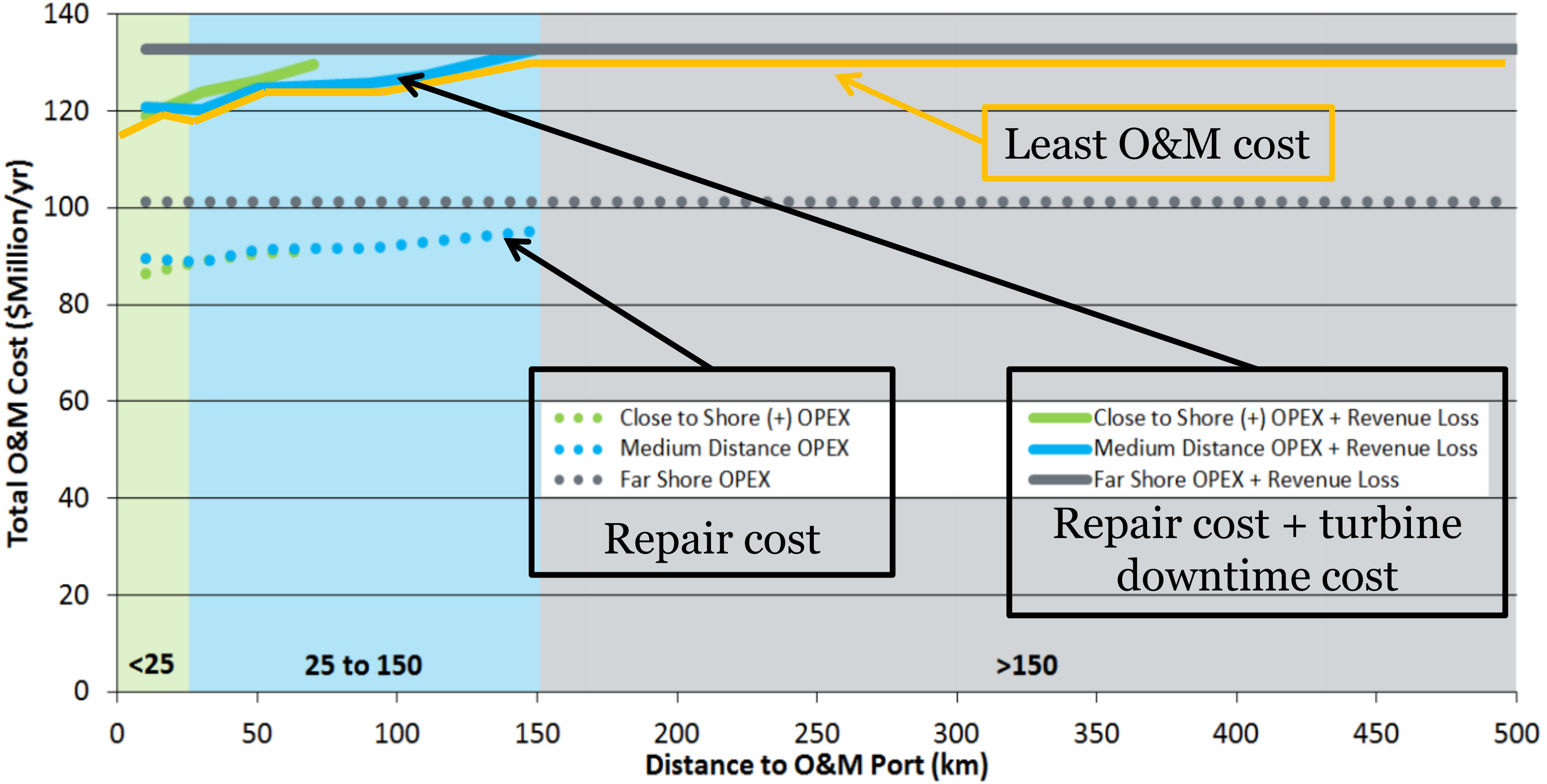
Crew Transfer Vessel Advanced (CTV+)

Surface Effect Ship (SES)

Service Operations Vessel (SOV)

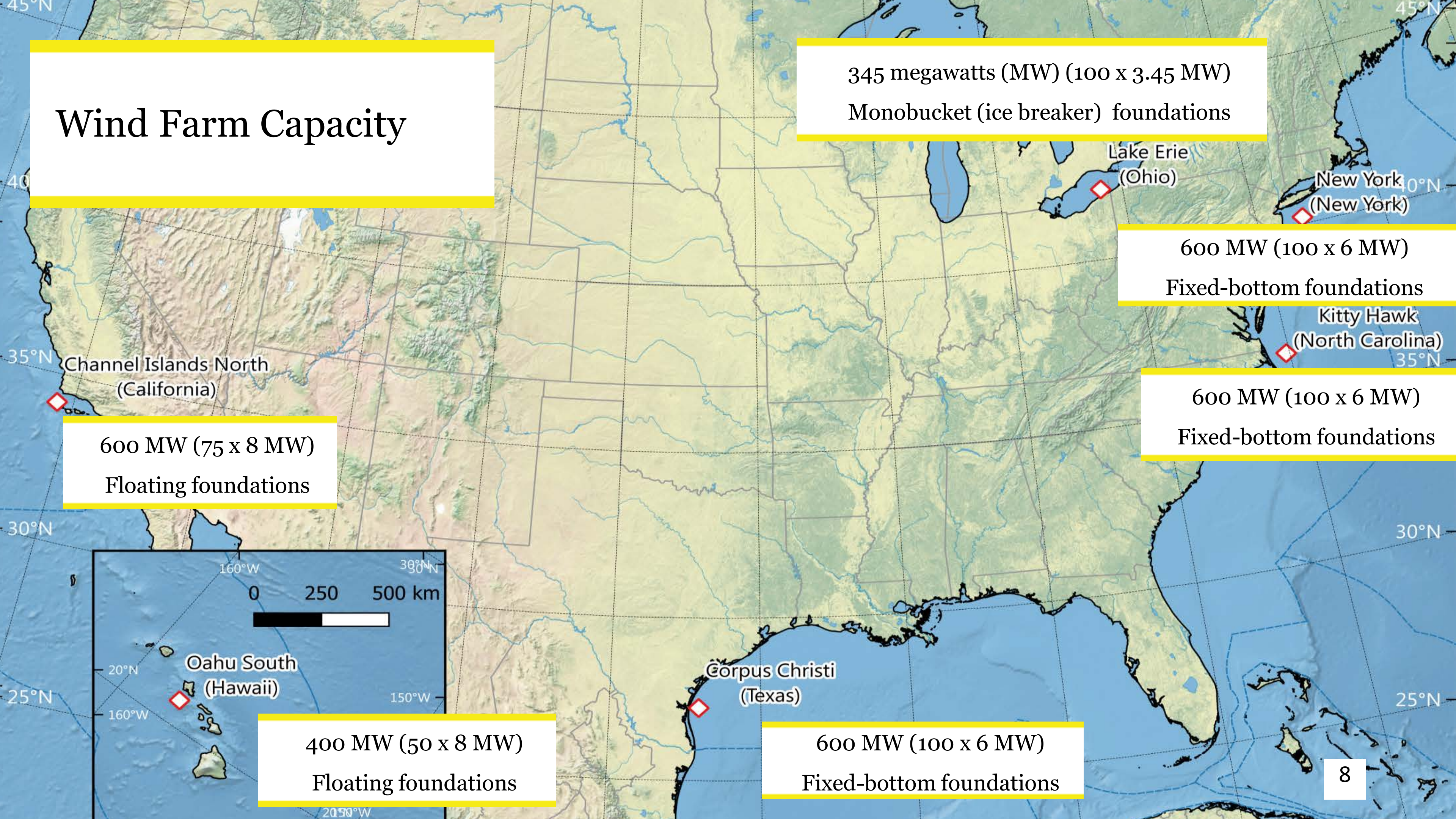
Approximately 198 model runs to determine O&M costs for the various combinations of access strategies and large maintenance activities

Total O&M Costs for Moderate Site with Turbine Supported by a Fixed-Bottom Substructure

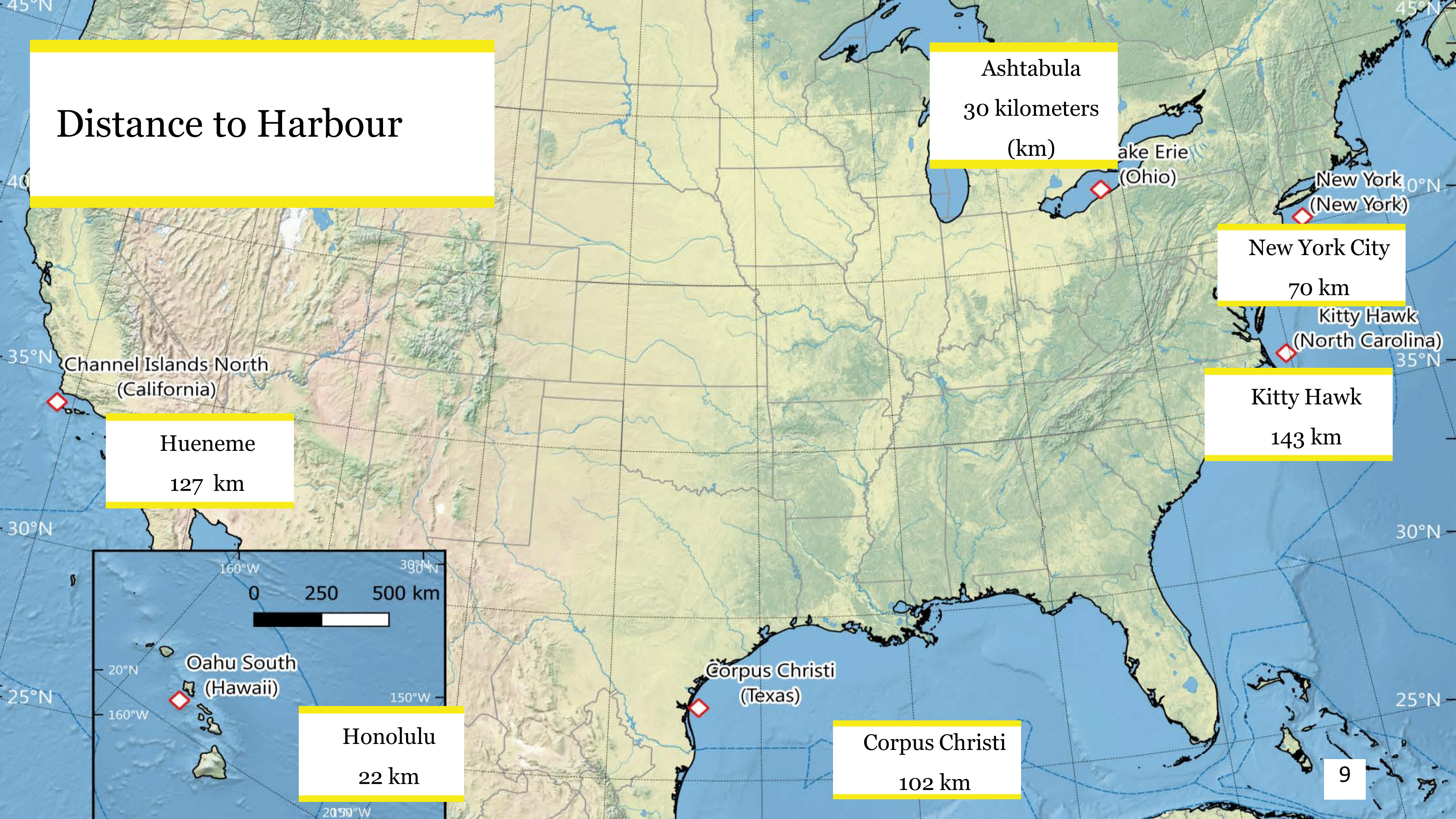


Metocean conditions tend to drive the O&M cost compared to the distance from the O&M port

Six U.S. Offshore Wind Sites


Wind Farm Capacity
345 megawatts (MW) (100 x 3.45 MW)
Monobucket (ice breaker) foundations
Lake Erie (Ohio)
New York (New York)
600 MW (100 x 6 MW)
Fixed-bottom foundations
Kitty Hawk (North Carolina)
600 MW (100 x 6 MW)
Fixed-bottom foundations
Channel Islands North (California)
600 MW (75 x 8 MW)
Floating foundations
Oahu South (Hawaii)
400 MW (50 x 8 MW)
Floating foundations
Corpus Christi (Texas)
600 MW (100 x 6 MW)
Fixed-bottom foundations
0 250 500 km
45°N
40°N
35°N
30°N
25°N
20°N
160°W
150°W

Distance to Harbour



Ashtabula
30 kilometers
(km)

