FINAL REPORT

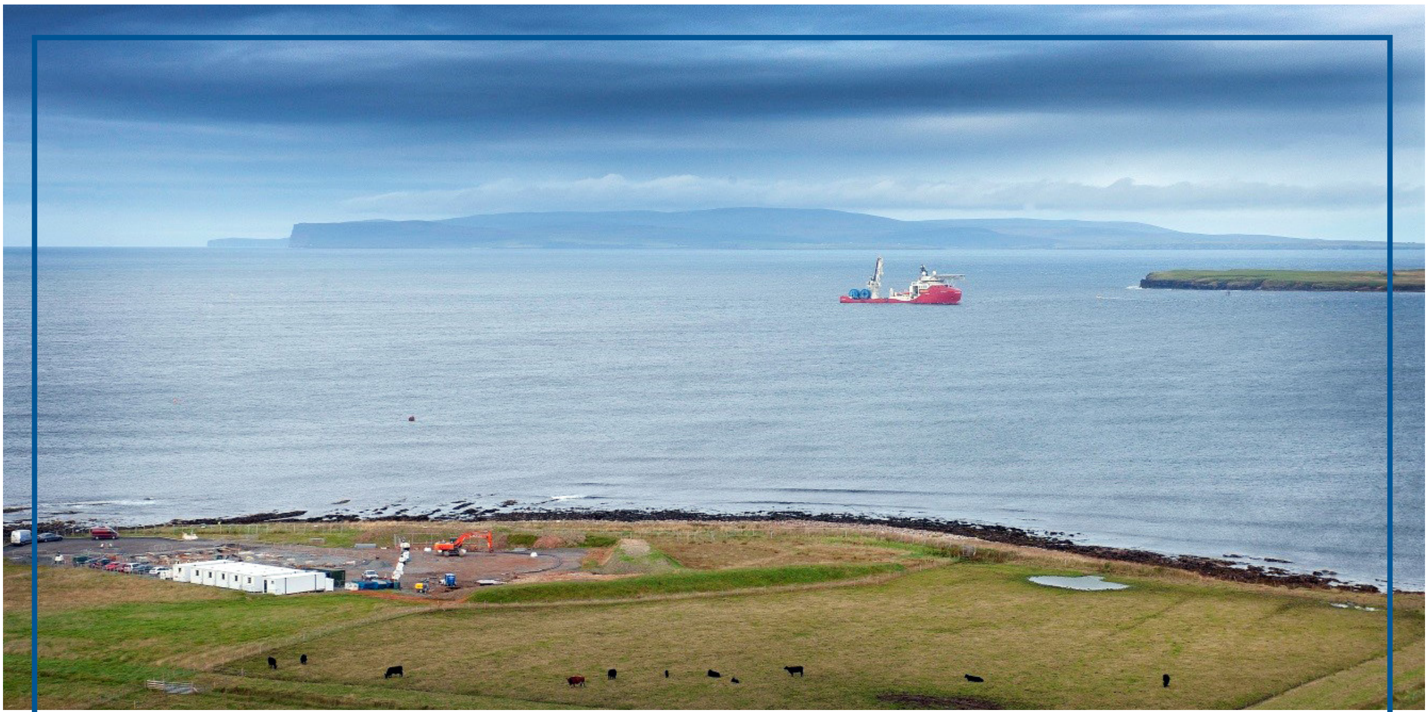
Lessons Learnt from MeyGen Phase 1A Final Summary Report

Lessons learnt from the design, installation and initial operations phases of the 6MW 4-turbine tidal array in Scotland's Pentland Firth

BLACK & VEATCH

Department for Business, Energy & Industrial Strategy

Scottish Enterprise via the Renewable Energy Investment Fund ("REIF"), Highlands & Islands Enterprise, The Crown Estate, and SIMEC Atlantis Energy



