

**Logistics and fabrication study to assess commercial
delivery of the WindFloat in the East Coast of USA**

Àlex Peracaula Ruiz

Thesis to obtain the Master of Science Degree in
Energy Engineering and Management

Supervisors: Prof. José Manuel Costa Dias de Figueiredo
Mr. Aaron Smith

Examination Committee

Chairperson: Prof. José Alberto Caiado Falcão de Campos
Supervisor: Prof. José Manuel Costa Dias de Figueiredo

Member of the Committee: Prof. Maria Margarida Martelo Catalão Lopes de Oliveira
Pires Pina

October 2017

Acknowledgements

In the first place I would like to thank Principle Power for allowing me to start growing as a professional inside their doors. Thanks to the company I have been able to learn about the industry and the professional world in many valuable ways. In this line thanks also to Innoenergy for defining the context of this internship and for its support, which made this stay possible.

In particular I would like to thank the members of PPI Lisbon office: Aaron Smith for his direction and advise, Loris Canizares for answering all my questions, Cyril Godreau for sharing his experience whenever I needed it and Daniel Toledo for his camaraderie.

I would also want to show my appreciation to Professor José Figueiredo, who throughout the six months has dedicated his time in our regular midday meetings to follow my work and advise me in an honest and useful way.

Thanks to all my friends and family who, presently or in the distance, helped me deal with the work during these months.

Last, but not least, I want to thank the Lisbon Players, who provided me a nourishing way to escape the routine and became a really important part of my stay in Lisbon; this work and effort belongs also to them.

Abstract

With the WindFloat, Principle Power leads the floating offshore wind technology market. The semi-submersible platform has successfully demonstrated its capabilities throughout 5 years of working in the North of Portugal and the company now faces the next steps to commercialize the technology. This research study is looking to the future projects of the company and aims to establish the requirements that port facilities must fulfill in order to be capable of supporting a serialized fabrication of WindFloats. Moreover, this report studies the fabrication process and costs, and designs a suitable strategy for delivering WindFloats to a potential 500 MW project in Massachusetts, East Coast USA, . By fabricating the basic components in Portugal and shipping them to the East Coast of USA (Bridgeport, CT) for final assembly and turbine mating, the research estimates a cost of fabrication. This cost is significantly lower than the current cost for pre-commercial projects due to economies of scale effects. Further on, the report evaluates the final assembly process more thoroughly by estimating duration and labor requirements to execute the process. In order to deliver a unit every 3 days the research offers an explanation of the duration of operations and allocates the minimum necessary resources through a Gantt-based model, reaching a conclusion on the number of people to hire and the impact in the cost. To conclude, the study uses Principle Power's cost models to calculate LCOE for the 500 MW wind farm, considering a 25-year business case, and an 8.5% weighted average cost of capital.. The LCOE obtained is higher than the current values for European commercial projects due to the immaturity and lack of competition of the US market. If the WACC is reduced to current bid levels then the LCOE reaches really competitive levels.

Resumo

Com a tecnologia WindFloat, a Principle Power lidera o mercado das tecnologias flutuantes em energia *offshore*. A plataforma semi-submersível já demonstrou as suas capacidades ao longo dos 5 anos que esteve a funcionar na costa norte de Portugal e agora a empresa enfrenta os próximos passos para comercializar a tecnologia num horizonte mais vasto. Esta investigação analisa projetos futuros da empresa e tenta estabelecer os requisitos que as instalações portuárias têm que cumprir para serem capazes de suportar uma fabricação em série de WindFloats. Além disso, utilizando como contexto um potencial projeto de 500 MW na costa de Massachusetts, costa leste dos Estados Unidos, esta investigação analisa o processo e os custos de fabricação e desenha uma estratégia para satisfazer a produção e oferta da plataforma. Mediante a fabricação dos componentes básicos em Portugal e o seu envio para a costa leste dos Estados Unidos (Bridgeport, CT) para montagem final e ereção da turbina, o estudo prevê um custo da fabricação na ordem dos 7.31 M€/WindFloat. Este custo resulta consideravelmente menor do que o custo atual de fabricação. Por fim debruçamo-nos sobre o processo de montagem final (montagem) calculando tempo e custo do trabalho. Esta análise permite detalhar a duração das operações e a alocação de recursos, chegando a estimativas sobre o número de pessoas a contratar e o seu impacto no custo, tudo isso para entregar uma unidade cada 3 dias. Finalmente a análise vai mais longe para mostrar o cálculo do LCOE (TRANSLATE BETWEEN BRACKETS), que resulta num custo de 113 €/MWh, tendo em consideração que a instalação eólica estaria a funcionar por 25 anos.