New York City
70 km

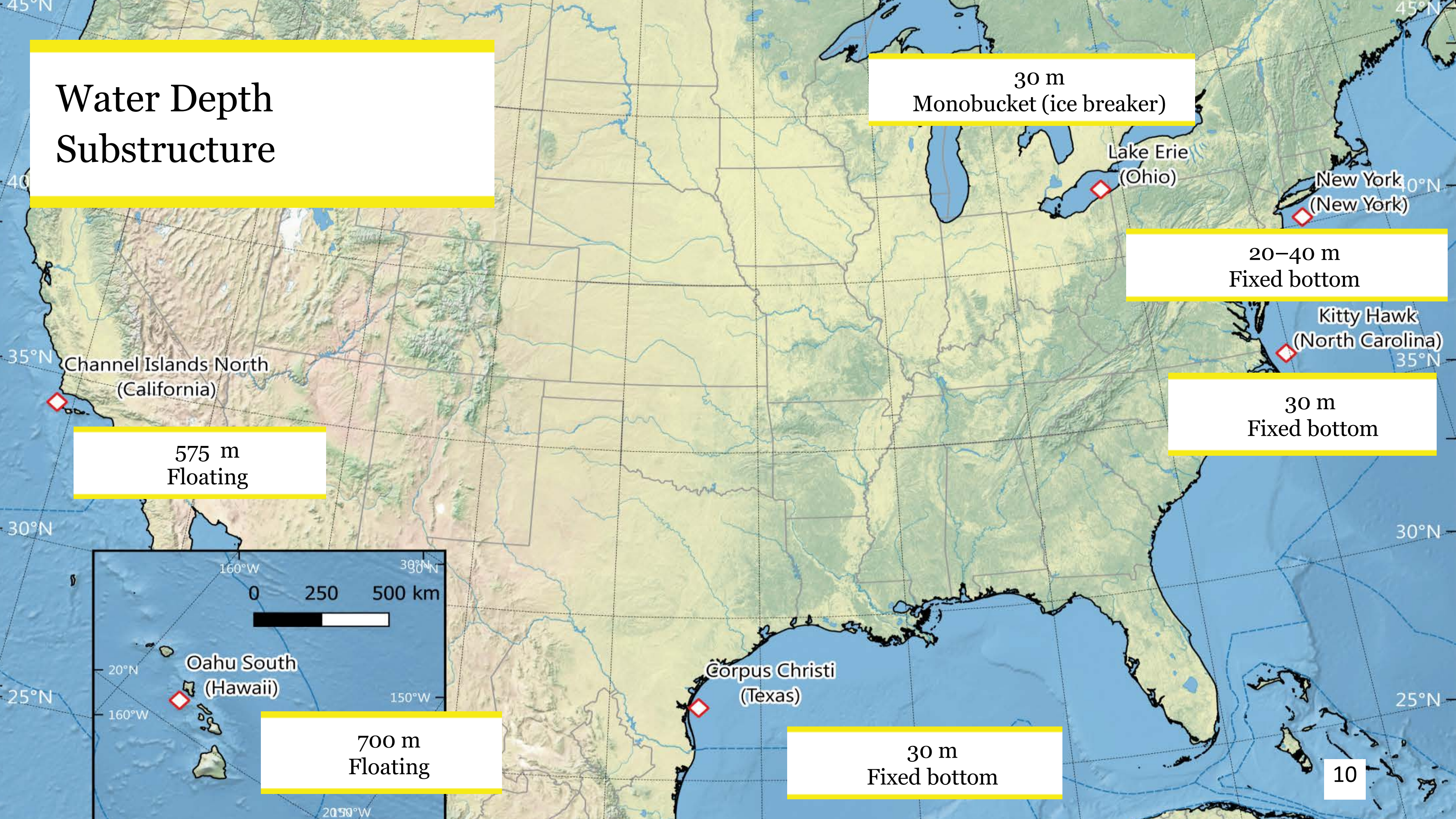
Kitty Hawk
143 km

Hueneme
127 km

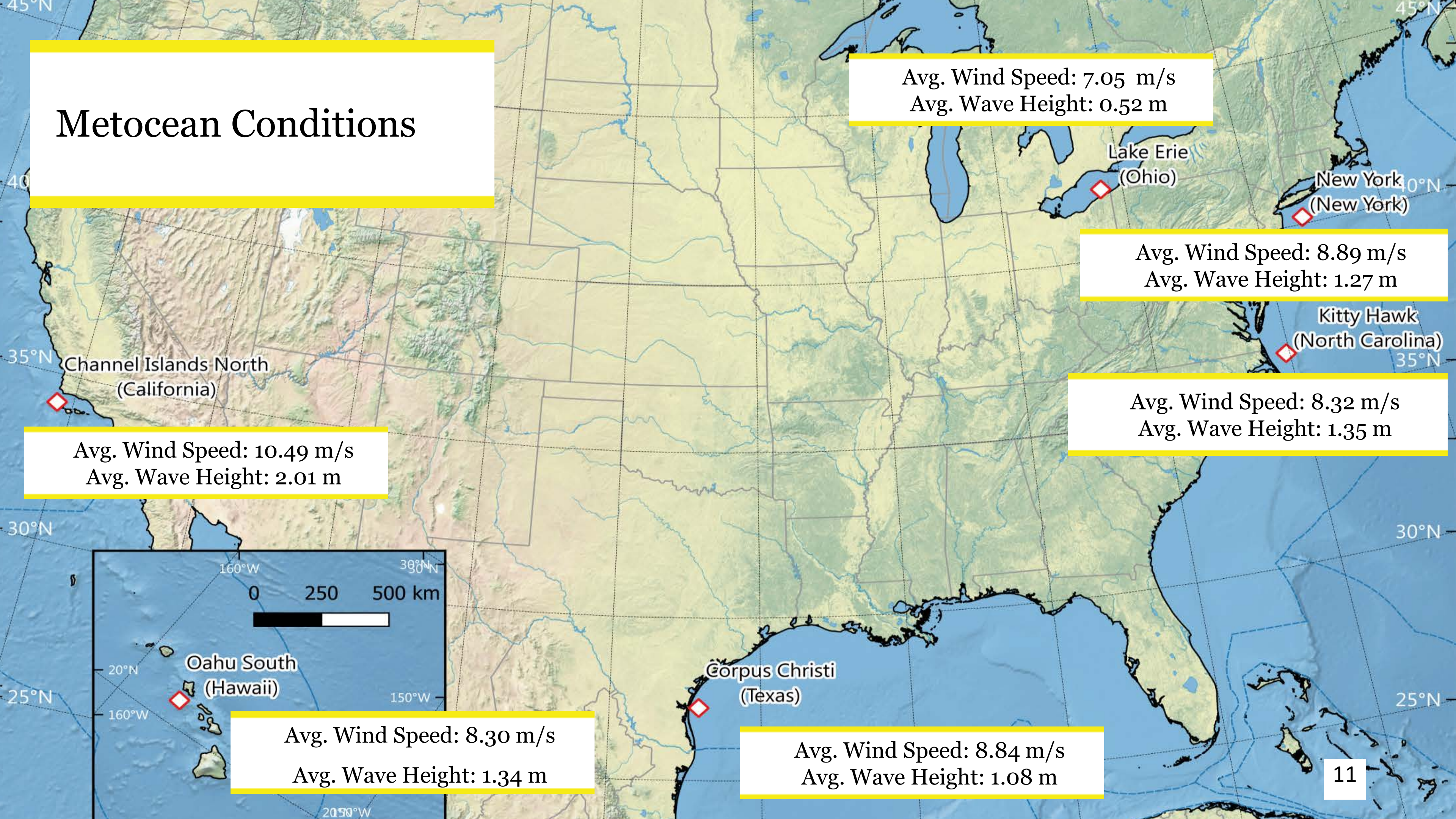
Honolulu
22 km

Corpus Christi
102 km

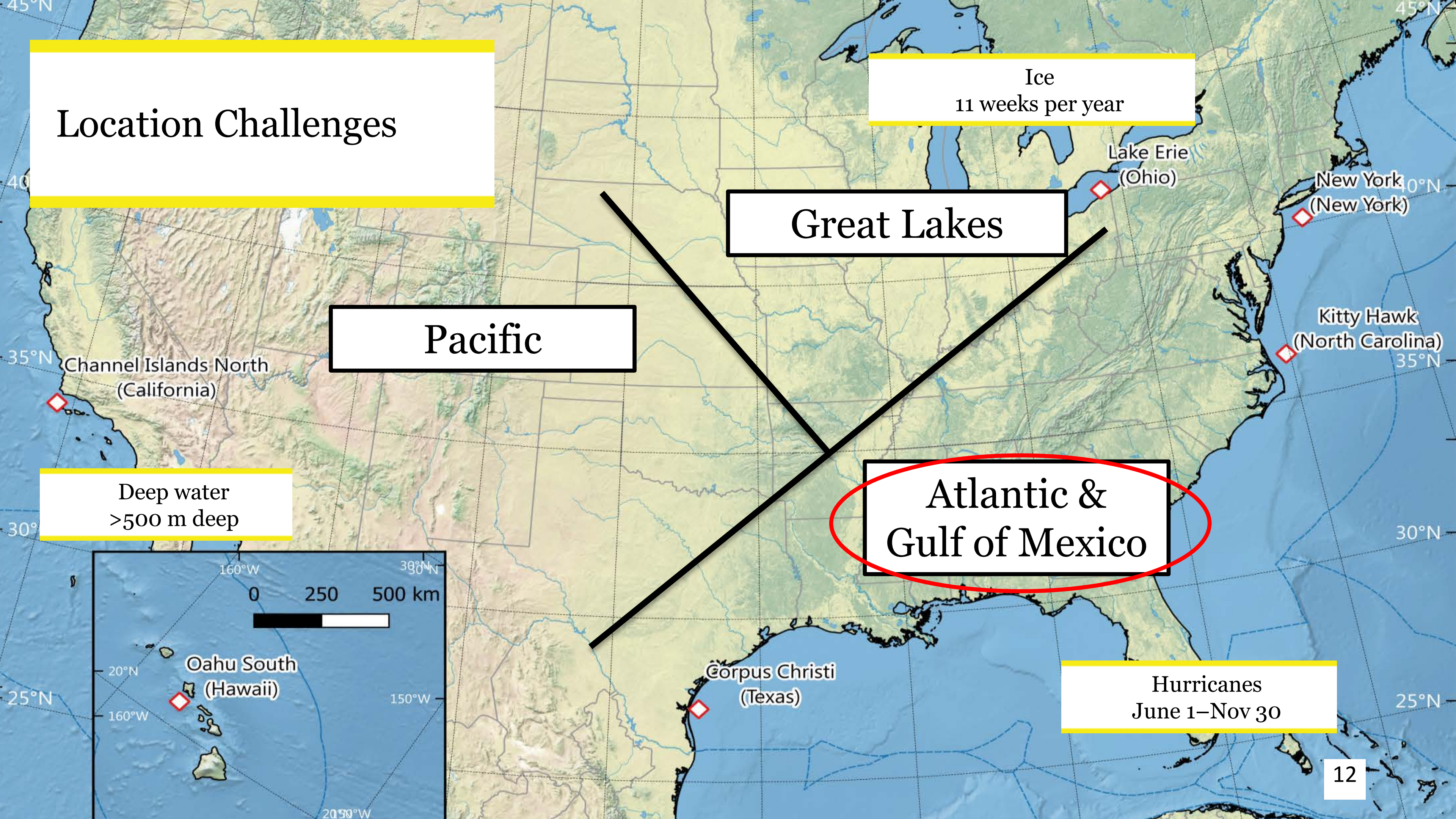
Water Depth Substructure



Metocean Conditions



Location Challenges




Atlantic & Gulf of Mexico; Gemini (North Sea)
Gemini
Comparison
New York
Kitty Hawk
Gulf of Mexico
60°N
40°N
20°N
United States of America
Mexico
Colombia
France
Spain
Algeria
Libya
Mauritania
Mali
Niger
Nigeria

Gemini (North Sea)

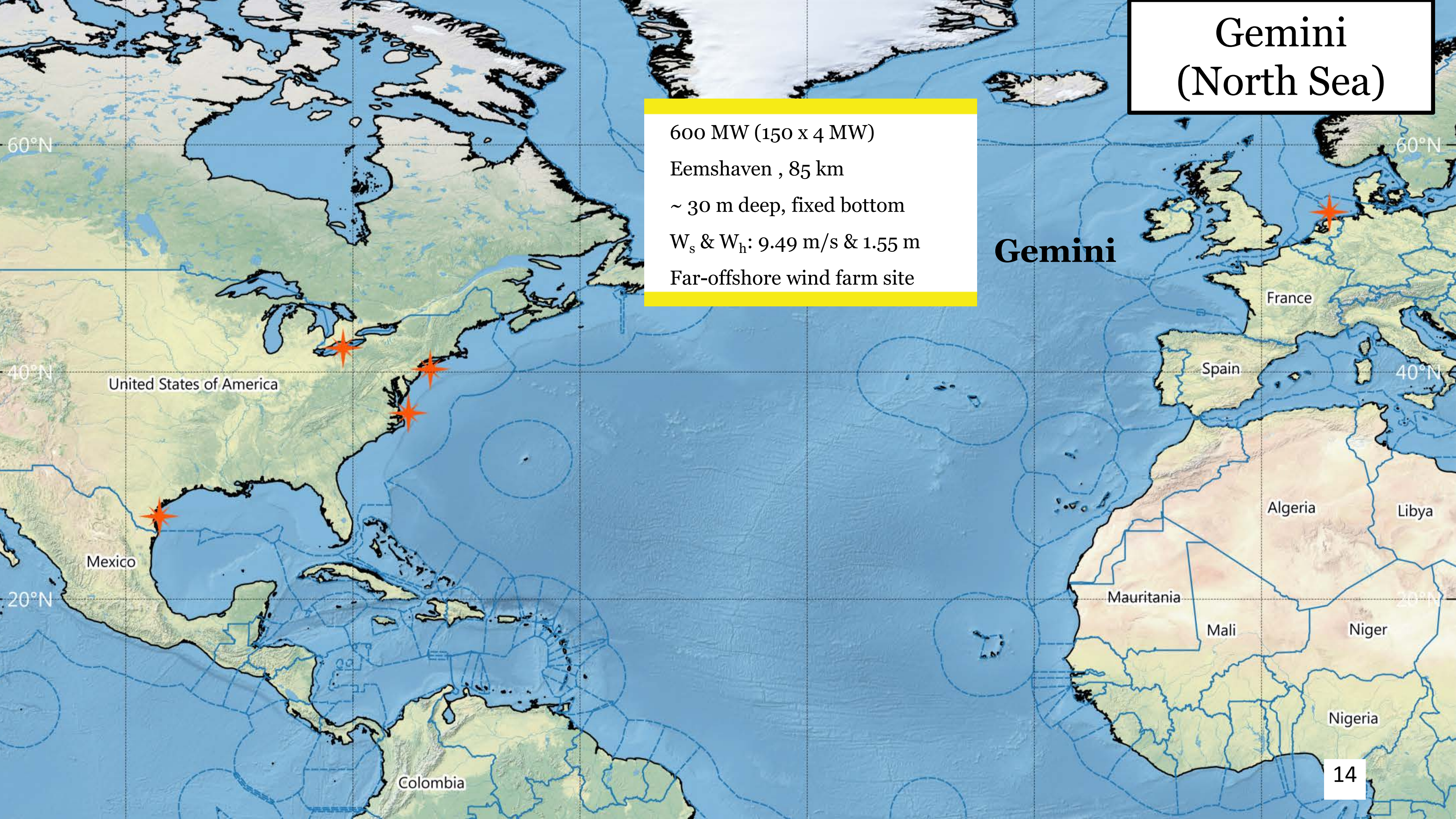
600 MW (150 x 4 MW)