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2						
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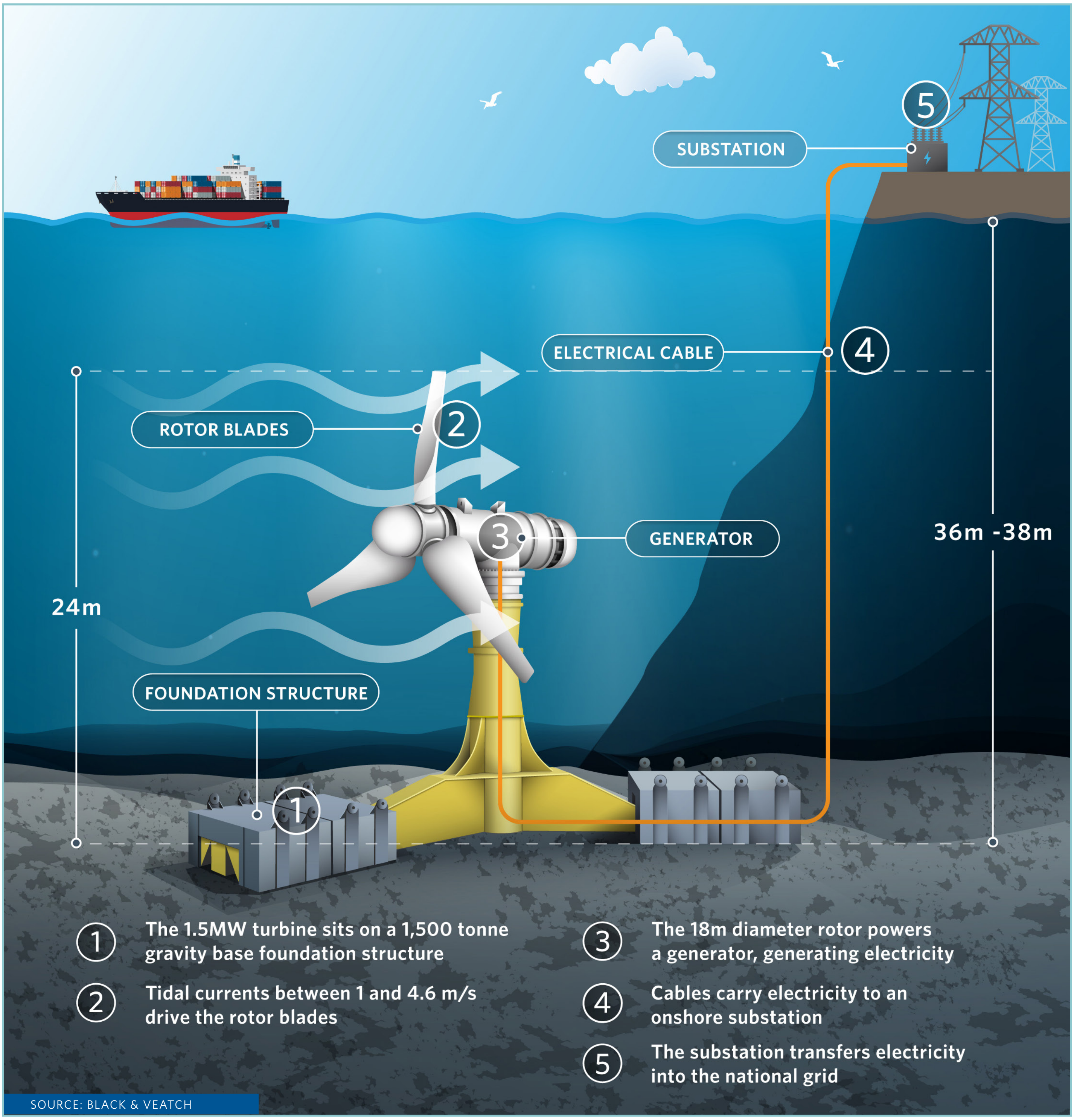
ACRONYMS

ADCP	Acoustic Doppler Current Profile
BEIS	Department for Business Energy and Industrial Strategy
BSI	British Standards Institute
CDM	Construction Design Management Regulations
CoG	Centre of Gravity
DP	Dynamic Positioning
EPC	Engineering, Procurement and Construction
FIDIC	International Federation of Consulting Engineers
HSE	Health & Safety Executive
H&S	Health & Safety
IEC TS	International Electrotechnical Commission Technical Specification
IP	Intellectual Property
JUV	Jack-Up Vessel
LRFD	Load & Resistance Factor Design
MEAD	Marine Energy Array Demonstrator
MW	Mega Watt
MWS	Marine Warranty Surveyor
O&M	Operation & Maintenance
RIDDOR	Reporting of Injuries, Diseases and Dangerous Occurrences Regulations
ROV	Remotely Operated Vehicle
SCADA	Supervisory Control and Data Acquisition
TSS	Turbine Support Structure
ULS	Ultimate Limit State

1 INTRODUCTION

MeyGen Phase 1A is a 6MW demonstration tidal stream energy array comprised of four 1.5MW tidal turbines in the Inner Sound of Scotland's Pentland Firth. The project formerly entered its 25-year operations phase in April 2018. As the first multi-MW tidal array, MeyGen Phase 1A is a trail blazer for the industry. The lessons learnt throughout the design, construction and initial operations phases of the project, relevant to other tidal energy installations, are presented here. Since the project has only been operational for 24 months, the lessons included here are drawn from the initial project phases; long-term conclusions on project performance and impact are not yet available.
Further background, project information and information on the lessons learnt process can be found in **Appendix A**.



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2 CONTENT OF THIS REPORT

In preparing this report, it became clear that the real value is contained in the detail of the experiences, rather than in the overall generic conclusions; high-level conclusions tended to appear either abstract or obvious and trite, and less likely to add value to the wider industry.

This report therefore provides some generic conclusions but also includes a number of the detailed experiences, as the aim is to allow the wider industry to draw their own parallels between the experiences of MeyGen Phase 1A and their own ventures, even if they do not face the exact same circumstances.

2.1 CONFIDENTIALITY

MeyGen and its suppliers are developing intellectual property (IP) that has commercial value to their businesses. Some of the experiences of MeyGen Phase 1A comprise part of this important IP. The sharing of this information must therefore balance the benefits of building a strong tidal industry and protecting the interests of particular companies and their investors.

The process followed in developing this report has been relatively open. However, there are some items discussed that have been withheld from publication. In these cases, wherever possible, the generic conclusion has been included in this report, and the related specific detailed experience reserved.

The MeyGen Phase 1A project interacts with many organisations. These organisations include equipment suppliers, contractors, the Funders (Department for Business, Energy & Industrial Strategy (BEIS), The Crown Estate (Scotland), Scottish Enterprise's Renewable Energy Investment Fund, and Highlands and Islands Enterprise) and licensing authorities. The names of some organisations have been withheld. Where this is the case, the organisations are referred to by their role or, where even this might identify them, they are referred to as Stakeholders.

There is no intention in this report to attribute any issues to individual organisations; the aim is to help all organisations learn from the experiences of MeyGen Phase 1A, which is recognised as a world-leading 'pathfinder' project for the tidal industry. MeyGen is to be congratulated for their achievements to date and their openness in allowing this report to be published, and the contents of this report should be read and treated in that context.

