On-shore assembly for mass production and rapid deployment of offshore wind turbines

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Problems addressed

- Wind power critical to meeting carbon reduction targets, due to low cost and 24-hour generation
- Offshore wind has great CF and proximity to load
- But offshore LCOE still above land-based wind and fossil
- Less work at sea is less expensive
- Larger turbines leads to lower LCOE

Why offshore Wind?

- Very large resource close to load centers (Northern Europe, US East Coast, Eastern Asia)
- Land-based wind in good resource areas (~7.5 m/s) is already the lowest-cost new generation—unsubsidized
    - But good land sites often far from load. Can we bring down price of offshore to as low as land?

This project

- DOE RFP: “develop a cost-optimized, integrated system design of an offshore wind plant in order to reduce the Cost of Energy (COE) and to shorten the deployment timeline”

- UD and contractors were awarded “Integrated Design to Industrialize Offshore Wind Power, with Example of Wilmington Canyon” DE-FOA-0000415

- Design is for waters 20 to 40 m, unit capacity 1000 MW (1 GW), on US Eastern Continental Shelf

- Assume 5 years of projects to amortize port upgrade costs

- Assume a 10 MW turbine (we will extrapolate to 20 MW)

Integrated Design

- Design of each component and system is re-evaluated, and possibly modified, in light of the other components
    - Historically, turbine manufacturers have been most resistant to changes in design
- We had a design team with multiple contractors.
    - UD provided science and pushed for synergies, testing each new concept on all specialists
- Proof-of-concept engineering done on two tower structures, plus on in-port assembly

Collaborators and Contractors

Project Lead:

UNIVERSITY OF DELAWARE

Sponsor: US DoE, award DE-EE0005484

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

WIND ENERGY TECHNOLOGIES OFFICE

PARTICIPATING COMPANIES AND CONTRACTORS:

MAMMOET

WEEKS MARINE, INC.