Eemshaven , 85 km

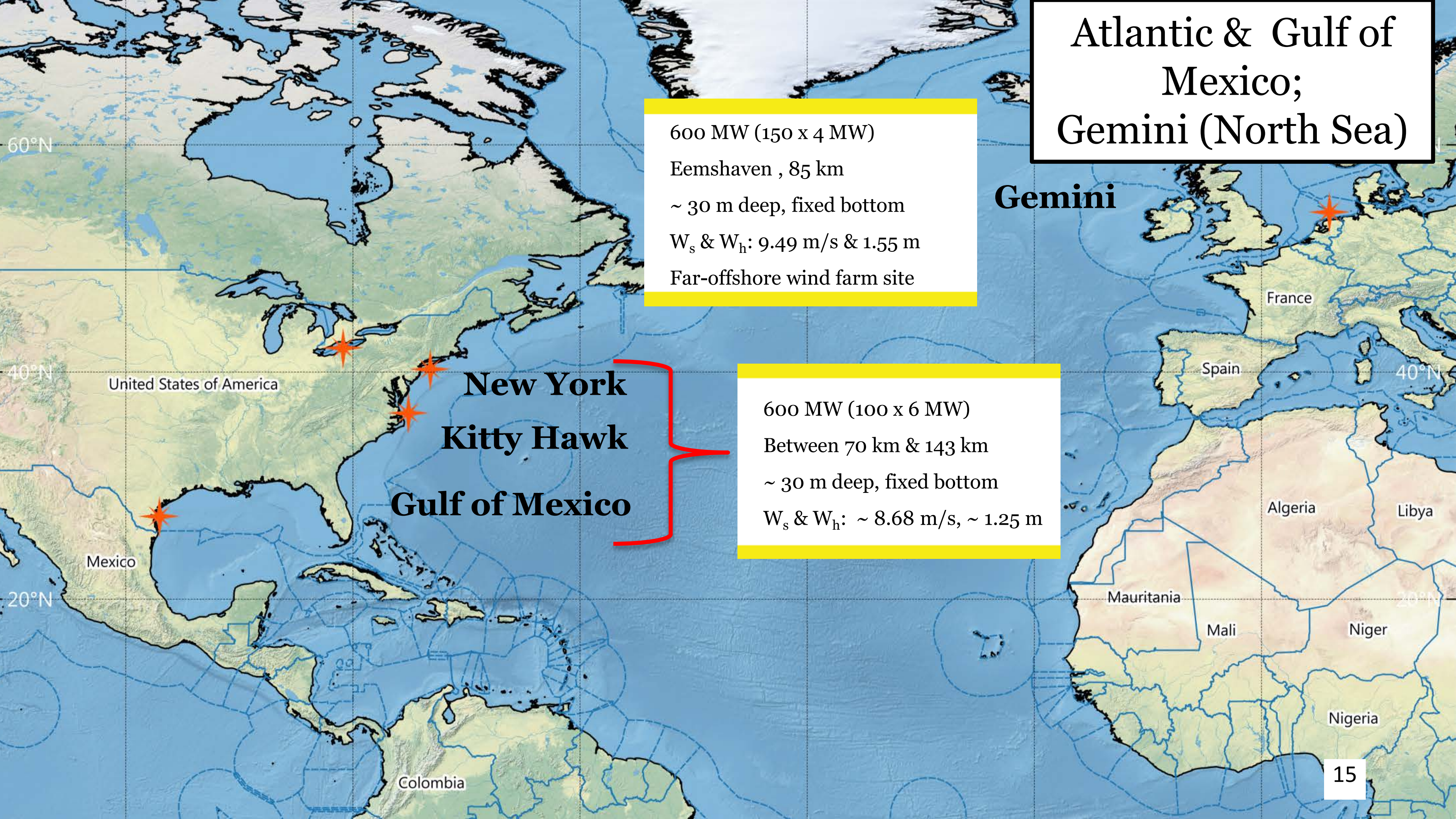
~ 30 m deep, fixed bottom

W_s & W_h: 9.49 m/s & 1.55 m

Far-offshore wind farm site

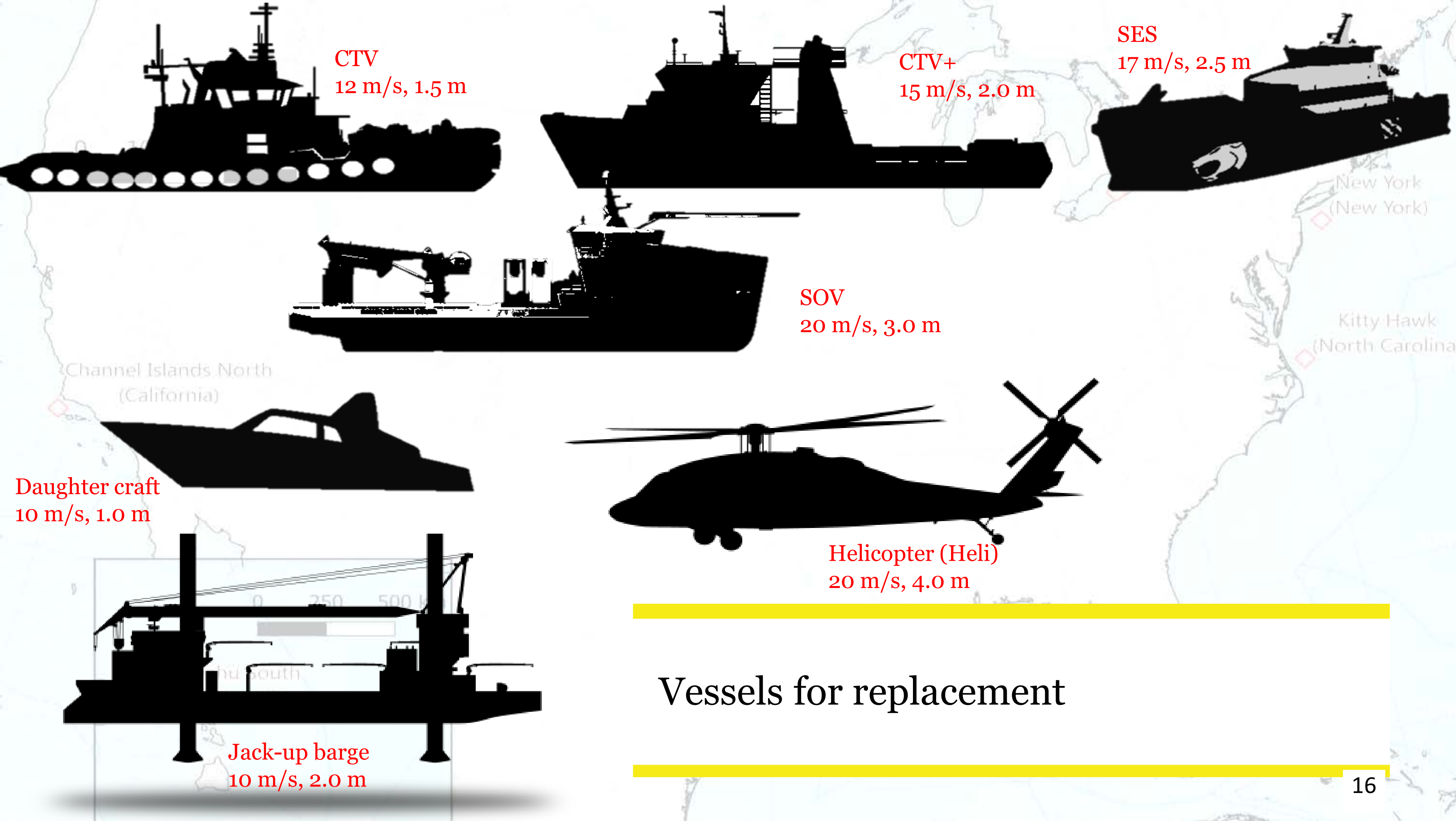


Atlantic & Gulf of Mexico; Gemini (North Sea)



600 MW (150 x 4 MW)
Eemshaven , 85 km
~ 30 m deep, fixed bottom
W_s & W_h: 9.49 m/s & 1.55 m
Far-offshore wind farm site

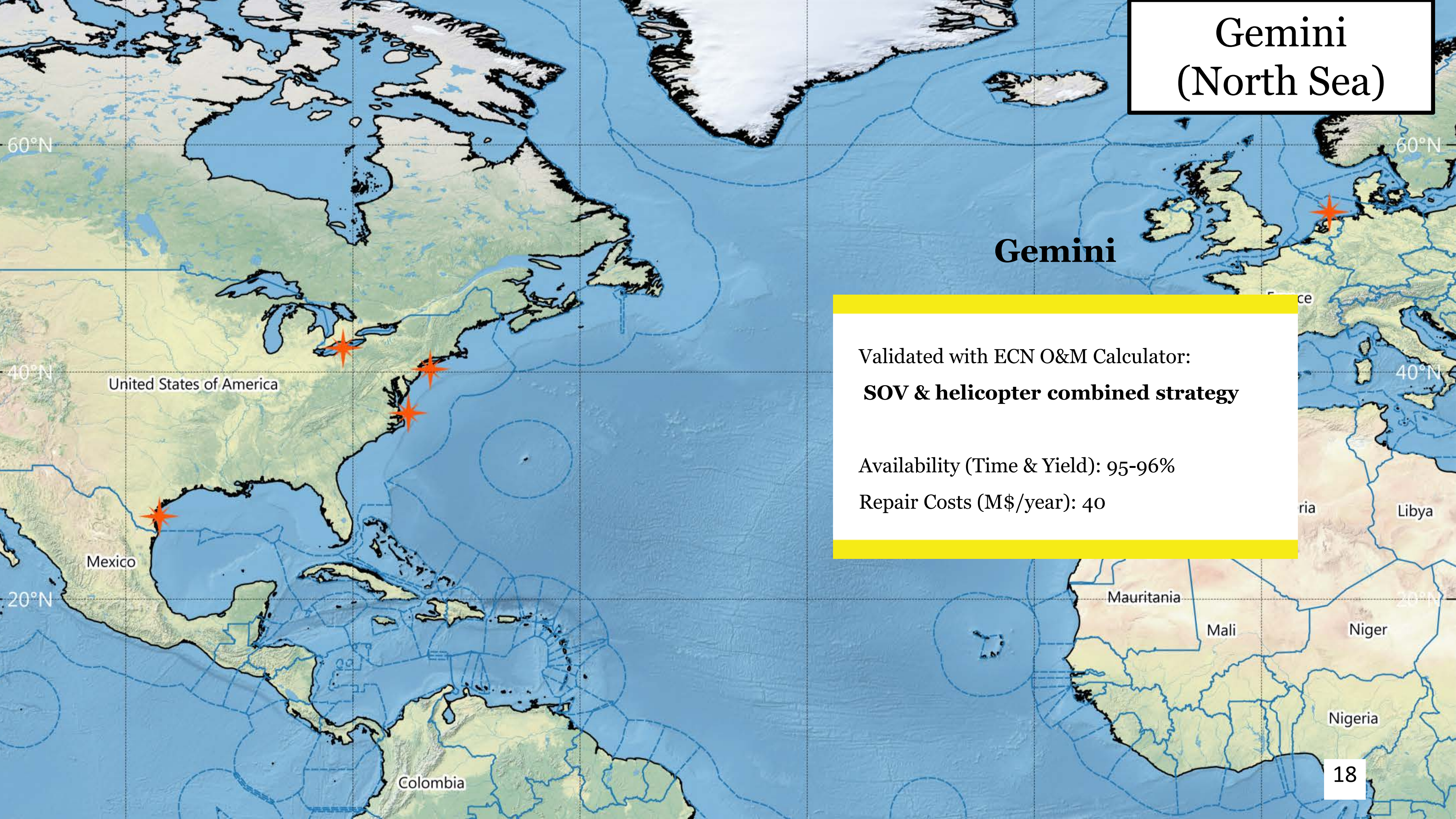
600 MW (100 x 6 MW)
Between 70 km & 143 km
~ 30 m deep, fixed bottom
W_s & W_h: ~ 8.68 m/s, ~ 1.25 m



Vessels for replacement

O&M Strategy: Selection of the logistic solution for Gemini

Gemini (North Sea)



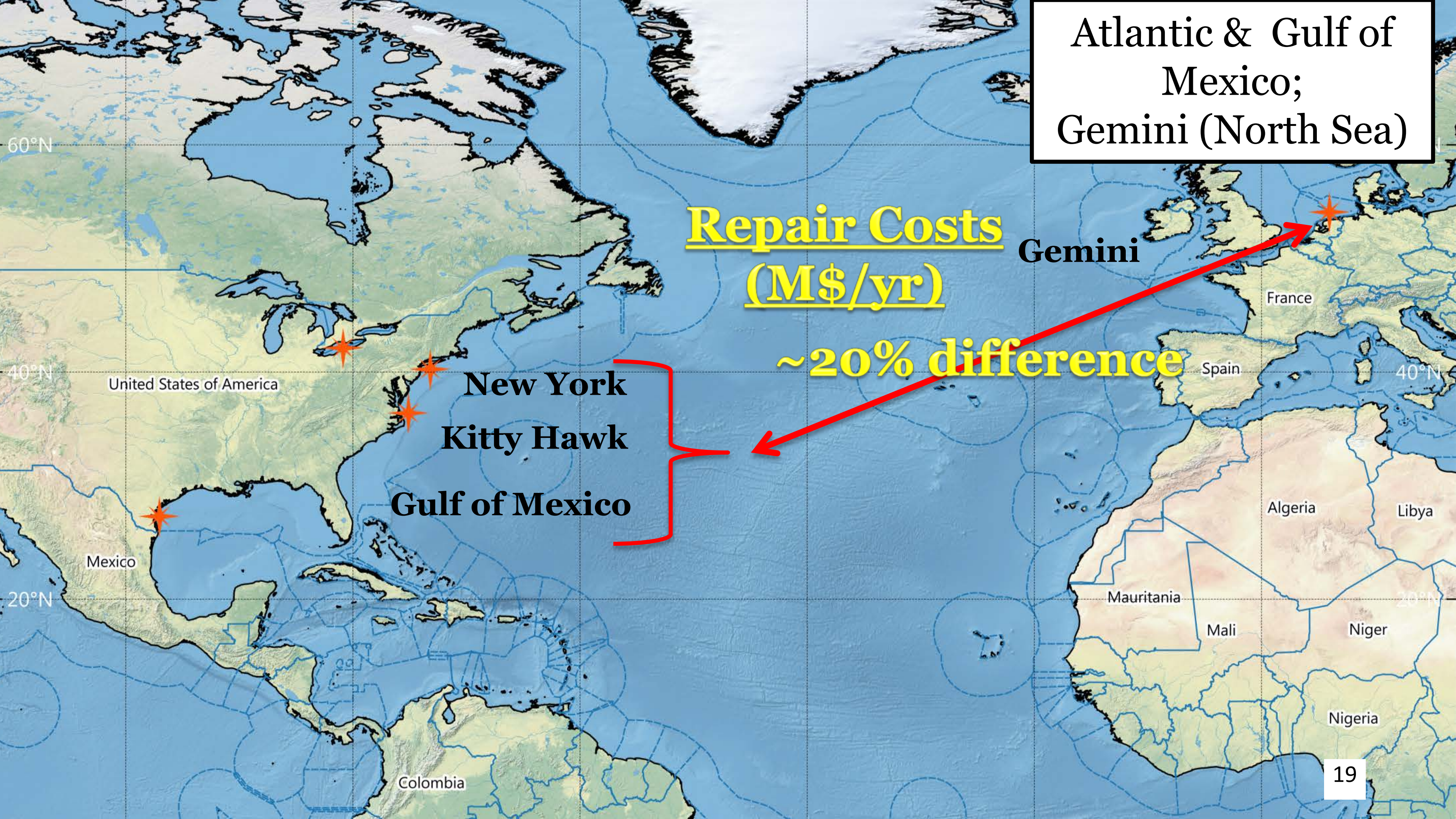
Validated with ECN O&M Calculator:

SOV & helicopter combined strategy

Availability (Time & Yield): 95-96%

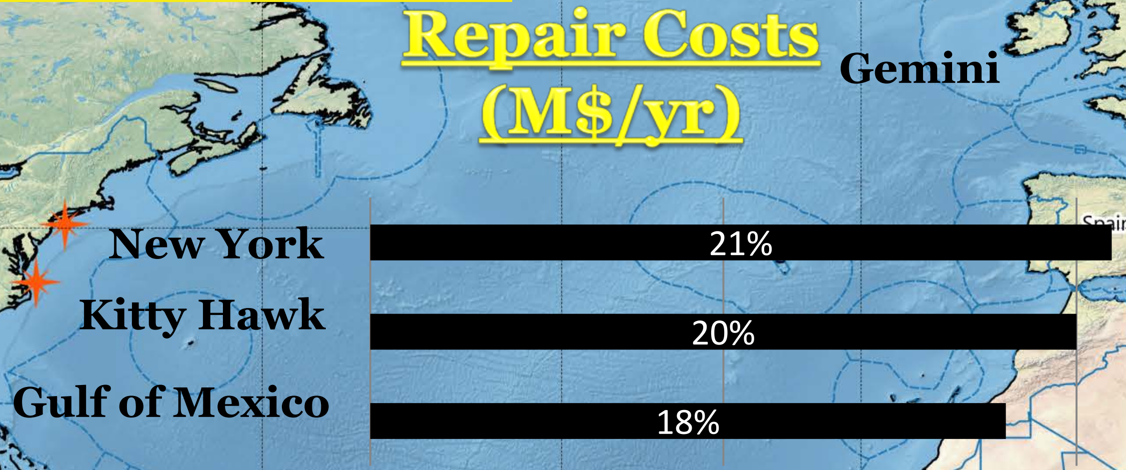
Repair Costs (M$/year): 40

Atlantic & Gulf of Mexico; Gemini (North Sea)



Difference in O&M Costs: United States & Europe

Atlantic & Gulf of Mexico;
Gemini (North Sea)



How to Reduce the Difference in Repair Costs?