3 LESSONS LEARNT

3.1 LEASING AND CONSENTING

- The level of detail required to meet offshore site leasing conditions, particularly in the early stages of the project, was relatively undefined. For example, differences between moorings and foundations were not clearly defined, and the scope and depth required of any third-party (design) review was also unclear (see Section 3.9). It would be useful to the industry if the requirements could be standardised, wherever possible, and the generic requirements communicated through online publications and conferences to the wider industry.
- In agreement with MeyGen, The Crown Estate reduced their initial requirement for a full Health & Safety review from monthly to annually, with only a summary level Health & Safety review being reported monthly as part of the standard monthly project progress reporting. MeyGen welcomed this as it reduced their reporting burden.

3.2 GENERAL CONTRACTING

- The works comprised a mix of high and low-risk activities, new and established technologies and multiple contract interfaces. MeyGen judged that it was not cost effective to use a single organisation to commercially wrap the whole project into a single contract and take all the interface risks. Consequently, MeyGen chose not to secure a full design and build (EPC) contract, and, instead, used a multi-contract approach.
- Whilst MeyGen aimed to have two to three main contracts, in the event, nine contracts were required to arrive at a contract structure that was economically viable and allowed the project to reach financial close. The main contracts were; turbine supply (from two suppliers), offshore installation, onshore infrastructure works (including power converters), turbine foundation (separate for design and fabrication), foundation ballast supply, Horizontal Directional Drill and cable supply. This was a significant compromise and meant MeyGen had to devote considerably more resource to managing contractual interfaces, which were the primary source of contract claims. It is still judged sensible to keep the number of contracts to a minimum. As the technology and its risks become better understood by the supply chain, it is hoped that there will be more opportunities to reduce the number of contracts and wrap the risks appropriately into each.
- MeyGen used the International Federation of Consulting Engineers (FIDIC) contracts for the majority of the work. Many contractors were not familiar with FIDIC contracts and this meant additional time was needed in the contracting stage, and also for contract management in the delivery of the project. MeyGen still expects that FIDIC can be used in future; however, depending on the suppliers' familiarity with FIDIC it is recognised that more time may be required by both parties to ensure that the project can be delivered effectively.
- The contractors were responsible for preparation of the documentation required to allow the technical sign-off of their own work and payments. The lack of sufficient detail in the contracts on the requirements of this documentation, combined with MeyGen's limited resource availability for contract management, contributed to many late submissions and, in turn, reduced the time available for review.
- MeyGen has come to the realisation that the supplier contracts were written primarily for the construction phase of the project, and the operations phase had not been sufficiently thought about or addressed. It would have been beneficial to take out service agreements with some of the suppliers, identifying an "operator" early on. Ideally such a service agreement would include a minimum availability percentage to motivate the suppliers to maximise performance. However, in practice, due to this project being the first of its kind, no supplier would have signed up to such a performance requirement although they may for future projects if provided with alternative incentives.

- System integration of the turbine, on-shore power convertor, and indeed the entire power train proved difficult due to the separate scopes and contracts for most of these components. This issue was compounded by some suppliers having little incentive to ensure that optimal system integration was achieved. MeyGen believes that the best way of avoiding this issue reoccurring would be to assign the turbine supplier the responsibility for the entire power train systems-integration. This would include, at the very least, the power-converter and turbine to ensure these separate components are integrated correctly, and could also include, for example, cables and switchgear. This would also make it easier for the turbine supplier to extract the data to develop the performance power curve at pre- and post-convertor locations.
- MeyGen found that, as a result of the project being the first of its kind, there were many issues with suppliers that were difficult to foresee. Even in cases where MeyGen was contractually protected, there was often a balancing act between insisting on damages/repairs/reworks and staying on a positive footing with a supplier, which in some instances resulted in a non-optimal working relationship. This type of situation is likely to improve as the industry matures and common issues are identified, and methods developed to resolve these.
- The suppliers were to required (by their contracts) to submit operational documentation for their products, but the level of detail in the documentation varied greatly across all suppliers. In some cases it was severely delayed or omitted entirely due to the suppliers' limited resource which, understandably, was focused on optimising the performance of the product instead. This meant that MeyGen did not have the information necessary to operate some products, and, instead, MeyGen staff had to attend external training courses or, alternatively, a supplier had to modify or operate the product as and when required. In hindsight, MeyGen believes that not having sufficient/adequate documentation and/or not having it when required could have been avoided if relevant payment milestones had been directly linked to the supply of information (as well as to the performance of the product).
- MeyGen found that it is important to not lose sight of the end game in all supplier contracts, therefore ensuring that payment milestones are linked to project completion aspects and not just the completion of a sub-aspect. For example, to link the supply of a power train aspect to its successful integration into the whole system rather than simply its installation.