SPT Offshore

Atlantic Grid Development

EEW

moffatt & nichol

Clipper

Eni Saipem

SIGNAL INTERNATIONAL

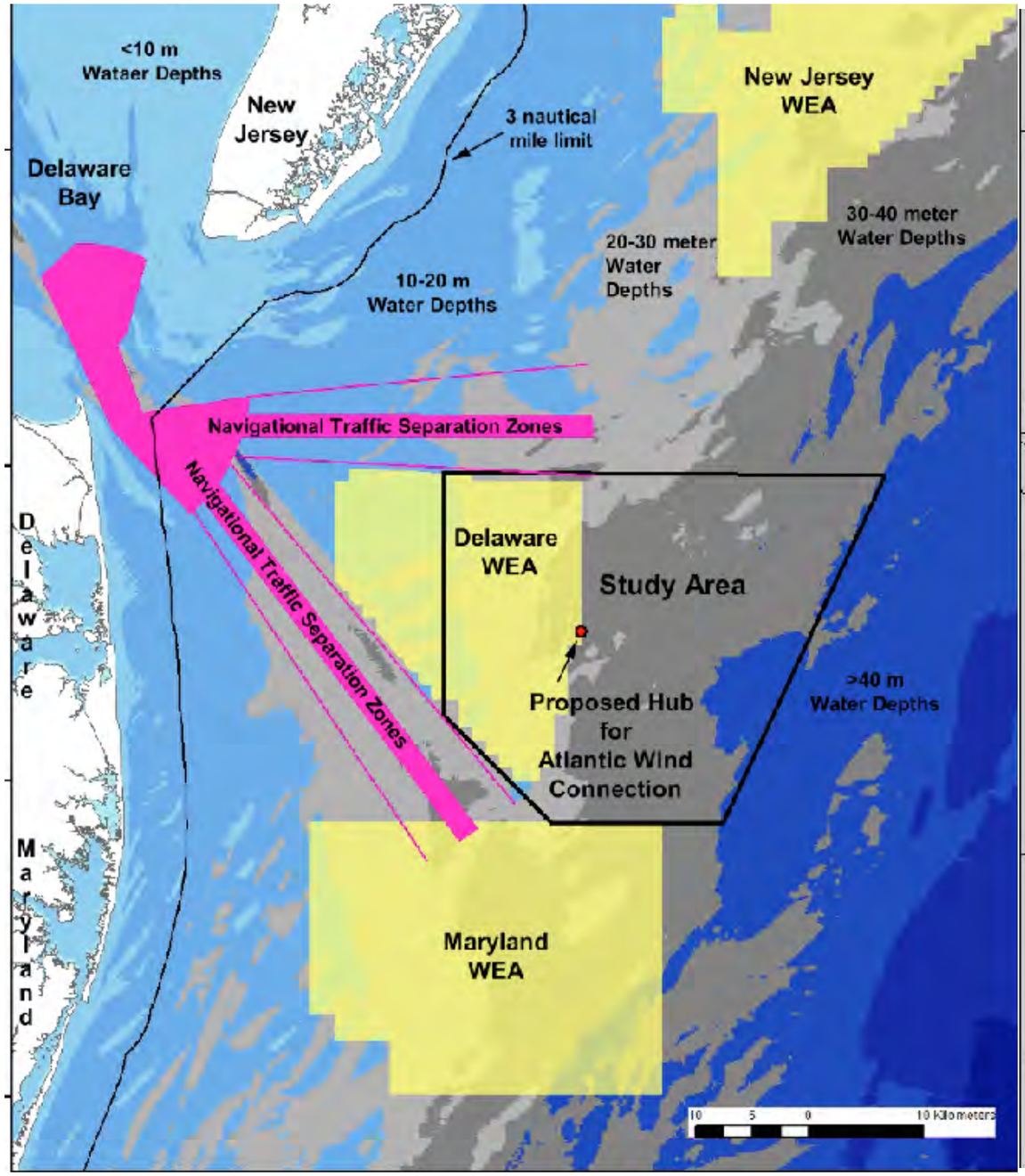
A Marine & Fabrication Company

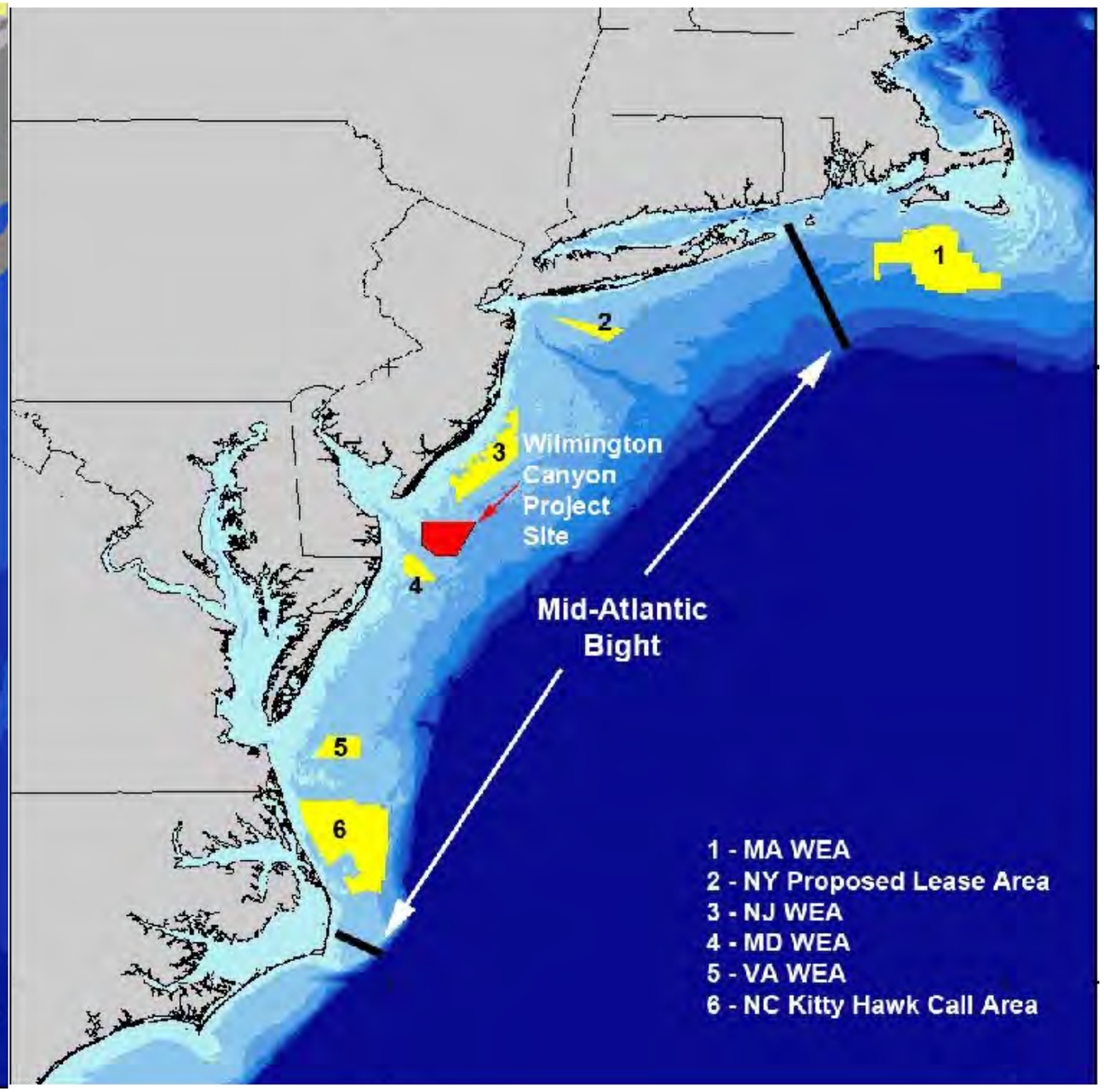
STEEL SUPPLIERS ERECTORS INC.