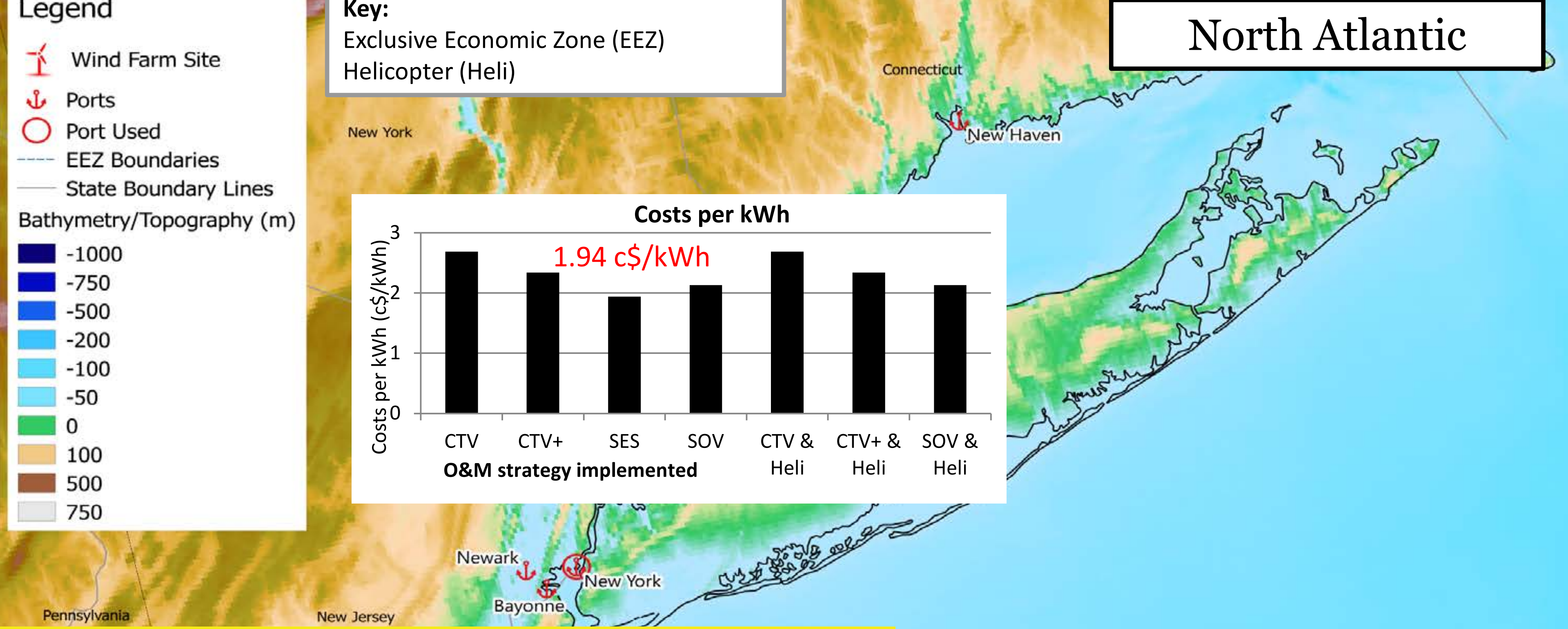
**Atlantic & Gulf of Mexico;
Gemini (North Sea)**

Optimisation and selection of the "most suitable O&M Strategy" with ECN O&M Calculator

- Criterion of min 95% availability (time and yield)
- Highest availability with a cost-effective solution

North Atlantic

Key:
Exclusive Economic Zone (EEZ)
Helicopter (Heli)



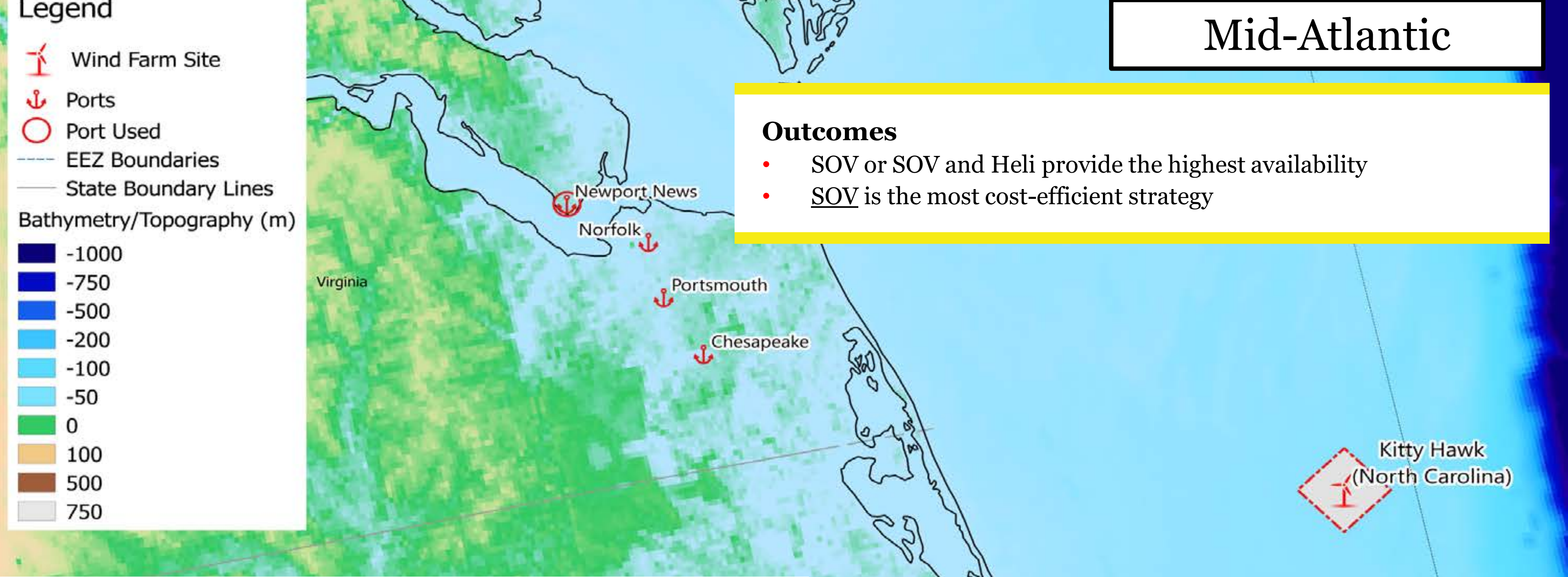
Outcomes

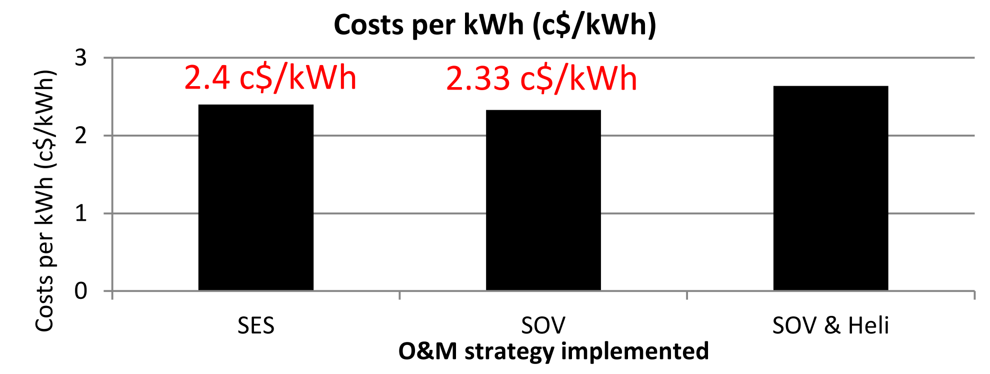
- SOV, SOV and Heli, and SES provide the best solutions in terms of availability (95%)
- SES is the most suitable O&M strategy

Mid-Atlantic

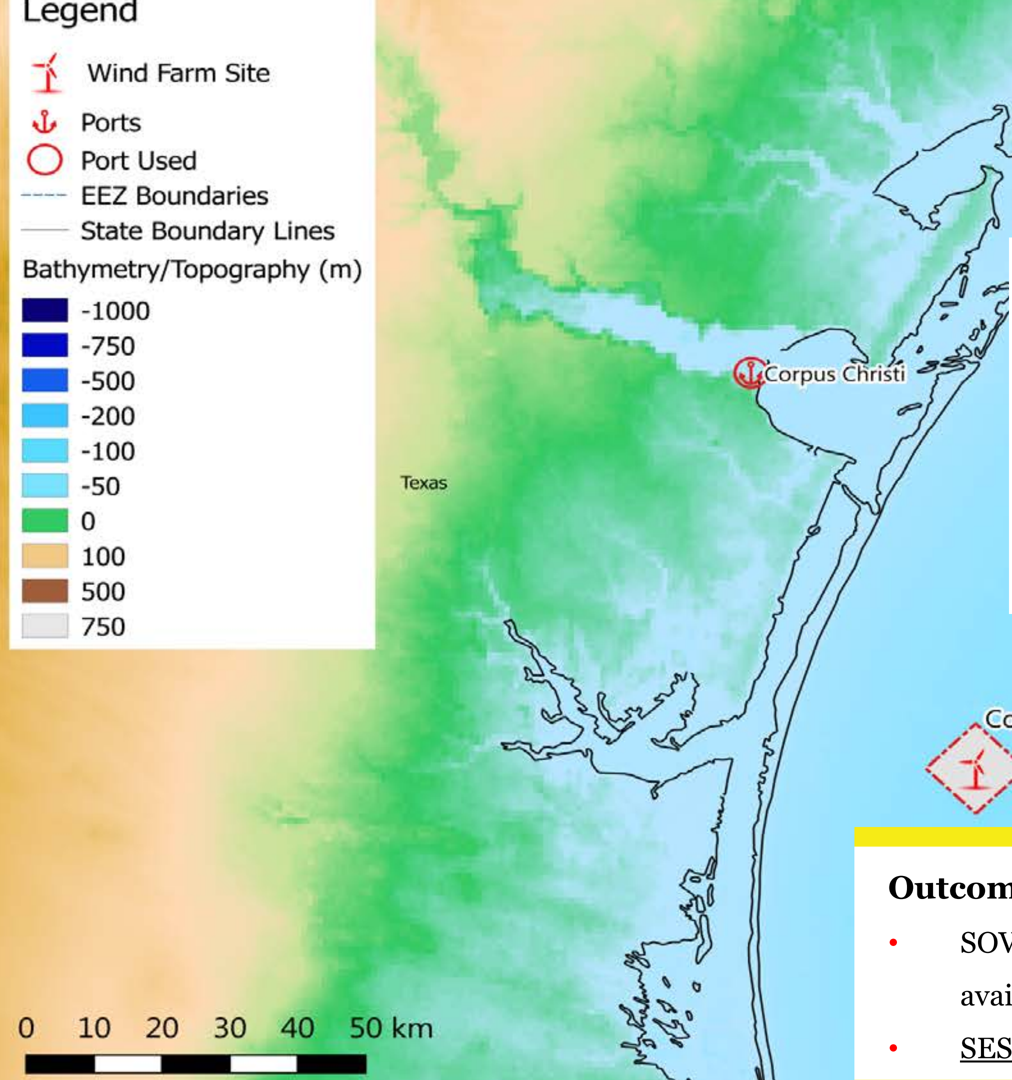
Outcomes

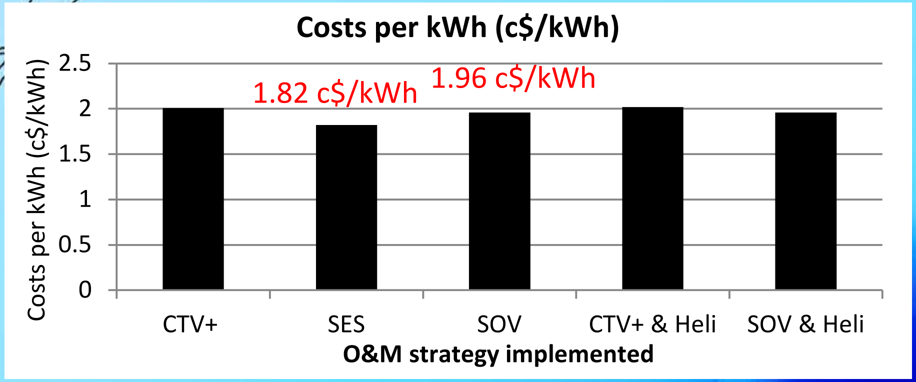
- SOV or SOV and Heli provide the highest availability
- SOV is the most cost-efficient strategy





Gulf of Mexico

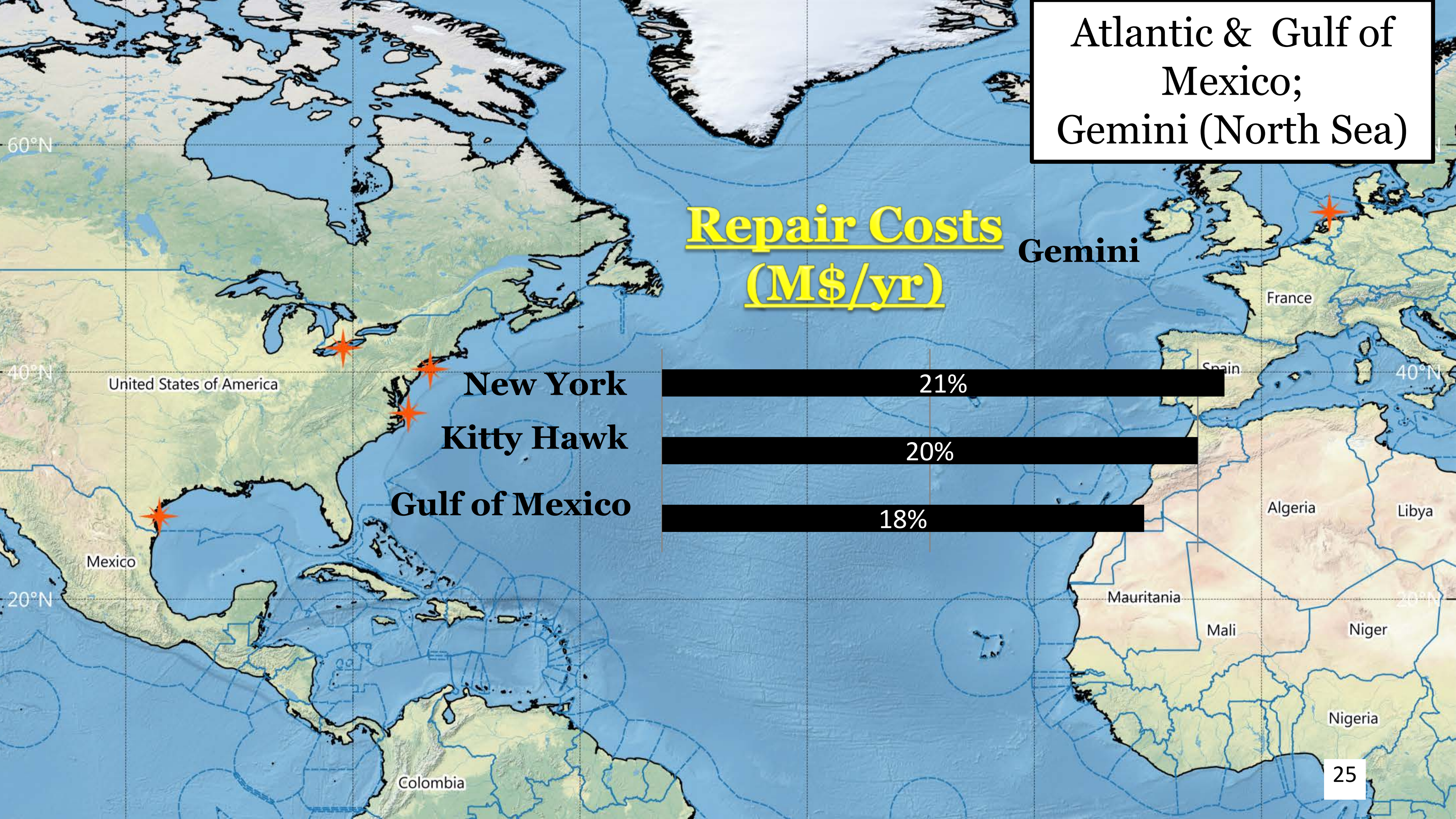




Outcomes

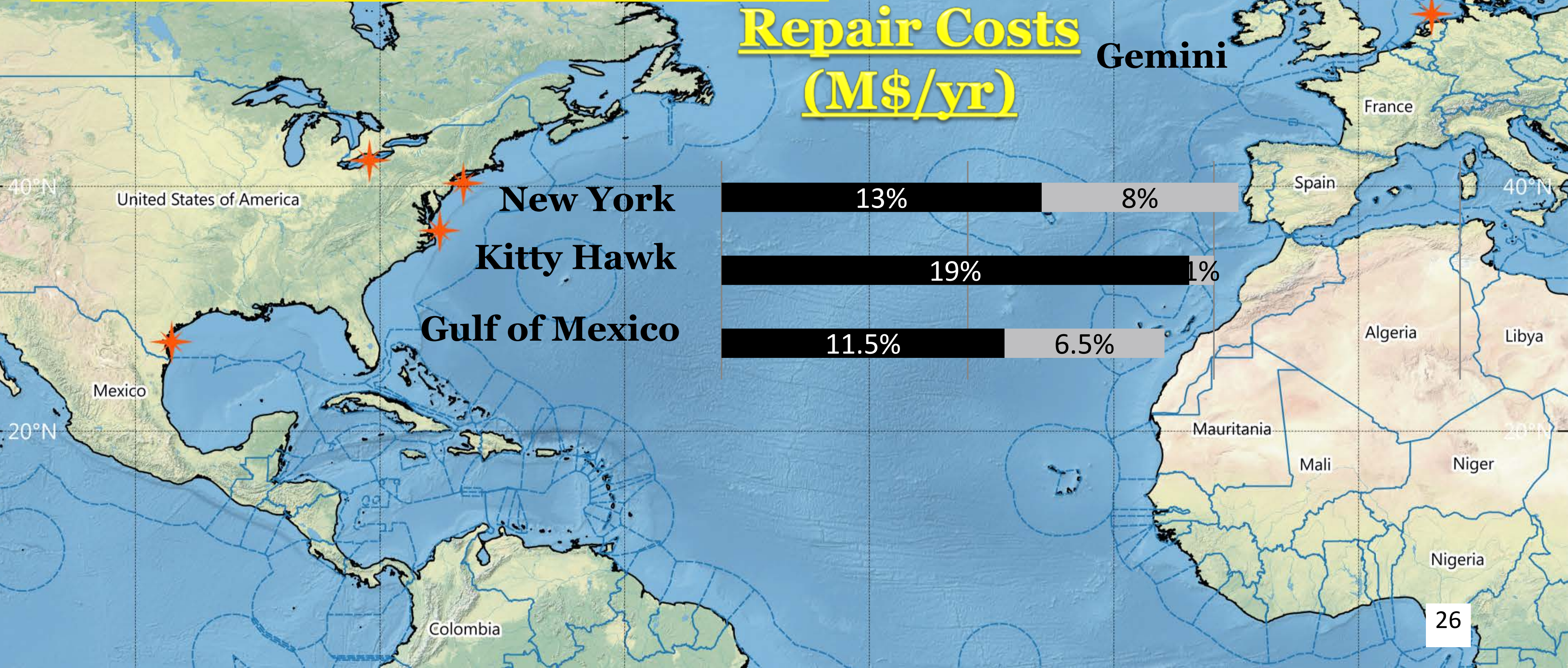
- SOV, SOV and Heli, SES provide the best solutions in terms of availability
- <u>SES</u> is the most suitable strategy