3.3 CONTRACTING DETAIL

- Some of the coordinate systems used (e.g., for the cable duct exit locations at the onshore site) varied across the different contractors and caused confusion between contractors and their interfaces. The coordinate systems could have been specified in advance in the Basis of Design (or similar) document, and included in the Employer's Requirements[1].
- In order to reach financial close, MeyGen agreed to contractually take on the risk associated with increased costs due to adverse weather, which would usually fall within the risk portfolio of the turbine installation contractor, in this case the turbine supplier. MeyGen also agreed to cover the port costs. All other risk was taken on by the marine contractor and the installation/operational work was carried out under a "best endeavours" agreement, whereby the supplier could not be held liable for unplanned events provided they had worked to their best endeavour. Due to the project being first-of-a-kind, this contractual arrangement was the only option that allowed the project to go ahead while keeping costs down. This approach was considered a reasonable compromise and worked well as MeyGen had a knowledgeable team that were able to monitor decisions whilst onboard the vessel. It is considered that this arrangement would perhaps not have worked so well without MeyGen's presence. As the industry matures it is expected that it will be easier to arrange a custom risk/cost approach as per the client's wishes.
- The original marine operations contract for turbine installation only included the option for retrieval as a contingency (as turbines were not anticipated to be retrieved as part of the construction contract). There were no procedures prepared for such retrievals, which led to some difficulties when this was required. In hindsight, it would have been better to include options for retrieval directly in the contract.
- MeyGen now has between 15 and 20 different subcontracts for the maintenance operations, whereas a single operations supplier would be preferred in the future to simplify operations and maximise availability.
- Despite contracts being complete, MeyGen has found that the turbine suppliers have been unable or unwilling to completely release control of their assets, and have continued to make modifications to control or configuration settings without the instruction of MeyGen. MeyGen recommends that the turbine suppliers are either also engaged under an operating contract or that handover procedures are agreed that make it clear how and when the turbine supplier must cease control of their assets and assigns penalties in the case of non-conformance. Contracts should also specify if and when design and control changes during operations by the turbine supplier are allowed and how they are agreed and recorded.

[1] Employer's Requirements is the name given to the technical section with a FIDEC contract that describes the scope of supply/services and, for example, acceptance criteria.

3.4 RESOURCE MANAGEMENT

Every organisation has limitations on resources. Most projects would benefit from more planning and upfront effort, and the MeyGen project is no exception. Whilst more resources may have been desirable, this might not have been practically or financially viable. For example, if more resources had been devoted earlier, the development cost may have been too high and the project may not have proceeded at all. Therefore, whilst this report lists examples where additional resources would have been helpful, it does not intend to conclude that deploying additional resources would have been viable or the correct course of action. The aim of the observations is to show the implications that low resources may have on similar projects and leave it to the reader to determine what the correct course of action may be for their particular project. Most significantly:

- MeyGen sought to balance the need to provide clear and detailed information to the contractors whilst ensuring that the contractors took responsibility for the design itself. Thus, MeyGen concentrated on managing the contract interfaces. If contractual interfaces had been better defined at financial close and during the project, and understood by the contractors, then there would have been fewer requirements for MeyGen to micro-manage these interfaces.
- If more resources had been available immediately after financial close, then the general problem of starting many lines of work at the same time would have been partially mitigated. MeyGen's management system provides contractors with a single point of contact at MeyGen which helped simplify communication, and generally worked well. However, in the early stages, MeyGen did not have sufficient resources available, and this led to detrimental effects on project schedule. Having the right level of resource at the right time is a significant challenge for any project.
- If more time had been available for design prior to manufacturing commencing, then fewer design changes that affected the manufacturing stage would have been needed.

3.5 GENERAL MANAGEMENT

- Contractors were required to submit monthly progress reports which were often late. In addition, programme updates from contractors were either submitted late, not provided or generally poor. Given that MeyGen engaged nine contractors, these issues exacerbated general difficulties in the overall programme management of such a novel project.
- Using an experienced and local Clerk of Works was very helpful in managing the site work. MeyGen also found that smaller, local subcontractors were generally more willing to complete work on time and take ownership. MeyGen will consider using a higher proportion of small, local contractors in future phases of the project, whilst balancing the overall intention to have fewer larger contracts.
- MeyGen did not assign a specific organisational role to oversee quality assurance across the different contractors. Instead, MeyGen generally relied on their contractors to provide this assurance. This approach should be reconsidered in future projects as, whilst there is some contractual protection, MeyGen was not insulated from poor quality deliverables or the knock-on effect on schedule from any work that may need repeating as a consequence.
- For future projects, there may be advantages in reducing the number of interfaces by having one contract for design, supply and installation of the turbine and similarly a single contract for the Tidal Support Structure (TSS); however, in practice this may be difficult to achieve. A formal interface management system, set up at an early stage of the project, with parameters and milestones for decisions, is key to reducing interface issues.

3.6 BUDGET

- When monitoring a contingency budget, it's important to consider actual work completed rather than solely focusing on monetary spend. If there had been a better understanding of the design status of the project at financial close and during the early stages of the project, then the challenges remaining, and the likely contingency usages, could have been determined more accurately at financial close and during the project. This might also have led to different or earlier decisions being taken regarding contingency usage.
- The MeyGen Phase 1A project deployed a single Atlantis turbine and three Andritz turbines. This low volume of turbine production is not sufficient to drive unit cost reductions. Much larger volumes, associated with later MeyGen project stages (e.g. Phase 1C), are still expected to bring significant economies of scale when dedicated production facilities and tooling can be justified.
- Compared to using only a single turbine type, having two turbine types has resulted in the Phase 1A project bearing additional costs. Overall, however, having two separate turbine suppliers is thought to have been beneficial, as it allowed the two suppliers to learn from each other. It has also allowed MeyGen to contrast and compare the different techniques and equipment, thereby providing a steeper learning curve.
- The turbines are all connected to shore individually. This brought economies of scale in the cabling supply, however, this effect was small compared to the total cost of supply and install.