AALBORG UNIVERSITY

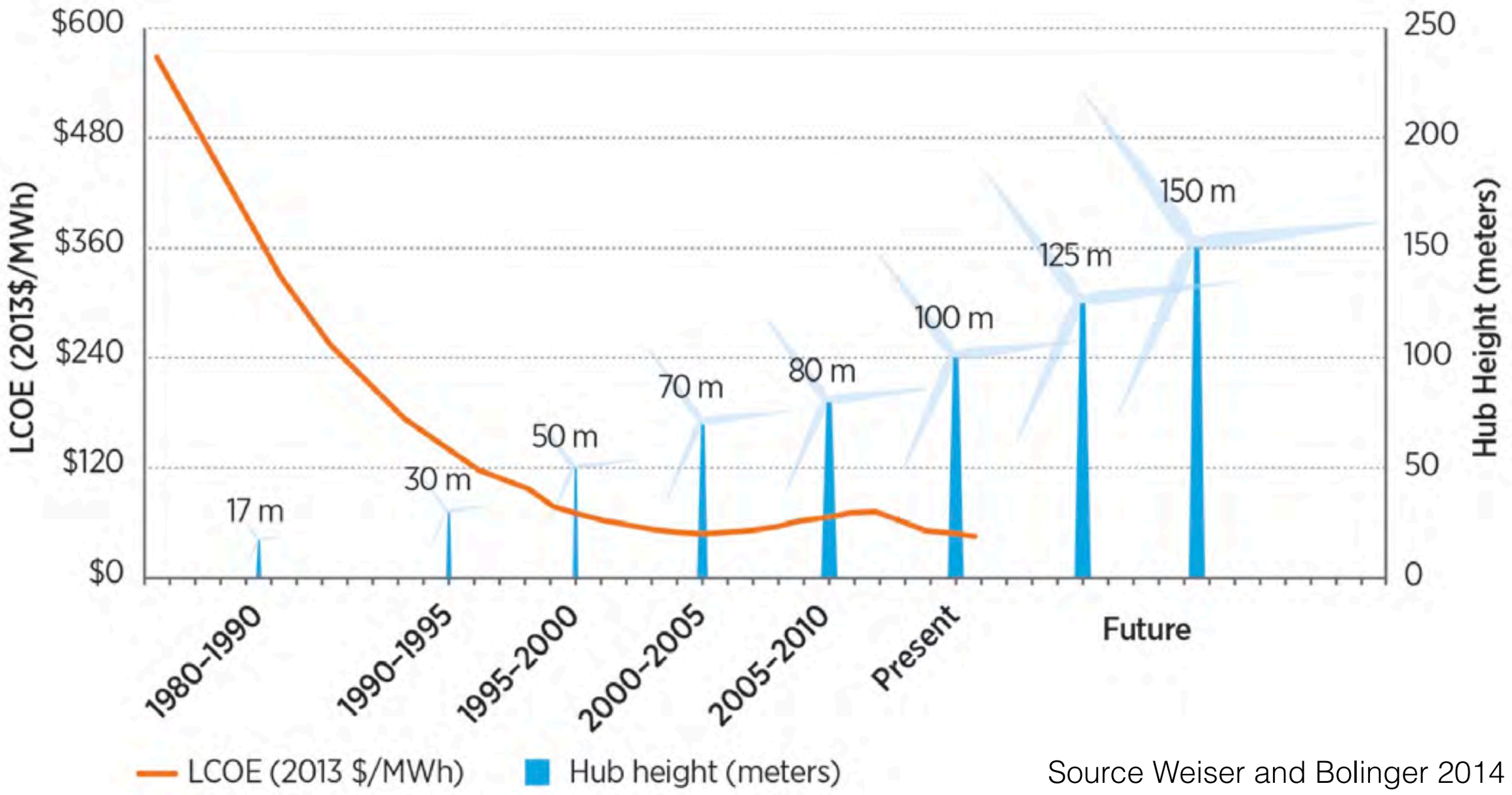
XKP

Characteristics of Study Area



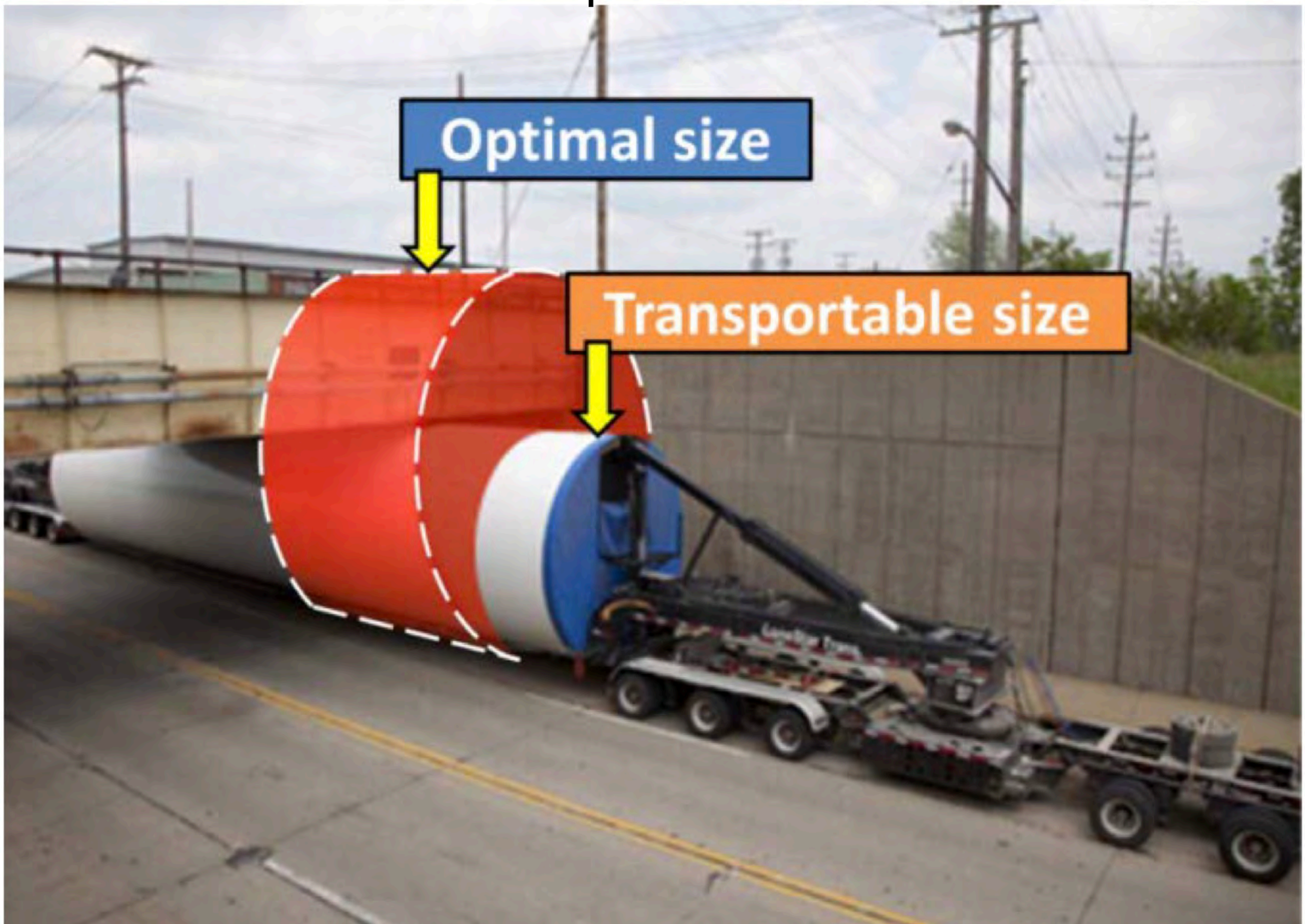


Increasing turbine size
one factor lowering cost



Source Weiser and Bolinger 2014

Land-based turbine size limited due to transport limits



From: Keystone Towers; DOE/EE-1218

Today's OSW deployment

- Components are brought to a deployment port, or laydown area, staged for installation
- Installation ships are "jack up vessels" that can put down "spuds" to become stable w.r.t. the ocean floor
- Monopile is driven into the sea floor, to ~40 m depth,
- Transition piece is placed over monopile, grouted