Atlantic & Gulf of Mexico; Gemini (North Sea)



Choice of the "most suitable" O&M Strategy

Atlantic & Gulf of Mexico;
Gemini (North Sea)

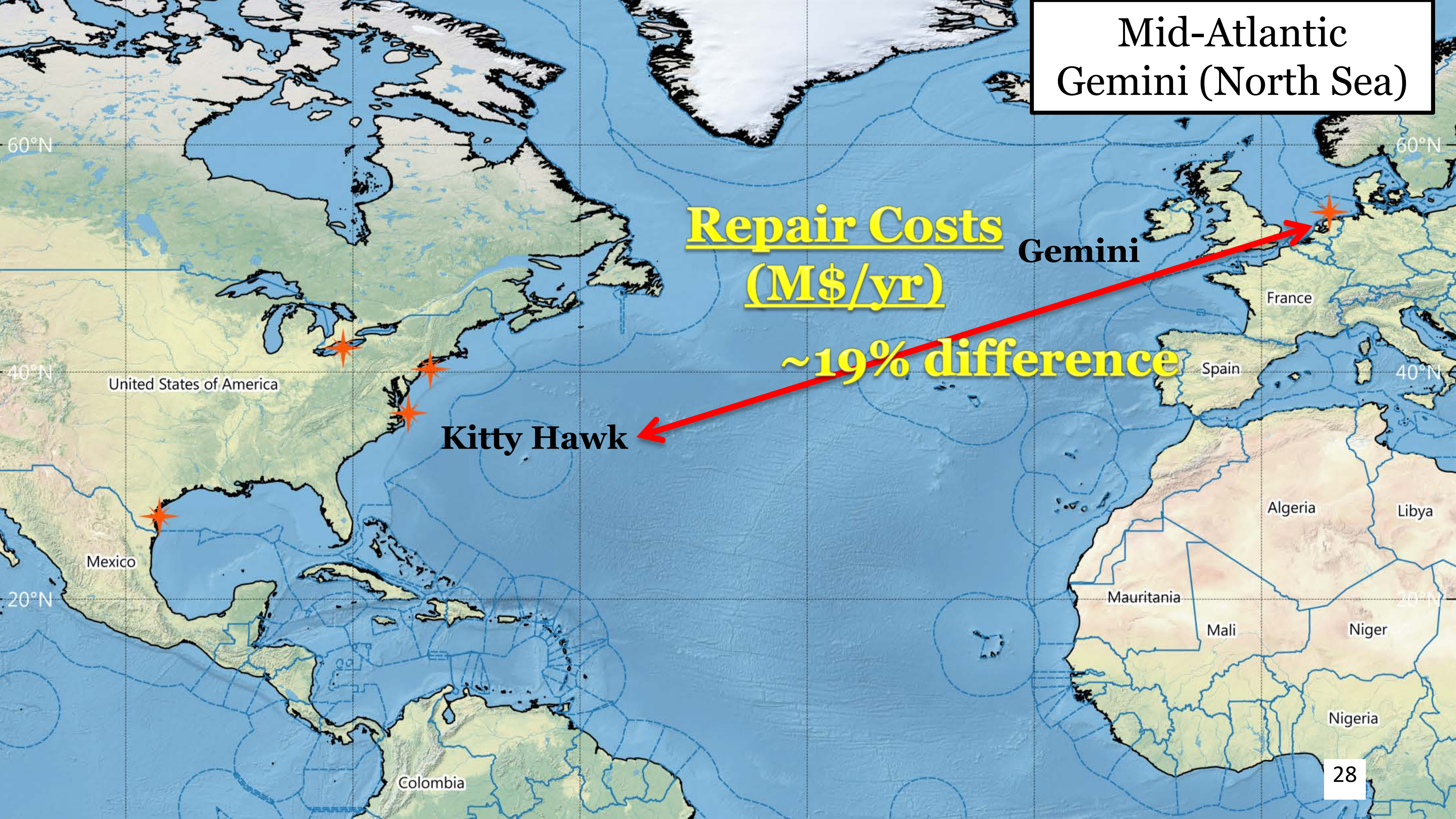


How to Reduce the Difference in Repair Costs?

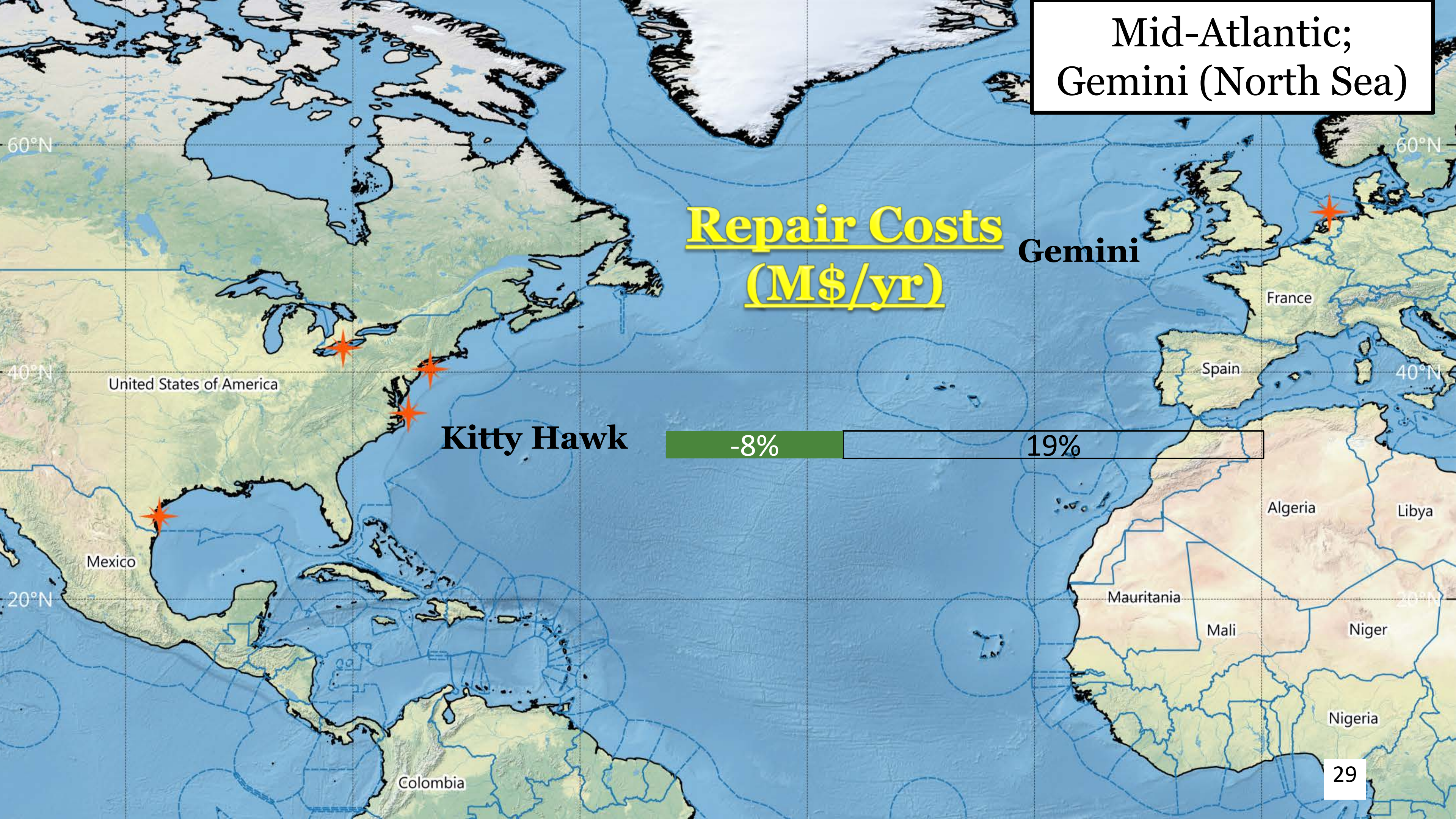
Mid-Atlantic
Gemini (North Sea)

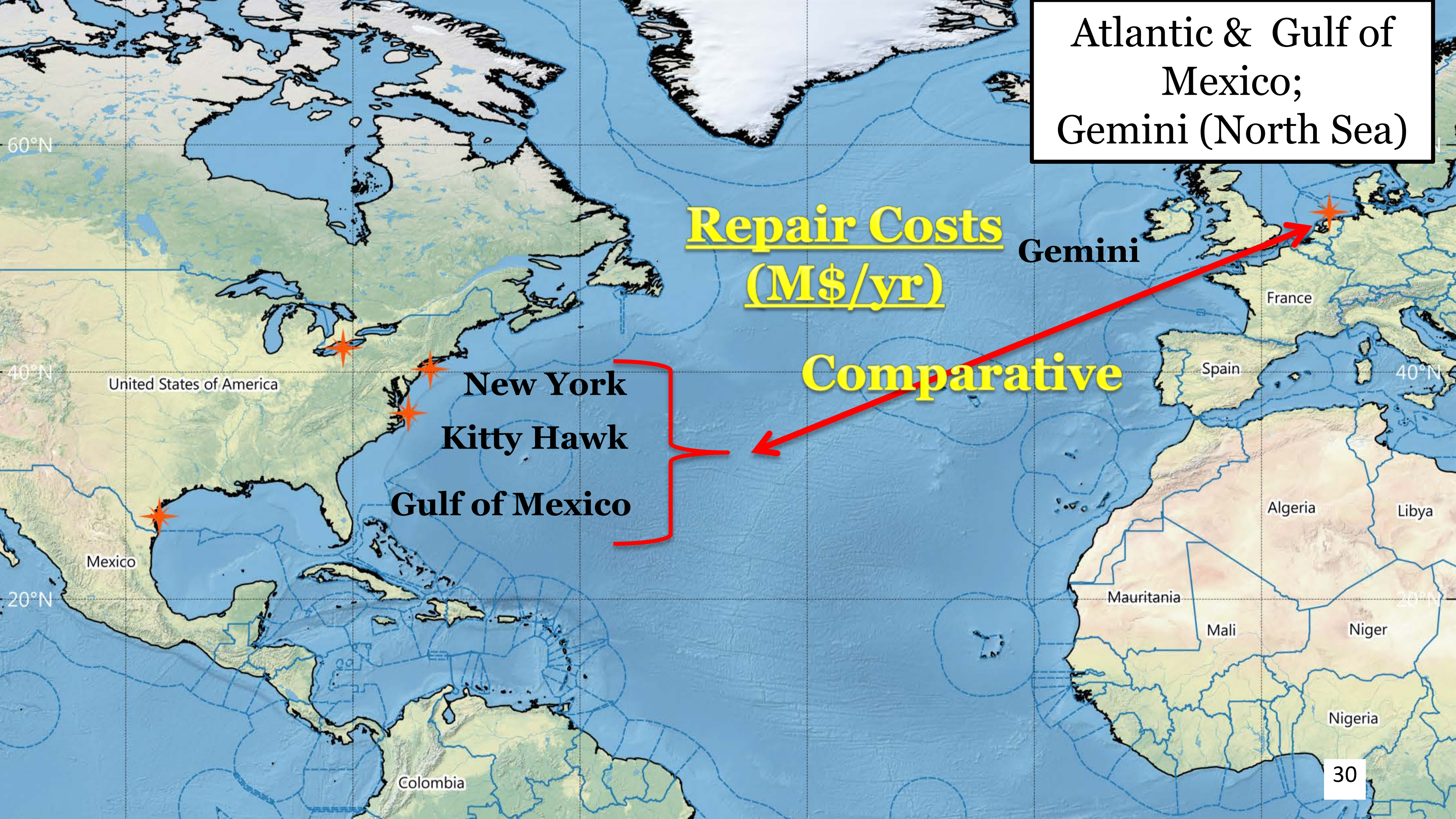
In-house manufacturing of vessels

- Alternative to current strategy of chartering vessels from Europe
- No additional support vessel requirement to comply with Jones Act
- Overall lower vessel price and less mobilization time