3.7 PROGRAMME

- The original programme included four turbine installation operations (one per turbine), with significant spacing between operations, designed to suit the turbine production schedules. In practice, turbine retrievals also had to be completed and the spacing between marine operations (for turbine installations as well as for turbine retrievals) was compressed. This increased the programme complexity and put more pressure on the team (as there were more marine operations but the same team size).
- In some cases, it was possible to complete two marine operations in one neap tide period. However, this also caused additional complexity, as it required the offshore installation contractors / vessel operators to revise their originally intended installation plans.
- The use of two installation contractors (one for turbines and another for turbine support structures) increased the interface risks, especially as this change was made during the project and hence was not envisaged in the original (single) marine operations contract. The impact of these risks on the programme was further exacerbated by the time of year in which the works were to be conducted (autumn and winter), and this further contributed to the compressed programme.
- The FIDIC contracts that were adopted contained a clause whereby the supplier could not cease work, even in the case of disputes, without terminating the contract. This proved invaluable on more than one occasion, and, without which, some works would have been delayed indefinitely, at a substantial cost, until after the arbitration of ongoing disputes.
- Vessel capabilities (e.g. station keeping and wave height limits) were not robustly assessed in sufficient detail, and sufficiently early, in the vessel chartering programme when assessing proposed installation methodologies.
- There were instances of vessels not being as capable as stated. Upon completion of vessel selection and sea trials, it became apparent that, contrary to expectations, some vessels were not able to hold station in the peak tidal flows experienced during the neap tide window. In some cases, this impacted upon the ability of the works to progress with continual operations throughout the planned neap tide period window in the manner which was intended.
- With typical contracting structures, marine contractors are likely to have a more conservative perspective of the programme (and hence costs) than the client. MeyGen's view is that it is better to have a programme which seeks to maximise installation opportunities (whilst acknowledging that this programme may not be achieved due to operational events), rather than work to a more conservative (baseline) programme. To achieve this approach, it is important to agree a contractual mechanism that gives both parties a sufficient 'gain' (for bettering the programme) to offset any 'pain' (which the contractor may experience for not meeting the programme).

3.8 DESIGN AND MANUFACTURING

- There were some design changes which occurred after financial close and impacted the manufacturing stage. This created challenges and was difficult to manage given the number of contract interfaces. Now that Phase 1A is complete, the design options available for future phases are much better understood and refined. This means that in future phases of the MeyGen project, i.e. Phase 1B onwards, these design changes are expected to be significantly reduced.
- MeyGen's knowledge of the influence of turbulence improved during the detailed design phase. These influences include the loads on the turbines and support structures and the dynamic interactions between them. This improved understanding helped the detailed design phase, which consequently took longer than anticipated. Designing turbine blades for turbines of this scale at a site this energetic (with respect to wave and turbulence loads as well as non-turbulent tidal loads) was also more challenging than anticipated.
- Whilst 'design for installation' was considered early in the design phase, it was not necessarily considered in enough detail as the project progressed to the detailed design of the turbine(s). If the whole lifecycle costs of the turbine(s) and support structure(s) and their installation and maintenance were considered and fully optimised (which generally requires very sophisticated contract strategies), some aspects of the manufacturing and installation stages may have been streamlined and significantly improved. Separating the design of the turbine installation (undertaken by the offshore contractor) from the turbine design (undertaken by the turbine supplier) may be a necessary contracting decision, but is likely to lead to a turbine that is more difficult and costly to install.
- MeyGen did not generally engage any third party to undertake expediting, or surveillance of the manufacturing processes. This meant that MeyGen's engineering resources were stretched, and this contributed to a relatively flexible programme and a lower level of understanding of contractors' progress with technical issues than might otherwise have been the case. However, some components that were cast in China were subject to third-party surveillance.
- MeyGen would have benefitted if more welding expertise had been available, for example by having a weld inspector to call on for advice during the design and specification stages. Having a weld inspector on site during fabrication would also have helped MeyGen to track progress and resolve technical queries and issues.

3.9 STANDARDS, CERTIFICATION AND VERIFICATION

(a) Standards

- The design of each TSS is based on the DNVGL suite of Offshore Standards and Recommended Practices. These refer to offshore steel structures, typically for the offshore wind industry. Supporting standards, codes and guidance documents have also been applied. Whilst the adopted standards are not specific to tidal turbines, they are recognised within the industry as being amongst the most appropriate. The governing standard is DNV-OS-C101 ('Design of Offshore Steel Structures, General (LRFD Method)') which is based on the Load and Resistance Factor Design (LRFD) approach through assessment of limit states.
- The selection of the Safety Class (i.e. low, normal and high) for a structure is fundamental to the design philosophy and directs the target (nominal) annual probability of failure and thus the LRFD safety factors to be adopted for design. The selection of the Safety Class is to be justified through evaluation of risk to human life, and the environmental and economic consequences.
- Each standard is calibrated with a specific set of Ultimate Limit State (ULS) partial safety factors (i.e. Load and Resistance Factors) and environmental load combinations with a specific return period which, when jointly considered, achieve a ULS design in accordance with the target safety level. The values of these parameters can vary across standards which can potentially lead to applying partial safety factors (or load combination return period) from different standards, which when jointly considered may generate a solution that falls below the required target Safety Class.
- As of October 2015, DNVGL has introduced an offshore Standard that has been specifically developed for tidal turbines, this being DNVGL-ST-0164 ('Tidal Turbines'). Whilst the design principles remain similar to DNV-OS-C101, the new Standard provides a greater level of guidance on developing tidal turbine specific load cases and considers representative site conditions.

