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BENCHMARKING MARINE RENEWABLE ENERGY TECHNOLOGIES

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INTRODUCTION

Marine Energy is generally viewed as too expensive. However, most costing studies report cost and economics at relatively small deployment scales that make it difficult to compare the technology's competitiveness to other generation options. This paper discusses important considerations for evaluating technologies in the wave energy sector, including:

- The projected cost as a function of technology maturity
- Uncertainty ranges in the cost assessment process
- Economies of scale with regard to plant size
- Learning curves
- Technology innovations that can make a significant contribution to long-term cost reductions

COST PREDICTIONS AT DIFFERENT TECHNOLOGY MATURITY LEVELS

The trend of increasing cost predictions observed over the last decade in marine energy is very common in the development of new technologies and new industry sectors. It is typical that during the early phases of product development, designers both are optimistic about device performance and have a limited understanding of all the factors that will eventually contribute to lifecycle cost and performance. As a design matures, a more-complete understanding of all aspects of the technology emerges, and cost predictions tend to move higher, as shown in Figure 1. With the deployment of the first commercial machine, the various components of a system's economic viability become fully quantified and understood. This baseline understanding can then be used to develop second-generation technologies, which can be used to reduce cost. Within the energy sector, the Electric Power Research Institute has developed specific observations in respect to this trend [1].

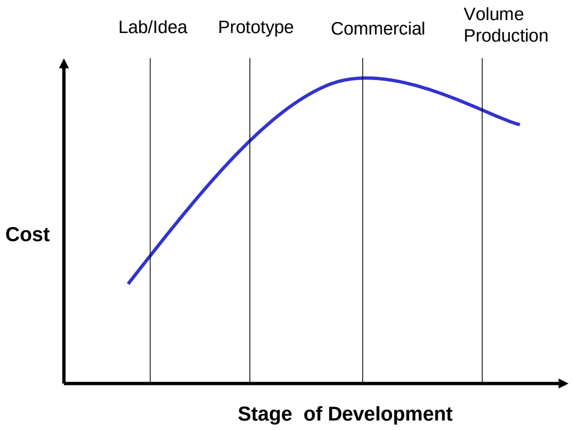

FIGURE 1: PROJECT COST AS A FUNCTION OF DEVELOPMENT STAGE.

The key challenge in predicting commercial opening costs in the wave energy sector is acquiring meaningful data. Very few data points are available from actual deployments, and all existing data points come from pilot demonstration projects, not larger-scale farms. The following section discusses uncertainties inherent in the cost assessment process.

UNCERTAINTIES IN COST AND ECONOMIC ASSESSMENTS

It is important to understand that most cost assessments carried out to date were based on projected costs and were not derived from direct project experience. The reliance on projected costs leads to uncertainties in the cost assessment process that can be substantial and also that depend on the stage of development of the technology and the assessment detail.

The best cost and economic assessment datasets come from demonstration or pilot plants and hence significant uncertainties remain, even if costs are predicted with great care. Typical ranges of cost uncertainty [1] for a demonstrated technology is on the order of -15 percent to +20 percent, while the cost uncertainty for a conceptual design has a -30 percent to +200 percent range. Evaluating the likely uncertainty ranges for costs is an important part in the benchmarking process.

EFFECTS OF PLANT SIZE ON COST OF ELECTRICITY

Wave energy technologies have been deployed in relatively small-scale plants as prototypes or small farms of devices of a few units. The cost of electricity (CoE) from these deployed devices is driven by a combination of factors, including:

- Lack of economies of scale in the manufacturing process
- Need to rely on expensive installation and maintenance methods devised for the offshore industry
- High borrowing cost of capital required to finance these early projects
- Need to overdesign early commercial machines to insure their survival in the harsh marine environment

Most of the above factors driving these high initial costs can be attributed to the lack of any significant deployment scale. Establishing detailed cost breakdowns at different deployment sizes can help to identify the cost-drivers and their importance as technology moves towards commercial scale.

Significant cost reductions can be observed in the costs that are shared between devices, including permitting and environmental assessment and Infrastructure costs. Cost reductions in these areas are fostered by the ability to share these costs between more devices in a project at a larger deployment scale.

Device-related costs tend to be dominated by steel costs. While cost reductions for manufactured steel are anticipated at large-deployment scale due to the ability to leverage economies of scale in the manufacturing process, these cost reductions are finite. Therefore, further cost-reductions required to make these technologies cost competitive with other sources of energy will require technological innovations and changes, such as:

- Different materials
- Improvements in device performance
- Minimizing load conditions and reducing the structural strength required by load-carrying elements

Even more significant are the cost reductions expected in the operation and maintenance (O&M) of marine energy devices. While replacement part costs stay about constant at increasing deployment sizes (no decrease in failure rates is considered), but other cost centers reduce O&M costs significantly including:

Insurance costs -- Insuring one-off devices in the offshore industry can be quite costly, on the order of 2 percent of CAPEX per annum. As technology becomes fully mature and technology-related risks are reduced, insurance costs are expected to drop to a level similar to those for onshore wind energy today – about 0.5% of CAPEX per annum.