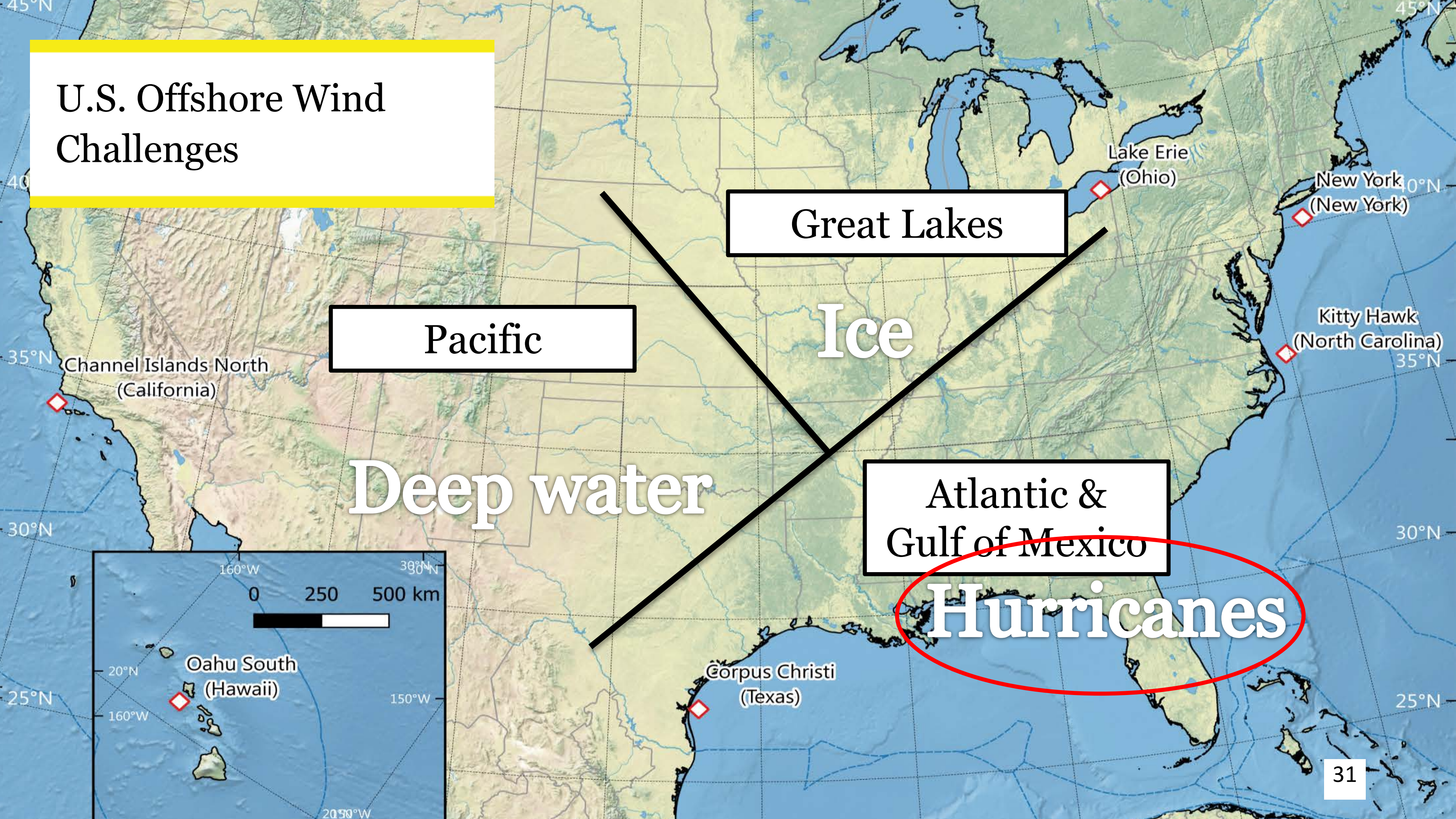

Mid-Atlantic
Gemini (North Sea)
Repair Costs
(M$/yr)
Gemini
~19% difference
Kitty Hawk
60°N
40°N
20°N
United States of America
Mexico
Colombia
France
Spain
Algeria
Libya
Mauritania
Mali
Niger
Nigeria

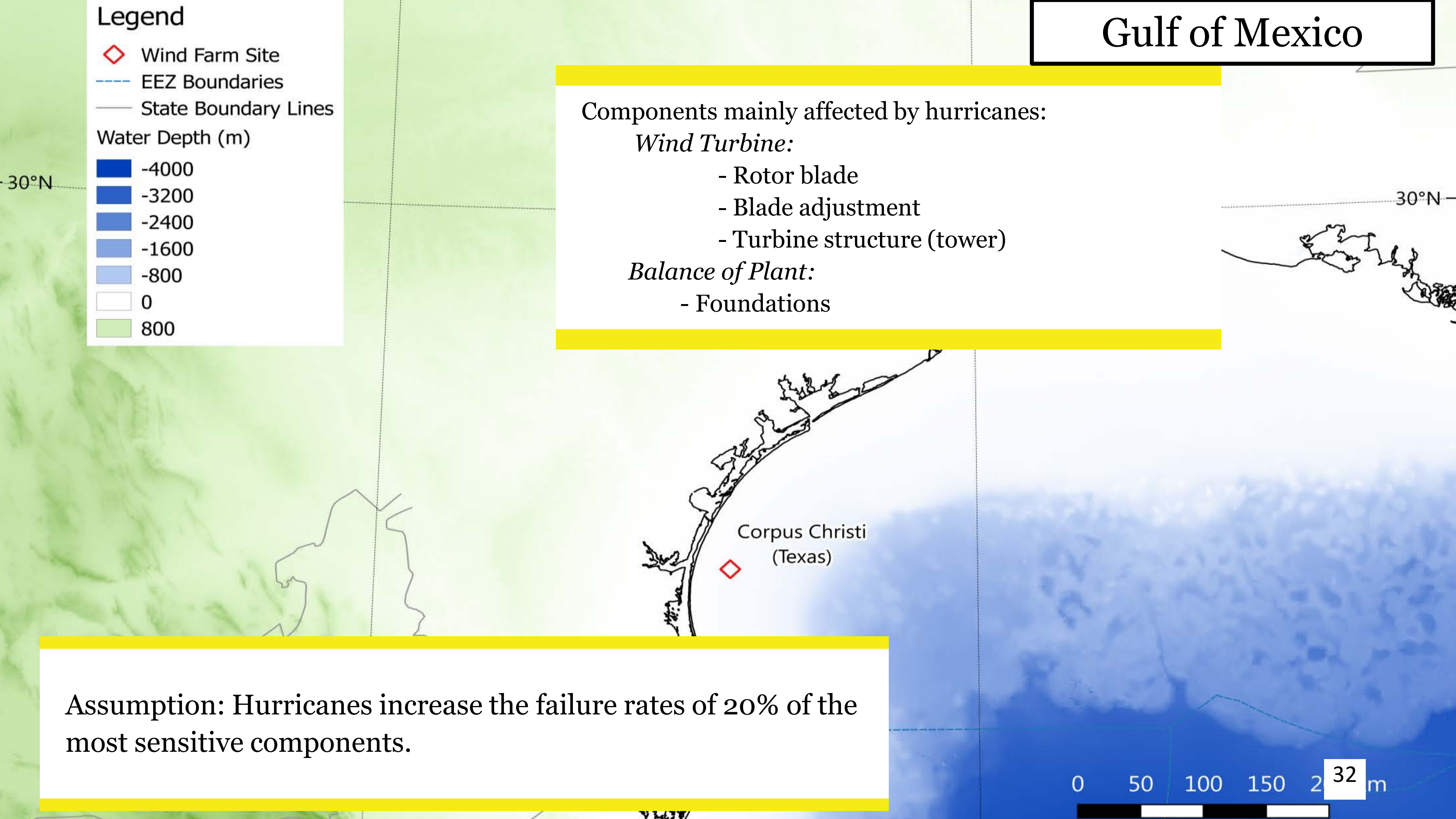
Mid-Atlantic; Gemini (North Sea)




Atlantic & Gulf of Mexico; Gemini (North Sea)
Repair Costs (M$/yr)
Gemini
Comparative
New York
Kitty Hawk
Gulf of Mexico
60°N
40°N
20°N
United States of America
Mexico
Colombia
France
Spain
Algeria
Libya
Mauritania
Mali
Niger
Nigeria

U.S. Offshore Wind Challenges





Gulf of Mexico

Components mainly affected by hurricanes:

Wind Turbine:

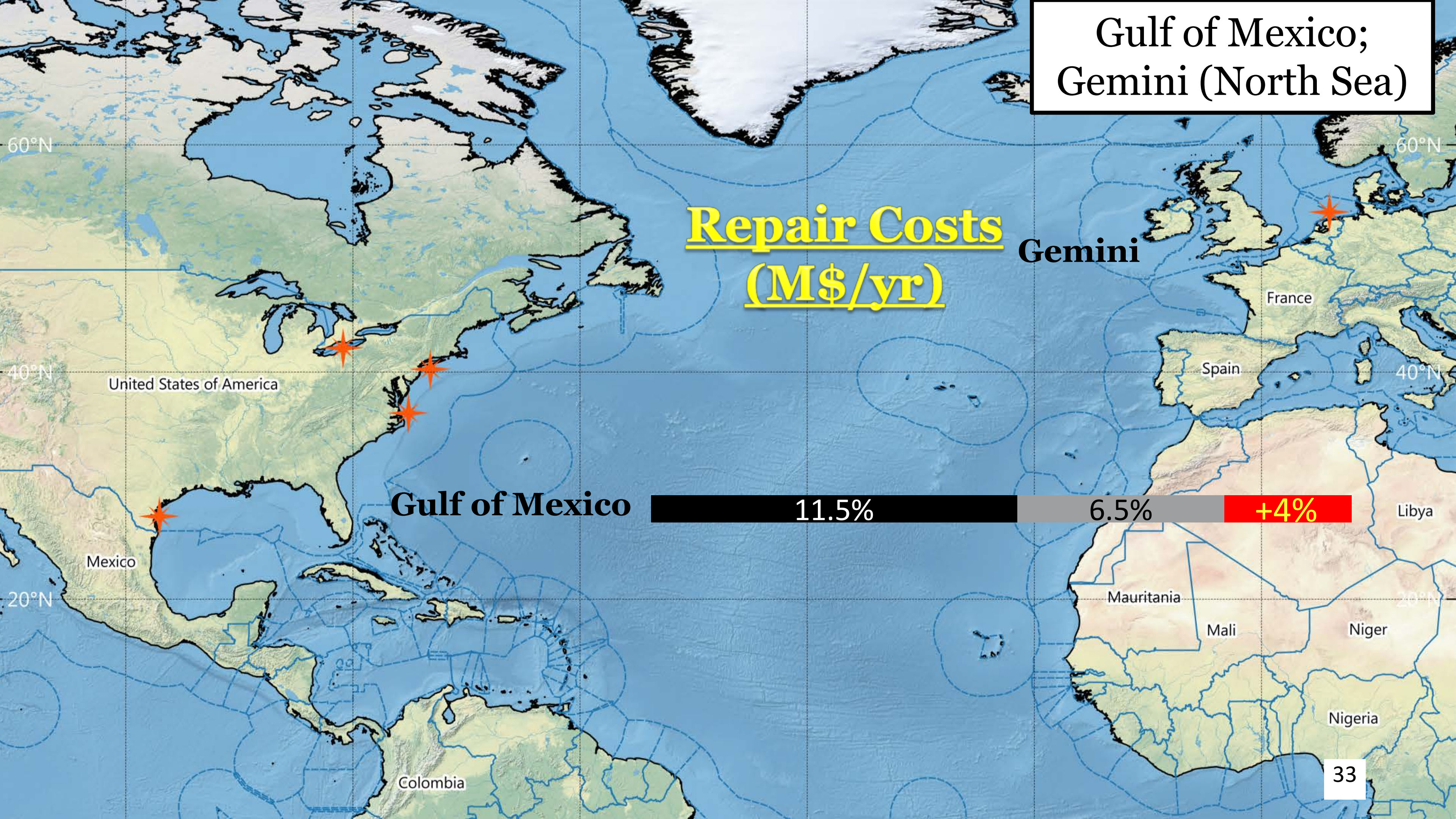
- Rotor blade
- Blade adjustment
- Turbine structure (tower)

Balance of Plant:

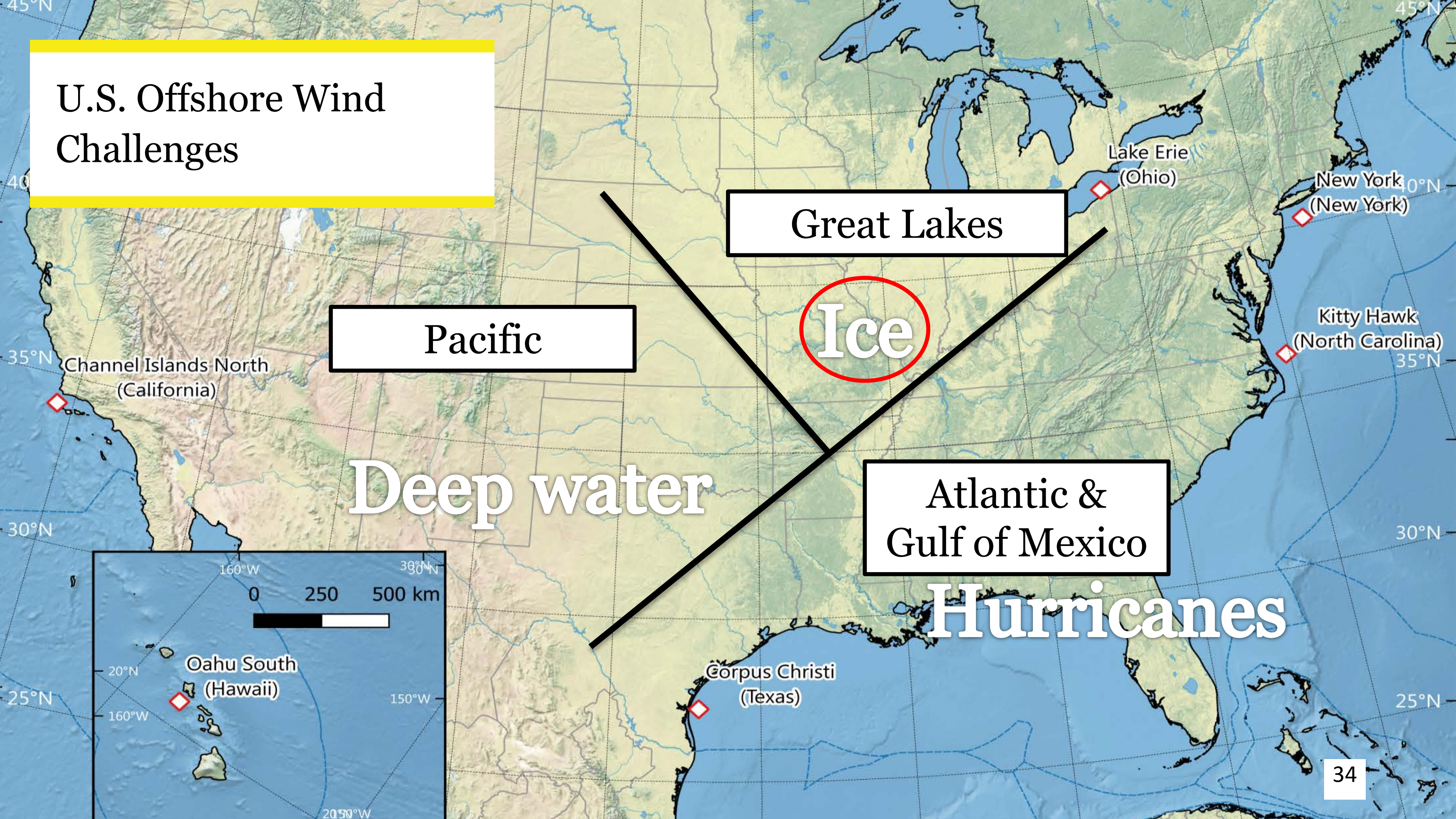
- Foundations

Assumption: Hurricanes increase the failure rates of 20% of the most sensitive components.