(b) Certification and Verification

- MeyGen (and the Stakeholders) considered requiring third-party certification of the turbines and various other aspects of Phase 1A. However, MeyGen did not feel that this process added sufficient value for Phase 1A compared to the cost. This was primarily due to the immature nature of the technology being deployed and hence the certification process itself, but also because, as industry leaders, the MeyGen technical team fast became experts in the field who felt they were able to sufficiently assess and understand the risks associated with decisions. Nevertheless, where type certification and testing were readily achievable, such as on the more standard aspects of the onshore works and the cables, it was pursued by MeyGen.
- MeyGen recognises that certification by a Certification Body could add value for later stages of MeyGen Phase 1, when the benefits to such larger projects could offset the costs. A certification process would generally include the following:
  - Design assessments and approvals;
  - Manufacture surveillance;
  - Installation (including transportation) surveillance;
  - Commissioning surveillance;
  - Agreement on the strategy for operational surveillance and maintenance of the certificate.
- Two of the project Stakeholders did require third-party (design) review of some aspects of the MeyGen Phase 1A project; however (perhaps considering the review needed to determine the applicability of existing standards and the immature nature of the technology), this requirement was not initially well defined. It would be beneficial if Stakeholders could specify up-front the detail associated with any required third party (design) review; for example, whether a detailed review of the design and the checking of various calculations was required, or only a review of the overall design methodology.

- The turbine suppliers also used third-party (design) review of certain components; the approach and value of this varied – perhaps reflecting the immature nature of the industry.

(c) Marine Warranty Surveyor

- The use of a 'can-do' Marine Warranty Surveyor (MWS) with experience of tidal projects was extremely valuable. The good working relationship with the MWS was important as it helped the project progress with flexibility where needed, even in cases where uncertainties existed.
- MeyGen brought the MWS into the project about halfway through the design phase. MeyGen judges this to have been a cost-effective balance between the value the MWS can bring early in the project and the associated cost, and considers that this early engagement with a MWS was a key component to the success of these aspects of MeyGen Phase 1A.
- The MWS satisfied the needs of the insurance company and the cost of offshore operations insurance reduced once the MWS became involved. The MWS was instrumental in ensuring that contractors understood the implications of their work on the insurance or other financing aspects. For example, the MWS actively helped enforce hold points required by the Funders or insurance companies.
- The MWS was able to check the marine contractor's processes against the Certification Agencies' standards, without needing to formally engage with the Certification Bodies.
- Where planned processes/operations were outside the scope of the existing standards, the MWS could only note this and observe. There was no direct feedback between the MWS and the Certification Bodies for example, so these areas remain unaddressed.
- The MWSs were not initially familiar with the kind of operational procedures in often strong currents required for a tidal energy project. Given this, MeyGen ensured that the MWS was fully briefed and in agreement with the procedures prior to leaving port. Ideally a consistent standardised set of procedures should be agreed which would avoid requiring re-approval if the MWS changes.
- All vessel-based marine operations had several go/no-go stage gates depending on the local metocean conditions, with the MWS usually having the final say on whether to go ahead or not. Since weather and current predictions did not necessarily match up with the on-site conditions, there were several instances where operations were aborted as a result of unsuitable metocean requirements. Having a real-time Acoustic Doppler Current Profiler (ADCP) current feed on site has therefore been invaluable as it allowed for detailed operational planning. It would have been even more beneficial to also have onsite real-time wave and wind measurements available.

3.10 CABLE DESIGN

- Insurance companies have previously been exposed to significant claims on cabling on various projects, most notably on offshore wind projects. Consequently, cable design is heavily scrutinised by the insurance companies.
- DNVGL standard DNVGL-RP-0360 provides standardised guidance on cable stability generally; however, there is no dedicated cable stability standard for on-bottom stability on rocky sea-beds, which is the most common seabed type in regions of high tidal flow. A BSI (British Standards Institution) standard on cable stability on rocky sea-beds is currently under development, to which MeyGen is actively contributing. A first draft is nearing completion.
- MeyGen sought a wide range of advice on cable design and installation before deciding on their final solution. Modelling and tank testing were used to help raise confidence in the cable design. However, MeyGen did not find a modelling or testing methodology that could deal with the cable in the region close to the seabed in sufficient detail or with sufficient confidence. Testing and modelling were not able to prove that the cable would be stable on a fractured rock seabed under the action of tidal and wave loading. Given this, MeyGen installed heavily armored subsea cable and positioned rock bags in areas of frequent cable movement and then introduced a frequent inspection/monitoring regime to conform cable stability. This approach allowed for significant cost savings to be made. The installation contractor complimented MeyGen on their overall approach of 'install and monitor' rather than (for example) the overly extensive use of rock bags (or other ballasting means). It is noteworthy that the monitoring work has indicated sliding of the cables and some wearing on the surrounding rock but no damage to the cables.
- The MeyGen Phase 1A cables are installed in directionally drilled ducts for around one third of their total length, before being laid on the seabed for the remainder. The lengths of these ducts were defined at the consenting stage and this led to a design that may not have been optimal. There is clearly a trade-off between the length and cost of the directionally drilled ducts and the overall cable stability. A better understanding of the potential design envelope at an earlier stage, or a more flexible consent, may have mitigated this issue.

3.11 CABLE INSTALLATION

- The accuracy of the directional drilling was found to be high, with the exit points installed within a couple of metres of the target.
- The cables are supplied on drums. MeyGen opted for the readily available and ostensibly cheaper larger drums. This had knock-on impacts on the costs of installation, as larger lifts were required. Smaller, potentially special order, drums would have reduced installation costs and may have been a more economic overall solution.
- MeyGen found that the best method to increase the density of the cable was by adding armouring, rather than making any changes to the main part of the cable itself, which would have had impacts on the cable handling, as above.
- The cable junction boxes were heavy, and this aspect would have benefitted from more detailed planning prior to installation.
- The installation team attempted to use an echoscope and various other means without success to help monitor the installation of the cable (using a Remotely Operated Vehicle (ROV) was not an option). With hindsight, a different cable monitoring system to guide the cable lay process would have been beneficial. The marine installation contractor felt that installing the cables 'blind', with just beacons (i.e. with no electronic survey equipment monitoring the cable landing) would have been more effective than the use of the electronic survey equipment that was used. In the future, MeyGen would consider using rock bags as bollards and turning gates, coupled with beacons, to control the routing of the cables during installation.
- Whilst the installation contractors achieved a high level of installation accuracy, they were unwilling to contractually guarantee their ability to do so. This is understandable given the industry's limited experience of operating in high velocity tidal stream sites.