- Tower, nacelle and blades all lifted

A2Sea video

Problems with traditional deployment

- Jacking up is a potentially unstable operation, need geotech on ocean floor under spuds
- Work at sea ~5x cost of work in port
- Large jackup-up crane vessel ~$100K/day! plus crew of 30+
- Each operation (jacking up, lifts, grouting, etc) adds time at sea
- Pile driving affects marine mammal hearing, this is largest environmental impact of OSW

Design Decisions: Foundation

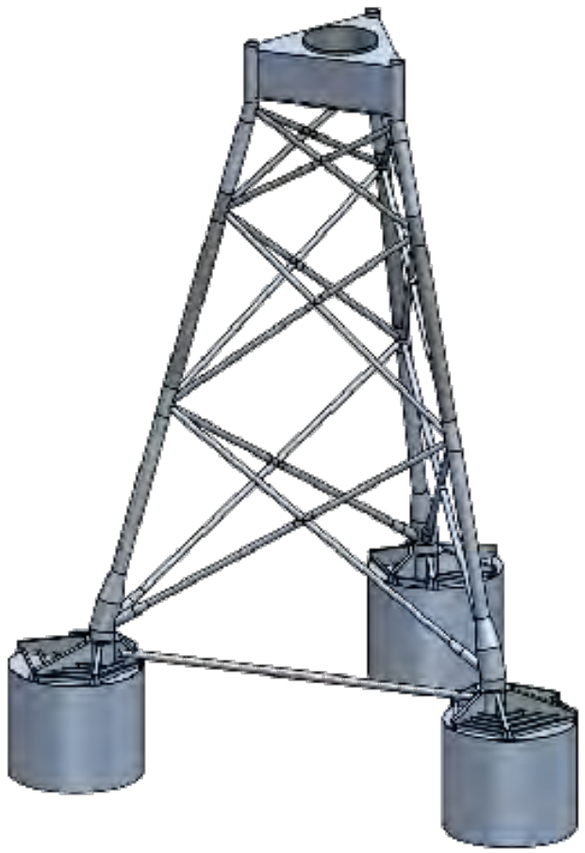
- Foundation driven not by static loads but by dynamic loads (waves, wind and rotor movement). Designs focus on stiffness.