Gulf of Mexico; Gemini (North Sea)



U.S. Offshore Wind Challenges



A challenge never experienced before:

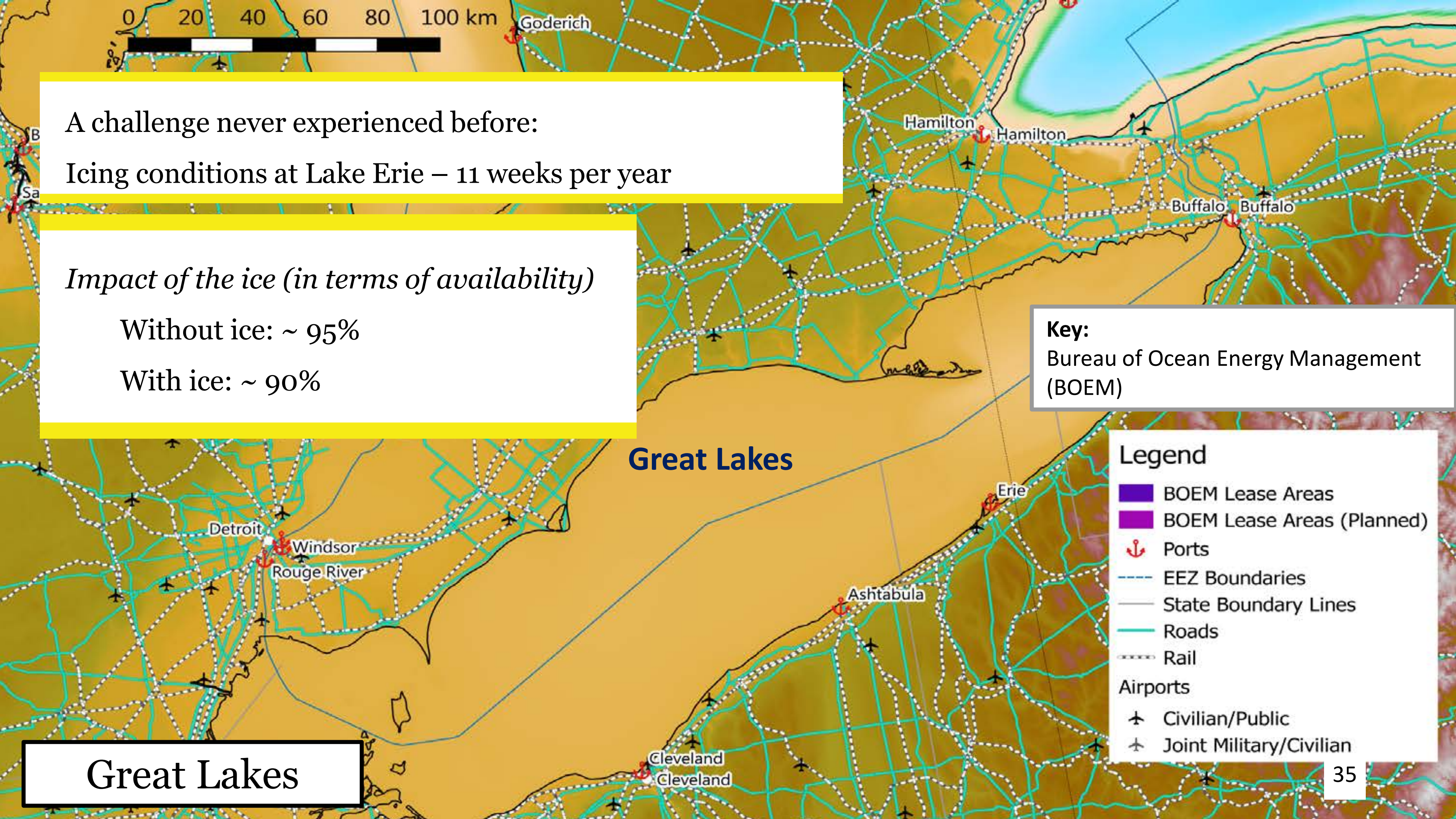
Icing conditions at Lake Erie – 11 weeks per year

Impact of the ice (in terms of availability)

Without ice: ~ 95%

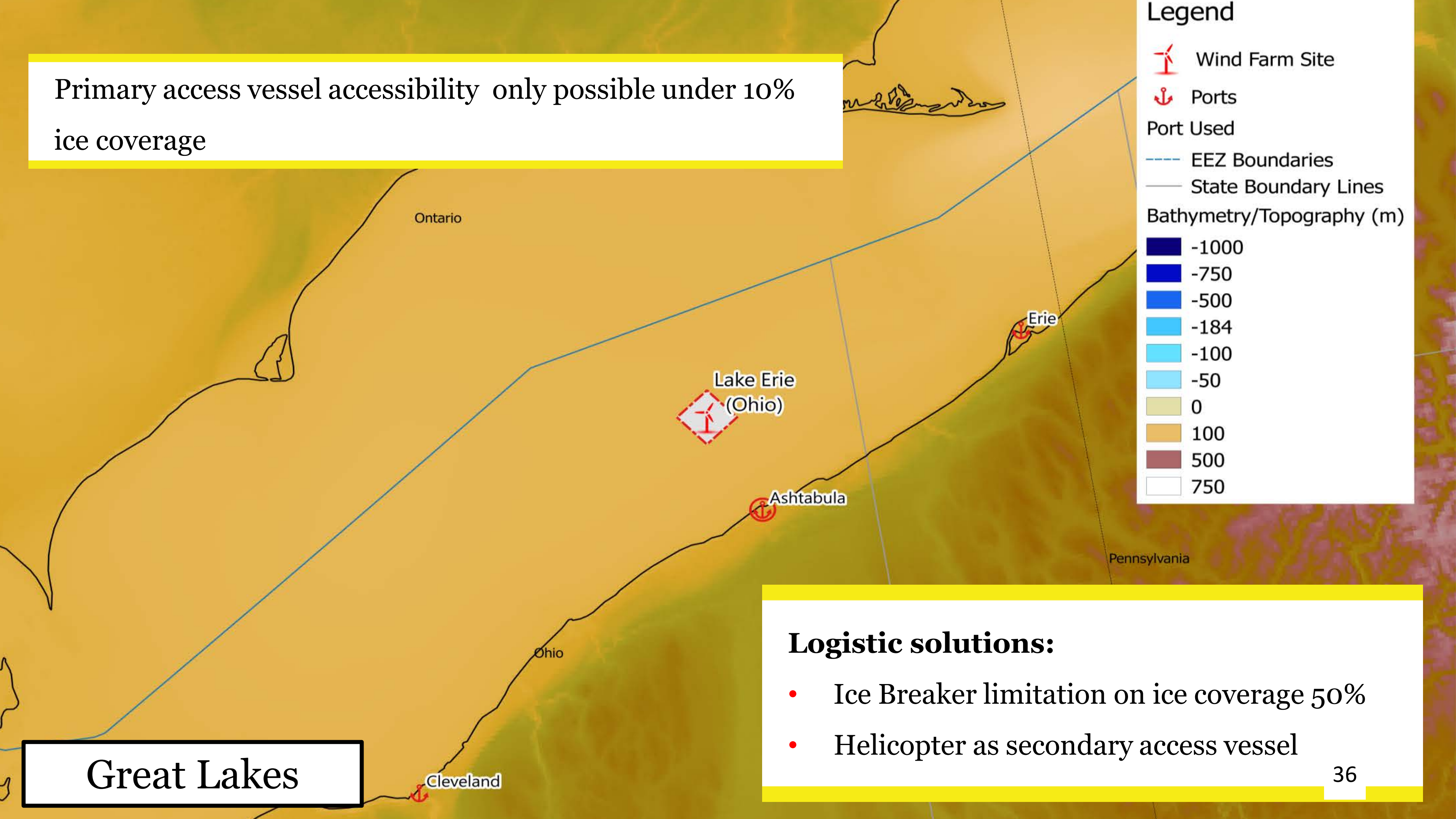
With ice: ~ 90%

Key:
Bureau of Ocean Energy Management (BOEM)



Great Lakes

Primary access vessel accessibility only possible under 10% ice coverage



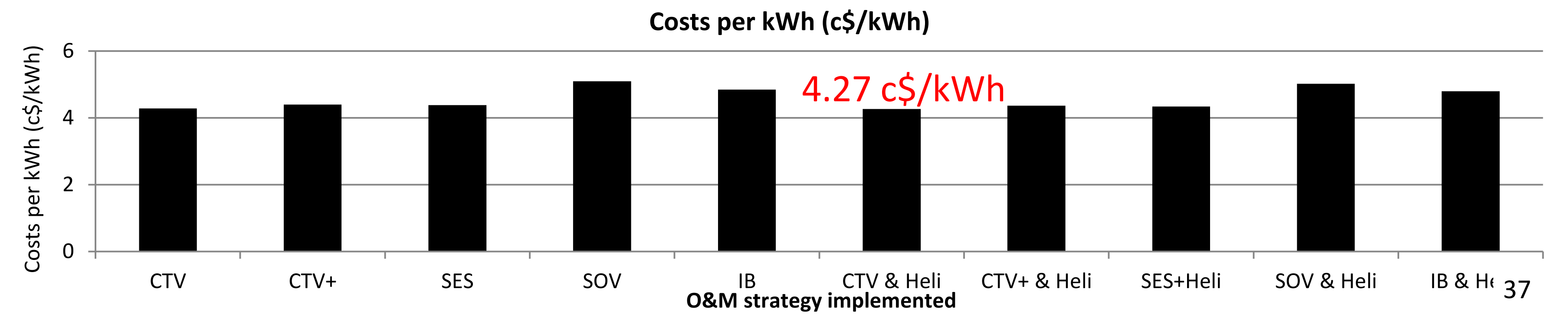
Logistic solutions:

- Ice Breaker limitation on ice coverage 50%
- Helicopter as secondary access vessel

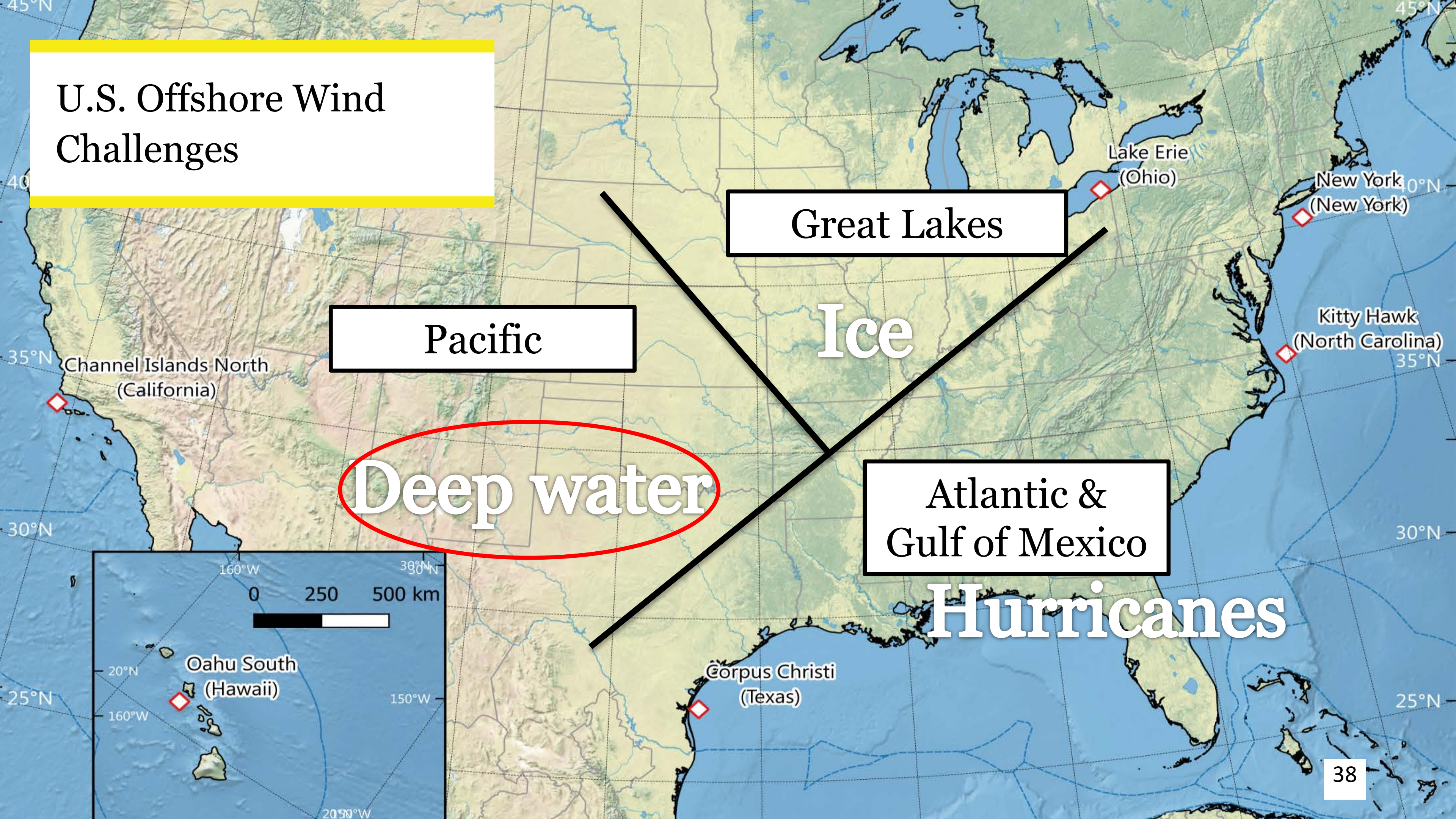
Great Lakes

Outcomes

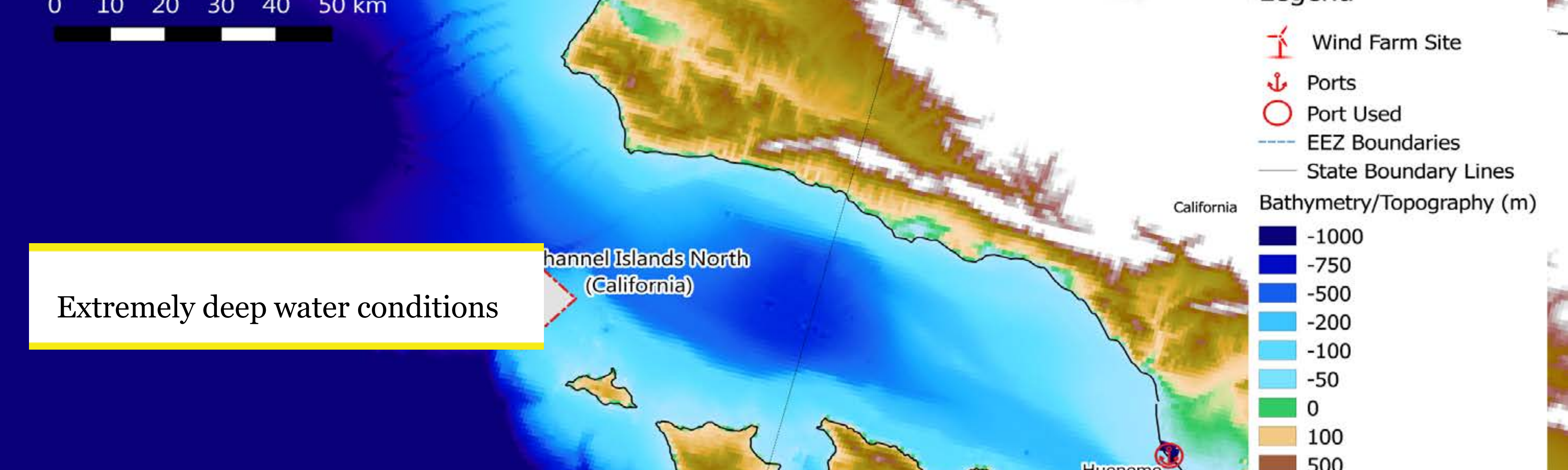
- Ice breaking vessel availability: ~ +0%
- Helicopter availability: ~ +3.2%
- CTV and Heli is the most suitable strategy