Contents

Acknowledgements..... ii

Abstract.....iii

Abstracto iv

List of Figures..... vii

List of tables..... viii

Abbreviations..... ix

1. Introduction..... 1

2. WindFloat Technology Overview 1

3. Port Requirements 1

3.1. Supply Chain Steps and Activities 1

3.2. Process bottlenecks..... 1

3.3. Facility requirements 1

3.4. Criteria selection 1

4. USA East Coast Site Assessment and Strategy 1

4.1. Massachusetts Wind Energy Area (MAWEA) 1

4.2. USA East Coast Port Options 1

4.3. Massachusetts Project Characterization 1

5. WindFloat serialized fabrication process..... 1

5.1. Preassemblies 1

5.2. Final Assembly and Turbine Mating 1

6. Fabrication Study Results 1

6.1. Top-down cost model approach..... 1

6.2. Detailed Final Assembly Process Study 1

7. MAWEA LCOE Cost Model	1
7.1. Model Basics and application to MAWEA	1
7.2. LCOE Model Results for MAWEA	1
8. Conclusions	1
References	1
ANNEX	2
Annex 1: List of most important port requirements	2
Annex 2: NREL study figures of wake losses for MAWEA	2
Annex 3: Port requirements source screening	2
Annex 4. Sample of the East Coast Port Assessment Table	2
Annex 5. Preliminary idea of how a WindFloat assembly line would look like.	2

List of Figures

- Figure 1. Offshore Wind Power Plants presence in Europe, 2016. Source: Cape Wind 1
- Figure 2. Quayside turbine erection of WindFloat 1, 2011. Source: Principle Power Inc. 1
- Figure 3. Views of the WindFloat from top and side. 1
- Figure 4. Conceptual layout of a WindFloat fabrication facility. Numbers are associated to list above. Storage/Stockyard.² 1
- Figure 5. Supply chain process, illustrating also the flexibility in site selection, from highest to lowest. .. 1
- Figure 6. BOEM Massachusetts Call Area with lease areas divisions. 1
- Figure 7. US East Coast Ports reviewed..... 1
- Figure 8. Wind speeds at 90m height for the Massachusetts Wind Area. Directly extracted from [9]. 1
- Figure 9. Offshore Wind Rose showing the prevailing wind direction to be SW. Directly extracted from [9]. 1
- Figure 10. Bathymetry map for the Massachusetts Wind Area. Directly extracted from [9]..... 1
- Figure 11. Distribution of the 1004 km² of MAWEA Area 3 according to water depth..... 1
- Figure 12. Several energy production parameters displayed for the four areas of the MAWEA. Highlighted in red is the Area of interest, this table was directly extracted from [9]..... 1
- Figure 13. Wind Resource at 105 m for MAWEA and Power Production under these conditions for turbine Vestas V164. Obtained by internal model of Principle Power. 1
- Figure 14. Commercial array layout, showing the different cables and properties..... 1
- Figure 15. Extracted from [12] , shows the three main grid interconnection points close to Martha's Vineyard..... 1
- Figure 16. Wind Speed and Wave Height Rayleigh distributions with limitations for installation process. 1
- Figure 17. Conceptual map of the fabrication sequence with the steps..... 1
- Figure 18. Bridgeport layout showing the 4 stations and the Staging Area to store components. 1
- Figure 19. Graph of the cost results corresponding to Table 9 and 10 above. Left graph shows the results for the Distributed/Hybrid scenario whereas right graph shows the complete fabrication in USA. 1
- Figure 20. Gantt charts for two units extracted from the Microsoft Project model built for this report's purposes..... 1
- Figure 21. Resources information in terms of workers needed and hours worked..... 1
- Figure 22. CAPEX conceptual breakdown..... 1
- Figure 23. LCOE past and forecasted evolution for offshore wind energy. Extracted from [13]. *Grid and development costs added, **Grid costs added and contract length adjusted, ***Development costs added..... 1

List of tables

Table 1. Estimated UK LCOE for projects starting in 2015. Source: Department of Energy and Climate, UK..... 1

Table 2. Major WindFloat Fabrication Activity Categories..... 1

Table 3. Final requirements and criteria parameters for different sites according to activities covered... 1

Table 4. Matrix of evaluated ports..... 1

Table 5. Portion of the assessment table for ports to contrast with criteria established in Section 2.(Decrease of quality and formatting due to size reduction)..... 1

Table 6. Net Capacity Factor and Annual Energy Net Production applied to Massachusetts site. The values used come from internal estimations recurrently used by Principle Power..... 1

Table 7. Final assembly steps and timings..... 1

Table 8. General inputs for the Portugal-USA case. Blue cells indicate the user must fill them. 1