Marine monitoring -- Many early adopter projects are expected to require ongoing monitoring of environmental effects from the plant to satisfy regulatory agencies. This includes among others active and passive acoustic monitoring, fish studies, and sediment transport studies. These costs do not increase much with increasing project sizes, and hence a net cost-reduction (on a $/kW basis) is anticipated.

Operational cost -- Cost reductions in this area come largely from being able to switch from carrying out maintenance activities from vessels of opportunity to relying on dedicated vessels that are optimized to carry out the operational tasks of the farm more effectively.

Anticipated LCoE reductions as a function of plant scale were studied during the Reference Model effort and were shown to have an average cost reduction of 47% (49% for wave – RM3, and 45% for tidal – RM1) from 10 to 100 units. This reduction is achieved solely through scale effects, without applying improvements to the core technology. For competitive, defensible comparison of LCoE to other renewables, adopting similar deployment scales across energy technologies is important. It is important to understand that cost-reductions at plant scale are a function of the number of machines installed, similar to the cost reductions observed in manufacturing processes, not capacity. As such, plant-level economies of scale should not be confused with learning curves.

LEARNING CURVES

While predicted commercial costs for larger-scale farms are well below present pilot and demonstration cost levels, significant cost reductions will need to be achieved by the industry if the technology is to be deployed at a large deployment scale in competitive utility-industry marketplaces.

Learning curves are typically used when predicting longer-term cost reductions for an industry. For each doubling of the deployed capacity, a certain percentage cost reduction is attained. Similar renewable energy technologies have historically attained learning rates on the order of 70–90 percent [2]. Wind technology, for example, which is the most closely related analog, has demonstrated progress ratios on the order of 85 percent. It is important to understand that these cumulative cost reductions are tied to a wide range of factors that can drive cost down, including manufacturing scale, operational efficiencies, improved reliability and availability, and fundamental design changes.

PRESENT DAY COST OF MARINE ENERGY TECHNOLOGIES

Various attempts have been made to try to benchmark the cost of electricity using independently developed reference models. To date these efforts have been largely unsuccessful because the design effort required to get to an optimized machine design has been well beyond the scope of these programs. As a result, the design uncertainty has rippled through to cost uncertainty, leading to an over prediction and/or under-prediction of cost and performance.

A better indicator of the present day cost from these emerging technologies are financial support mechanisms developed around the world. The following two examples outline likely costs at near-term 5-10MW scale plants.

Canada – Developmental Tariff: In November 2013, the Nova Scotia Utility Board approved a “declining block” Developmental Tariff. Feed-in rates were set at $455CAD/MWh for 1MW - 5MW scale projects and $375CAD/MWh for 5MW - 10MW projects. In December 2014, four developers were approved to build out 17.5 MW of tidal power under this scheme. The decision-support documents provide cost breakdowns for deployments at these scales, which were established through an industry consultation process. At a present exchange rate of 0.85, this represents a levelized cost of electricity of $386/MWh at a 5 MW scale and $318/MWh at a 10 MW deployment scale.

United Kingdom– Contract for Difference [3]: The UK government, through the Department of Energy & Climate Change, established a rate structure that guarantees rates for wave and tidal. This program replaces the earlier Renewable Obligation Certificate (ROC) program, a support mechanism that was funded by a carbon trading scheme. Rates were set at 305 UK pounds/MWh for wave and tidal . At an exchange rate of 1.51, this represents a representative levelized cost of electricity of $460/MWh for wave and tidal.

These two programs have created significant traction within industry that will lead to deployments of small arrays over the next few years. It is unlikely that private industry would not put its capital at risk if it wasn’t certain that it can deliver projects at these price-levels. As such, these data sources should be regarded as the most authoritative as of to date. Actual commissioning and operation of early array projects will be required to confirm that these price levels are adequate. Similar FIT programs have been very successful at creating initial traction within all renewable energy sectors. A primary example of such technology-specific support mechanisms is Germany’s Feed-In Law, which went into effect in 2000 and successfully encouraged deployment of a wide range of renewable energy technologies.

It should be pointed out that the LCoE for early commercial arrays includes risk-premiums that normally are accounted for in the cost of capital. This means that the early adopter markets established through FIT-type incentives are likely conservative indicators of LCoE.

Finally, there appears to be better traction on commercial projects in the tidal sector then in the wave energy sector. This difference is largely due to the fact that there are more opportunities for technology transfer from wind to tidal, reducing technical hurdles.