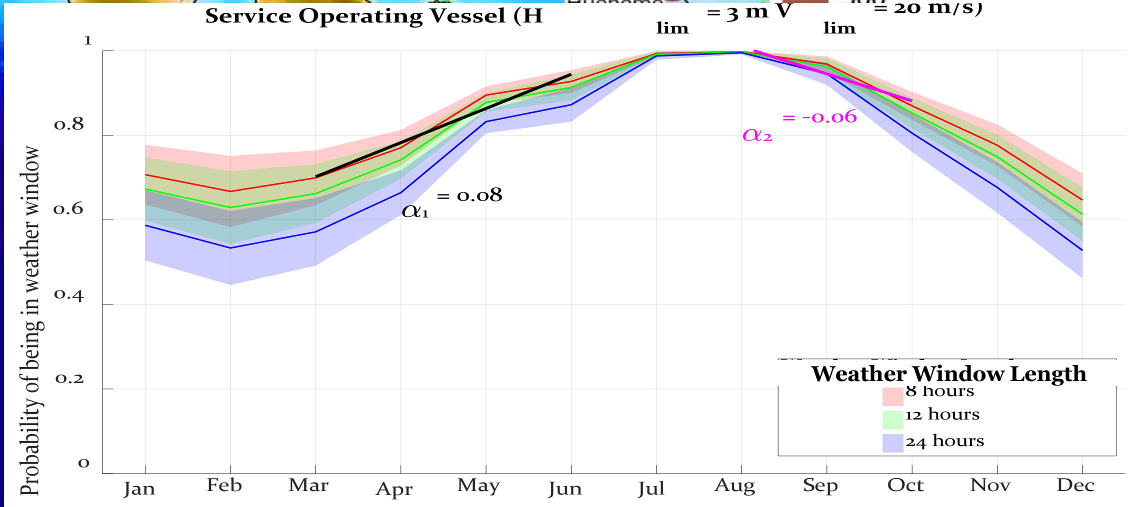


U.S. Offshore Wind Challenges

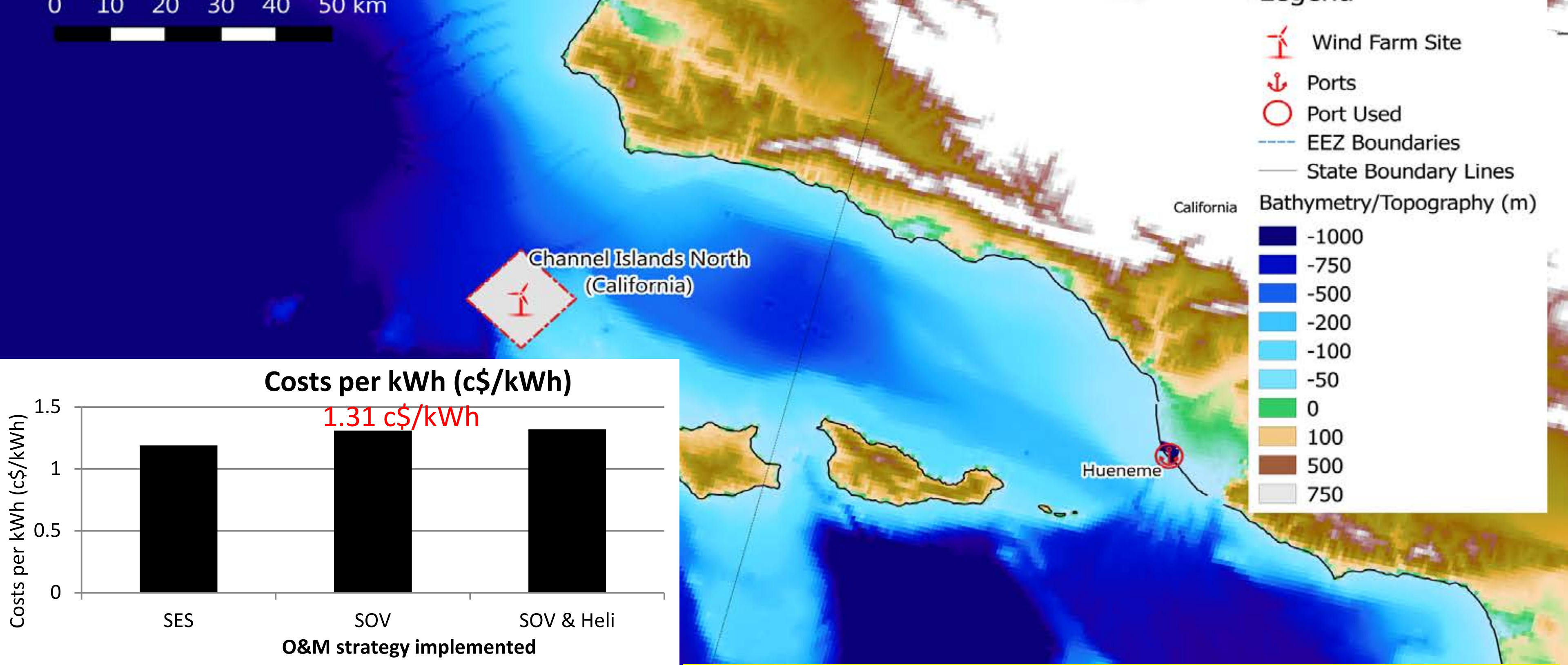


Extremely deep water conditions





North Pacific

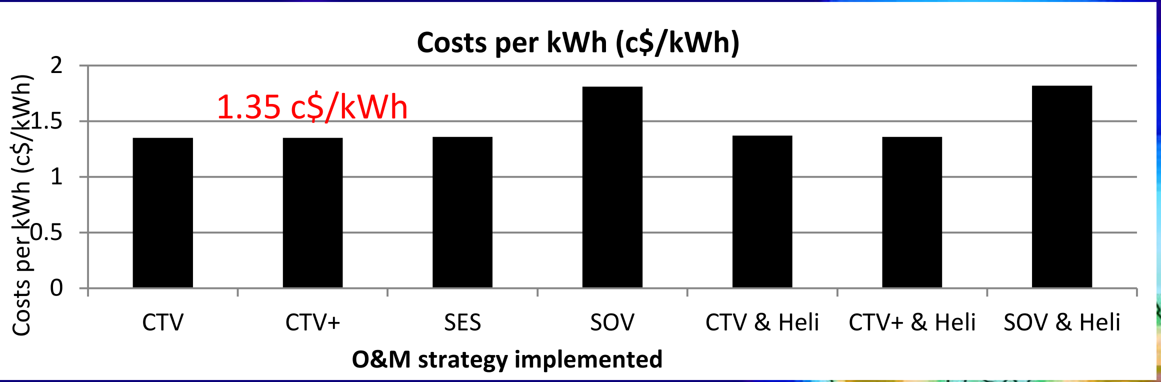


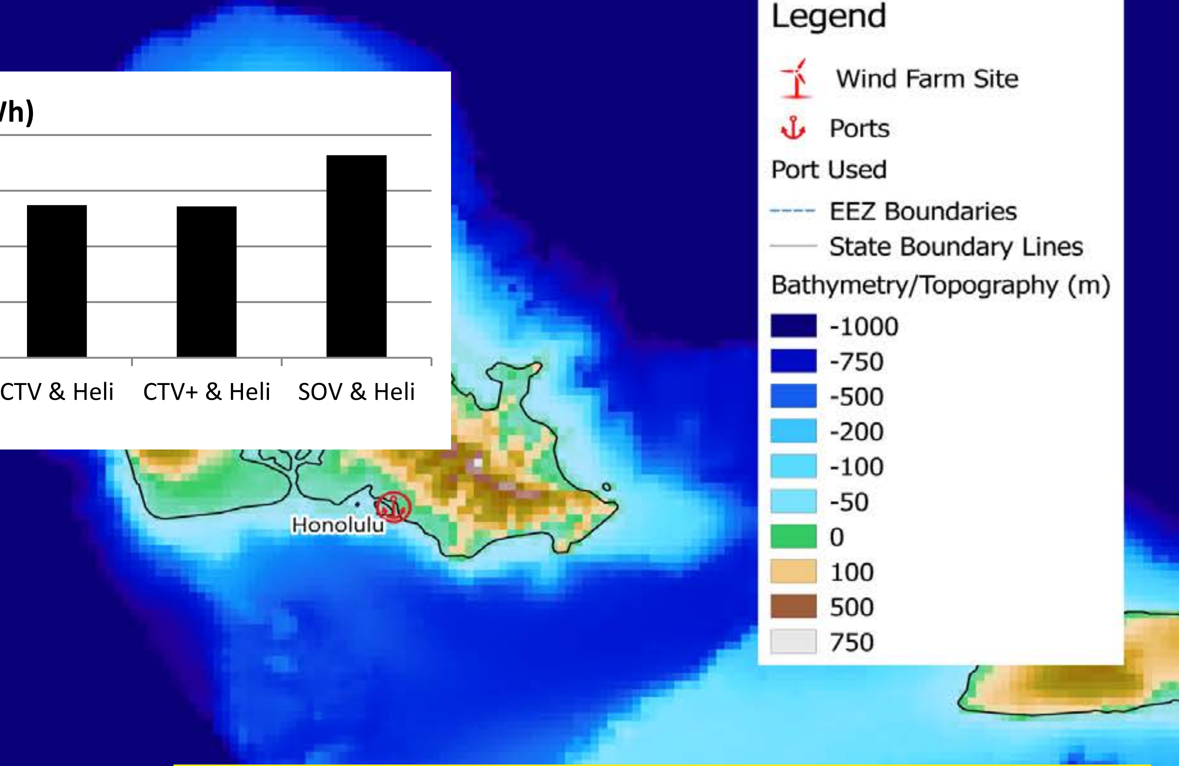
North Pacific

Outcomes

- O&M strategy with only SES and SOV possible
- SES gives lower availability (~ 93%)
- <u>SOV</u> is the most suitable strategy

Pacific Hawaii



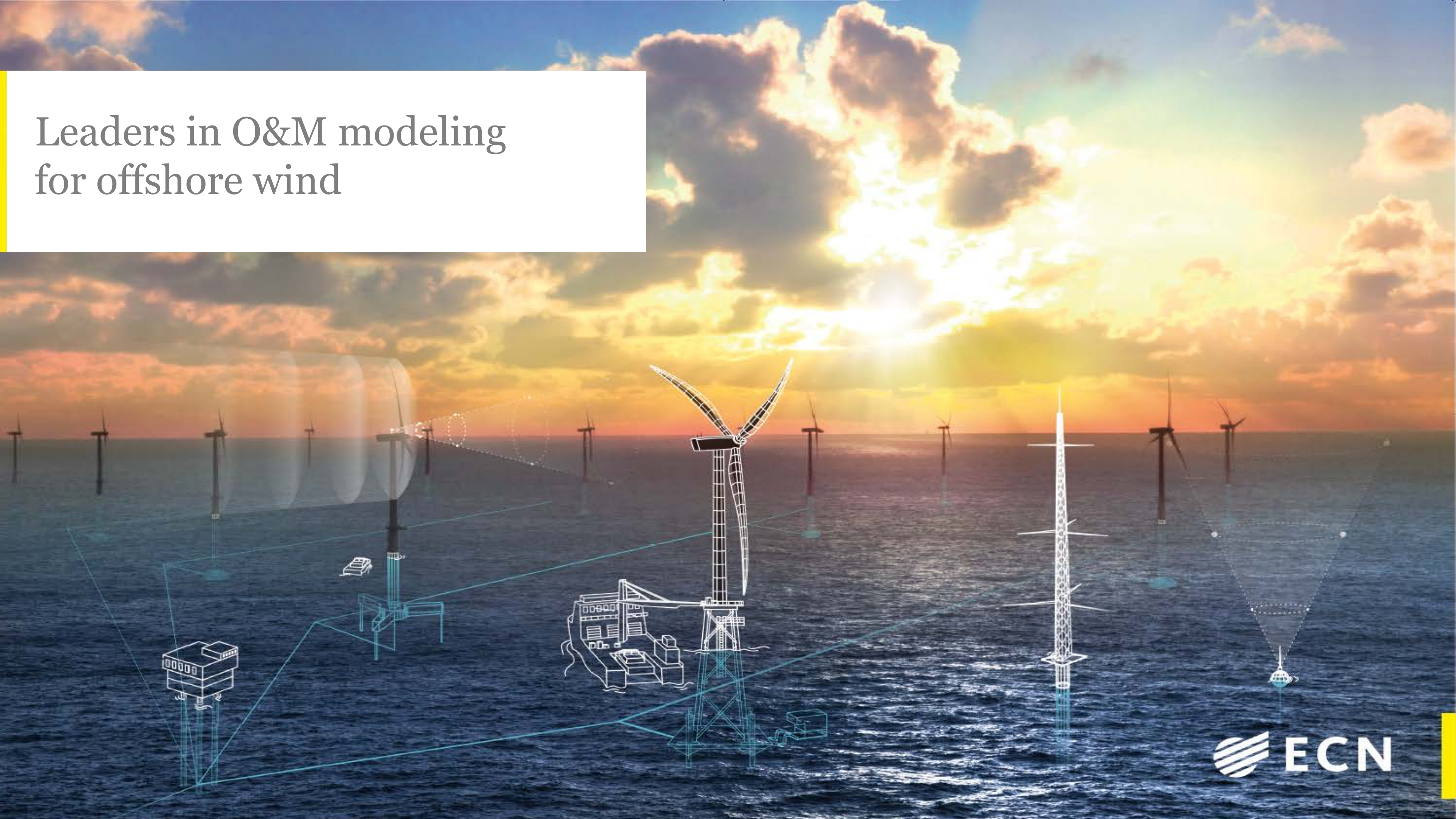


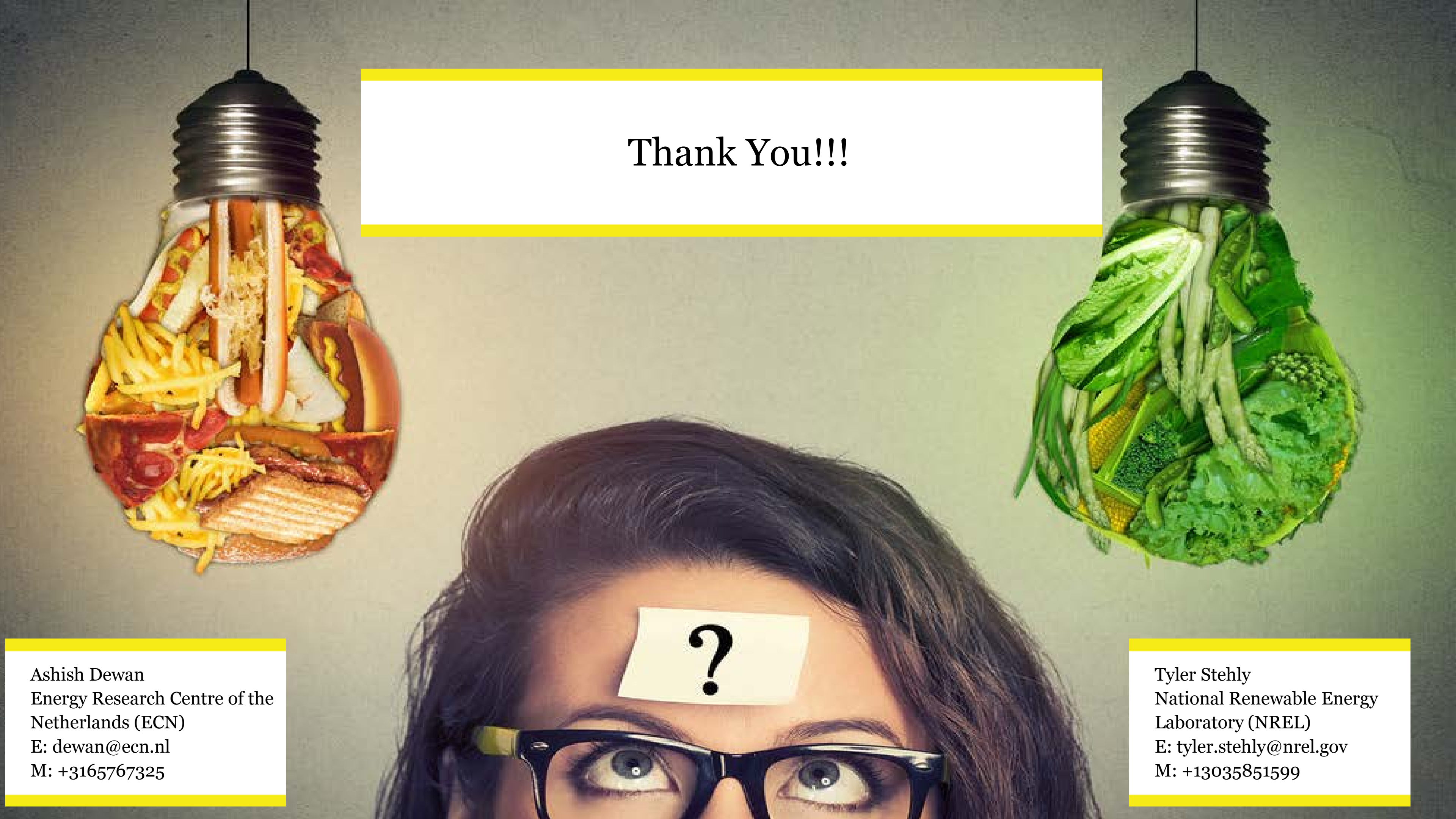
Outcomes

- CTV+, SES, and SOV provide the highest availability
- <u>CTV+</u> is the most suitable solution

“Each site needs a dedicated O&M strategy”

Leaders in O&M modeling for offshore wind





Thank You!!!

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