Table 9. Cost reductions and productivity inputs of the model..... 1

Table 10. Investment inputs..... 1

Table 11. Primary and secondary steel cost related inputs. 1

Table 12. Cost results for Portugal-USA fabrication scenario 1

Table 13. Cost results for complete USA fabrication scenario..... 1

Table 14. Salary distribution of the hired personnel..... 1

Table 15. CAPEX and OPEX breakdown into different categories explained in section 7..... 1

Table 16. LCOE results for 500MW project in MAWEA area number 3 1

Table 17. Source identification. 2

Abbreviations

AEP	Annual Energy Production
ASM	A. Silva Matos, construction company
CAPEX	Capital Expenditure
COD	Commercial Operation Date
DEA	Drag Embedment Anchor
FID	Final Investment Decision
IAC	Inter Array Cable
LCOE	Levelized Cost Of Energy
MAWEA	Massachusetts Wind Energy Area
OPEX	Operational Expenditure
VLA	Vertically Loaded Anchor
WACC	Weighted Average Cost of Capital
WF	WindFloat
WF1	WindFloat 1, prototype in Portugal from 2011-2016
WFA	WindFloat Atlantic
WFM	WindFloat Mediterranean
WEP	Water Entrapment Plate
WTG	Wind Turbine Generator
WoW	Waiting on Weather

References

- [1] IRENA, "Innovation Outlook: Offshore Wind," International Renewable Energy Agency, Abu Dhabi, Report 2016.
- [2] Roland Berger, "Offshore Wind Power: Takeaways from the Brossele Wind Farm," Roland Berger, Article 2016.
- [3] IRENA, "Floating Foundations: A game changer for offshore wind power," International Renewable Energy Agency, Abu Dhabi, Complement to Innovation Outlook 2016.
- [4] Ram Narasimhan , Thomas Poulsen Jan Stentoft, "Reducing cost of energy in the offshore wind energy industry: The promise and potential of supply chain management," *International Journal of Energy Sector Management*, vol. 10, no. 2, pp. 151-171, 2016.
- [5] Carbon Trust, "Floating Offshore Wind: Market and technology review," Carbon Trust, prepared for Scottish Government, Report June 2015.
- [6] World Energy Council, "World Energy Resources: Wind ," World Energy Council, Market and Tech. Report 2016.
- [7] US Energy Information Administration, "Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2017," EIA, Outlook April 2017.
- [8] Principle Power, "DECC OSW Component Technologies WindFloat Design and Industrialization Study Final Study Document," Principle Power , USA, Confidential 2014.
- [9] Z. Parker, J. Fields, G. Scott, D. Elliott, C. Draxl W. Musial, "Assessment of Offshore Wind Energy Leasing Areas for the BOEM Massachusetts Wind Energy Area ," NREL, Golden, CO, Technical Report NREL/TP-5000-60942 , 2013.
- [10] Larry Caretto, "Use of Probability Distribution Functions for Wind," California State University Northridge,.
- [11] Massachusetts Clean Energy Center, "Offshore Wind Transmission Study," ESS Group, Inc., Rhode Island, Consultant Report 2014.

- [12] ISO-NE, "Draft 2015 Economic Study Evaluation of Offshore Wind Deployment," ISO New England, New England, Public Report Sept. 2016.
- [13] Loris Cañizares, "Industrialization potential and cost optimization for a commercial floating wind farm. ," Principle Power and Instituto Superior Tecnico de Lisboa, Lisbon, Master Thesis September 2016.
- [14] NREL, "2016 Offshore Wind Technologies Market Report," US DOE, Market Report 2016.
- [15] Gavin Smart, "Moving Toward a Subsidy-Free Future for Offshore Wind: Understanding the April 2017 German Auction," Catapult Offshore Renewable Energy, Corporate Report April 2016.
- [16] DONG, "Offering Circular DONG Energy 2016," DONG Energy, Offering Circular 2016.
- [17] Carbon Trust and Catapult Offshore Renewable Energy, "Floating Wind Joint Industry Project: Policy & Regulatory Appraisal," Catapult & Carbon Trust, Scotland, Report January 2017.
- [18] Shane Phillips Aaron Porter, "Determining the Infrastructure needs to support Offshore Floating Wind and Marine Hydrokinetic facilities on the Pacific West Coast and Hawaii," US Department of Interior, Bureau of Ocean Energy Management (BOEM), Edmonds, Report March 2016.
- [19] BVGAAssociates, "Strategic review of UK east coast staging and construction facilities ," BVGA, UK, Report August 2016.
- [20] Tetra Tech EC, INC, "Port and Infrastructure Analysis for Offshore Wind Energy Development," Tetra Tech INC, Boston, MA, prepared for Massachusetts Clean Energy Center February 2010.
- [21] BVGAAssociates, "Virginia Offshore Wind Port Readiness Evaluation. Report 2: Port utilization scenarios.," BVGA, Virginia, A report to the Virginia Department of Mines, Minerals and Energy May 2015.