TECHNOLOGY AREAS CONTRIBUTING TO LCOE REDUCTION

Globally only a limited number of wave energy devices have been deployed, with a cumulative installed capacity of less than 10MW. Furthermore, the wave technology space is characterized by a wide range of different technical approaches, typical for an emerging technology with limited deployments and very similar to wind about 20 years ago. The limited global deployment also means that no technology lock-in has occurred yet, which is typical for more-established technology sectors. Technology lock-in occurs as a particular technology approach is perfected, manufacturing capacity is built up, and it becomes increasingly more difficult for an alternate technology-topology to enter the market place and compete effectively. A typical example is wind technology, where the 3-bladed, upwind, variable-pitch turbine technology has become the dominant technology. The lack of a technology lock-in makes transformational technology shifts easier to accommodate in the marketplace and opens up the possibility for rapid cost-reduction pathways.

Within the following set of cost-reduction categories, we used in-house techno-economic models to evaluate how much the CoE from wave energy could be reduced within the near-term, based on the improvement potential of technologies now under development:

- Development of efficient operation and maintenance strategies -- Although O&M strategies used in the offshore industry are often adapted for wave energy, they are frequently inefficient and costly. Developing and optimizing O&M strategies and relying on custom vessels specifically built to carry out wave energy operations could allow for a significant reduction in the O&M costs of these devices. Furthermore, recent advances in unmanned vehicle technology (for both surface and underwater vehicles) could allow the use of these vehicles to perform routine inspection and maintenance tasks, a significant opportunity for cost reduction. Early adopter commercial arrays could be used as test-beds for such intervention technologies.

- Improving device power capture --The total costs of most wave power machines today are dominated by structural costs. Specifically, these devices show a poor ratio of power output to the structural cost of the absorber. Most of the wave energy devices deployed today are tuned by adjusting the damping on the power takeoff slowly from sea state to sea state. Many of the device concepts studied to date show significant potential to improve power capture if optimal tuning strategies can be applied. To accomplish this improvement, three different areas of technology innovation are needed [4-6] --
  - The ability to accurately predict waves in the open ocean on a time horizon of 30 seconds
  - Development of control strategies
  - Development of power-conversion systems that allow the implementation of rapid-tuning techniques

- Reducing structural overdesign through improved load-prediction tools-- Most design standards used in the offshore industry are very conservative, leading to a tendency of overdesigning the structure. This overdesign is a direct result of the uncertainties in predicting the driving-load cases for which the structures must be designed. An improved understanding of these loads could significantly reduce required safety factors and hence the total material (and cost) of these devices.

- Use of alternate materials -- Prototype devices are mostly built from steel today. While steel is a great material choice for building one-off devices and can easily be repaired and modified if needed, it is labor intensive to manufacture and hence expensive. In many cases, composites and concrete could be used instead, providing significant opportunities to reduce labor and material costs in the manufacturing process.

- Improve reliability -- The system reliability drives O&M costs because it dictates intervention cycles and also replacement part cost. It is expected that with deployment experience, these system will become more reliable and robust over time.

CONCLUSIONS

The LCoE from marine energy devices deployed today is high, primarily because of the lack of any large-scale deployments. However, careful analysis shows [7] that the commercial opening cost of marine energy is just slightly higher than offshore wind. The detailed study of innovation pathways that can lead to a reduction in CoE furthermore shows that significant cost-reduction potential exists, which could reduce the CoE from commercial-scale marine energy systems to less than 15 cents/kWh in the near future. Nurturing this innovation potential and carefully benchmarking novel concepts and technologies will be critically important over the coming years if substantial cost reductions are to be attained.

REFERENCES

[1] Electric Power Research Institute (March 2008), Renewable Energy Technical Assessment Guide – TAG-RE: 2007.

[2] Yelle, L. (1979). The Learning Curve: Historical Review and Comprehensive Survey. University of Massachusetts Lowell.

[3] UK Department of Energy and Climate Change (December 2013), Investing in renewable technologies – CfD contract terms and strike price.

[4] F. Fusco and J. V. Ringwood, A Study of the Prediction Requirements in Real-Time Control of Wave Energy Converters, IEEE Trans. on Sustainable Energy, vol. 3, no. 1, (Jan. 2012)

[5] J. Hals, J. Falnes, T. Moan, A comparison of selected strategies for adaptive control of wave energy converters. Journal of Offshore Mechanics and Arctic Engineering, 133 (3) (2011)

[6] M.Previsic, K.Shoele, J.Epler, A.Karthieyan. Validation of Theoretical Performance Results using Wave Tank Testing of Heaving Point Absorber Wave Energy Conversion Device working against a Subsea Reaction Plate, Global Marine Renewable Energy Conf., 2014

[7] M.Previsic, et. al, “The Future Potential of Wave Power in the United States”, download available from www.re-vision.net.