- Fabrication labor adds roughly 4x the cost of the steel commodity.

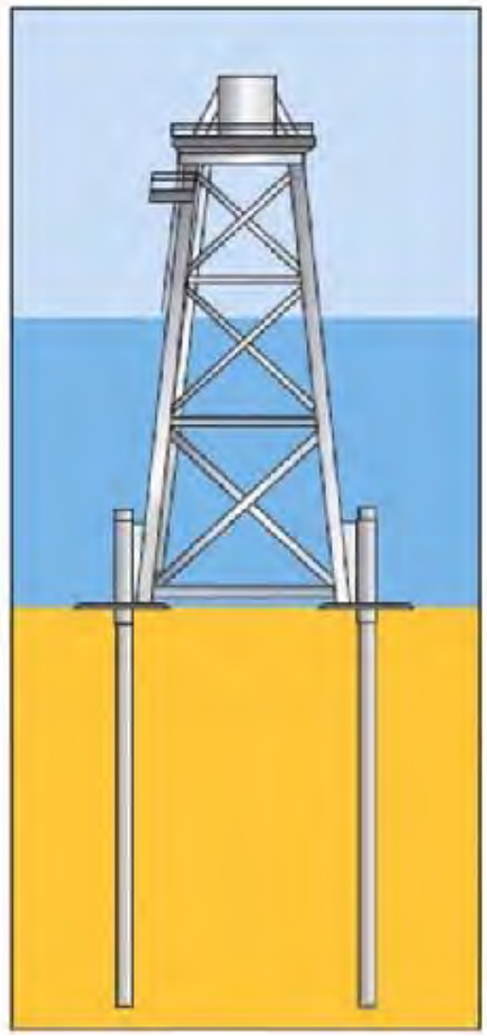
- Lattice can withstand larger wave loading than monopile.

- Use lattice for lower section of vertical support: lattice is stable; allows for multiple seabed fastening points.

Foundation Alternatives



- "Base" design for comparison
  5 MW turbine with traditional piled jacket



- Design Alternative 1: Piled jacket
  - Jacket structure with piles
  - Multi-step offshore assembly
  - Jack-up vessel
  - 10 MW turbine
  - Detailed engineering

- Design Alternative 2: Suction Bucket
  - Turbines assembled in quay on jacket structure with suction buckets
  - Deployment in a single offshore step via shearleg crane barge
  - 10 MW turbine
  - Detailed engineering

Design Decisions: Port Assembly and Installation

- Port Assembly:
  - Assemble foundation, tower, and nacelle on quay
  - Attach blades to tower not on hub, more stable at sea, less stress on bearings
  - Pre-assembly turbines can be nearly continuous; install during weather windows

- Installation
  - Shearleg crane vessel to transport completed structure to installation site
  - All work done from floating vessel
  - Assembly and installation can be done in parallel

Design Decisions: At sea

- No jack up vessels; No pile driving
- Shallower bucket depth (10m) allows acoustic sub-floor scanner
- Crane vessel installs entire structure in one operation
- Blades hoisted by workers with winch in nacelle, not by lift vessel

Integrated Design video here

Overall Costs

Design	Foundation ($/kW)[1]	Sea Work ($/kW)[2]	Port Work ($/kW)[3]	Turbine and Nacelle ($/kW)[4]	Electrical Infrastructure ($/kW)[5]	Total Cost ($/kW)*
Jacket Foundation (5 MW)	808.08	882.50	25.20	1952.00	937.50	4605.28
Jacket Foundation (10 MW)	462.46	465.60	23.50	1615.00	600.00	3166.56
Suction Bucket (10 MW)	514.65	333.40	32.55	1615.00	600.00	3095.60

Preliminary data

Closing thoughts

- Integrated design led to a substantially different approach to installing offshore wind power plants
- Mass-production of assembled turbines ashore with transport to site has been designed
    - Long term, this could lead to a cost advantage of offshore over land installations
- Extendable to 20 MW turbines with minimal changes
- One GW/year installation rate from a single port
- More potential for economies of scale, thus potentially much lower costs going forward