- Improving the quality and size of the cable rollers onshore would have helped with the cable pull.
- The onshore layout must allow a sufficiently large space for the cable pull equipment.
- The cable cost was roughly equal to the cable installation cost.
- The onshore and offshore cable installation scopes were contracted separately. Given that the two scopes are so strongly aligned and interlinked, with hindsight, it may have been beneficial to have a single contract.
- Demonstrated compliance with key consent requirements, e.g. the Section 36 consented area, should be listed as specific success criteria for the installation.

3.12 VESSEL CHARTER

- MeyGen was able to achieve good vessel rates through use of the spot market; however, this resulted in short windows in which to finalise documentation for review and approval. In the future, MeyGen would aim to:
  - Undertake as much detailed work as possible prior to vessel selection;
  - Carry out workshops to review these initial procedures to iron out non-vessel-specific details and agree a baseline procedure and deck layout;
  - Encourage a collaborative approach to achieve the required timescales with:
    - Marine contractors to work diligently and quickly once vessel has been selected;
    - Client to be at their disposal to review documents;
    - MWS aligned with expectations to review and comment;
    - The document control system being capable of supporting this approach.
- In hindsight, not enough detailed analysis was carried out on the vessel selection at an early stage and this led to overly optimistic expectations on Dynamic Positioning (DP) capability and crane capacity. MeyGen has now developed a questionnaire to enable a quick assessment of the suitability of vessels for the site. For example, crane capacity is often a limiting factor and all vessels (for tidal operations) need azimuth thrusters. However, standard vessel performance plots do not give enough detail to allow their full assessment for tidal sites such as MeyGen, so it is necessary to run simulations to understand the actual vessel performance and sensitivity to the turbulence experienced on tidal sites.
- The contractual relationship relating to vessel charter can become complex. For example, in this case, the marine contractor was required to recommend vessels which MeyGen then chartered. However, there was no particular incentive for the marine contractor to select the most cost-effective vessel or to negotiate the optimal vessel rate(s).
- MeyGen found that using a shipping agent for vessel selection/procurement did not always result in the most cost-effective overall solution, as the agent's selection criteria focused on the cost of a single operation rather than long-term operations. For example, in one instance, the agent selected a pricey demobilisation/mobilisation fee, when it would have been cheaper to pay a standby fee for a particular vessel. Frequently changing vessels also meant that the O&M procedures had to be changed to suit the new vessel which in some instances unnecessarily overcomplicated matters and required more time before the new procedures were established. MeyGen therefore found it more cost-effective to train and establish a vessel-selection procedure in-house.
- One of the most impactful lessons learnt by MeyGen from a cost perspective is that DP vessels do not normally work in currents stronger than 6 knots. In stronger currents, the vessel's navigational system would introduce an offset to the target position that had to be manually adjusted and changed with flow speed. Once identified this offset was monitored by the DP Operator to allow works to continue.

3.13 TURBINE SUPPORT STRUCTURE (TSS) INSTALLATION

- MeyGen Phase 1A uses gravity foundations which have three feet that each require a suitably level seabed. MeyGen has found it challenging to find locations that satisfy the foundation requirements for all the feet of all the foundations. In particular:
    - Given this difficulty, MeyGen found that an earlier more detailed study of the seabed conditions, including bathymetric and visual inspection, would have been valuable;
    - Greater allowance for micro-siting the foundations should have been made, thus enabling a better positioning of the cables;
    - MeyGen should have given a higher weighting to this issue when deciding between the use of gravity base or monopile foundations in the early engineering stages;
    - The seabed at some of the individual foundation sites needed to be consolidated due to the presence of large boulders;
    - MeyGen prioritised the standardisation of the foundation design over flexibility to suit the different seabed conditions, and would have benefitted from a more flexible foundation design;
    - Seabed compaction due to the placement of the gravity base foundations is an important design driver and is difficult to determine before full installation.
- Through the application of detailed engineering and planning (as well as site-specific sea trials), the safe use of a large Jack-Up Vessel (JUV) at a high velocity tidal site such as MeyGen was proven to be possible (this approach had previously been questioned within the industry for a number of years). This allowed the TSS to be installed within +/-2.5 degrees tolerance on verticality and +/-5 degrees on heading. MeyGen's view is that for installation of large structures such as the TSS, a JUV can be cost effective; however, MeyGen would still expect to use a Dynamic Positioning (DP) vessel for turbine and cable installation.
- The crew was able to position the JUV as the tidal velocity reduced to slack water by continuously monitoring vessel thrust as the legs were lowered in a series of stages. Typically, there was enough time around slack water to safely complete this operation. As this method was not developed prior to the installation, the MWS requested that sea trials were completed to demonstrate the safe lowering of the jack-up legs at this specific site.
- No 'punch-throughs' of the seabed were experienced during the positioning of the JUV.
- The JUV crew was aware of vortex shedding (one of the expected issues related to the use of a JUV in high velocity tidal sites due to previous experiences) and at some points this resulted in yawing of the JUV platform around the JUV legs. However, the motion was not significant enough to prevent operations. Studies may n eed to be carried out to review whether sustained operation of JUVs in these conditions (e.g. for a large array, or multiple array installations) would reduce the design life of (parts of) the JUV.
- The TSS design included 'feet' to prevent the main structure (i.e. legs) from contacting the seabed. In some cases, these articulated feet landed at an unfavourable angle and the foundation had to be lifted and repositioned (which in itself is not a trivial operation and one which adds time to an extremely time-sensitive programme).
- Where possible it is advantageous to use assets for their primary purpose. For example, the JUV operator brought in a supply vessel to transfer the ballast blocks from the local staging port to the JUV, allowing faster transfer and allowing the JUV to remain on station.
- It is important not to overlook the wet test of any survey equipment prior to the installation works commencing.
- It was found to be beneficial that the crew was able to access survey information at their vessel workstations rather than in a remote cabin (e.g. placed some distance away on the deck requiring information to be relayed via radio).
- Operational methods were refined with experience of each additional operation. Ideally, this process should be allowed for, if not encouraged, through the contracting mechanism.

3.14 TURBINE INSTALLATION

- Having separate contracts for turbine supply and installation meant that the turbine suppliers were not necessarily incentivised to make design decisions which would reduce installation costs (see also Section 3.8). There could be significant benefits in getting the turbine supplier and installer to work to minimise the overall cost prior to financial close, or aligning these incentives by another means.
- To simplify installation, the dry and wet Centres of Gravity (CoG) should be very close to each other. A much simpler lifting frame can be used when there is no significant shift in the CoG when transitioning from a dry to wet environment. Furthermore, four load points on top of the turbine were found to be less complex to handle, and therefore the design of the nacelle should ensure that this can be accommodated (for example, in locating inspection hatches).
- A good rule of thumb is that the turbine dry weight should be less than c. 65% of the proposed notional crane capacity (recognising that crane capacity in various sea states and with different boom lengths must be considered in detail).
- Repeatedly lifting the turbine (and in particular, sensitive components such as wet-mate connectors) through the splash-zone should be avoided if alternatives are possible. For example, it was found that it was more effective to achieve exact alignment of the turbine once below the waterline rather than lifting the turbine out of the water to make alignment adjustments.
- The turbine suppler should ensure that the turbine's external design, particularly handling interface points, is approved by the marine contractor and any changes are carefully documented and agreed in order to reduce handling risks, e.g. snagging lines or umbilicals.

- An extruding lift point engagement feature, such as Atlantis' "lobsterpot", proved to be very useful in seating the lift frame onto the turbine and reducing the time required to retrieve a turbine.
- Consider how blades (or other controllable features) might be used to assist heading alignment during installation. Initially, it was assumed that having the blades pitched to feather would be the best approach. However, it was found that installing the turbine with the blades pitched to drag, with flow from behind, was an effective way to stabilise the turbine and prevent it from yawing in the water column.
- Planning operations should include detailed, infrastructure-specific analysis. For example, if a turbine can only be successfully lifted from the quayside at high tide, there may be benefit if delivery can be arranged so that it can be transferred directly to the vessel without being put onto blocks on the quayside.
- Planning and design for sea-fastenings should be given sufficient consideration, and ideally interfaces between the transport frames and the turbine would mirror the subsea interfaces between foundation and turbine.
- Ensure that any requirement for temporary electrical power from the vessel to the turbine is designed for, and the selected vessel has adequate connection points and electrical supply characteristics (e.g. the required voltage). If the exact requirement is not available, consider the use of an additional temporary power supply rather than the vessel's on-board systems.
- The installation works at MeyGen experienced a number of minor incidents which saw partial damage to the lift frames and the umbilical cables. These incidents resulted in modifications being made to the frames to reduce snagging risks in future operations:
  - The umbilical was routed up to the main lifting hook to take it away from the load being lifted (i.e. a turbine) and the ROV work area;
  - The umbilical was suitably managed on deck and protected from contact forces.
- MeyGen found that the use of dry-mate connectors significantly increased the complexity of the turbine installation, due to the need to handle the cable tails attached to the turbine. MeyGen's preference going forward into future phases of site development would be to use wet-mate connectors; however, if cable tails are to be used then they would employ different cable management methods (for example, use of a cable pallet and carousel) to manage the cable tails during the lifts. The use of cable tails increased the mobilisation time required, and also required standby periods between operations. Additionally, the use of dry-mate connectors restricted the permissible current velocity for installation operations, as the vessel remained connected to the sea bed. This limited installation windows to neap tides, which made it more difficult to negotiate on vessel rates due to the lack of flexibility.
- The potential need for handling a turbine connected to a sub-sea cable whilst the turbine was on deck presented significant challenges and risks which were not fully recognised until the detailed method statement for the operation was prepared. Such challenges can lead to disagreement between parties on the best way to resolve them. In this specific case, wet-mate components would have mitigated the potential risk.

3.15 GENERAL INSTALLATION

- MeyGen has generally found that ROVs are not suited to the conditions.
- MeyGen still prefers to minimise the use of divers for Health & Safety reasons, although divers still offer unparalleled dexterity. Divers with local knowledge were found to be the most valuable.
- The onshore and offshore teams would have benefitted from better radios to communicate with one another.
- Where possible, remove the need to use a work-class ROV to support the main activities (as this is likely to extend the operational window for subsea works), for example:
  - GeoSea installed ballast blocks without any ROV in attendance;
  - Atlantis landed their recovery frame aided by an observation-class ROV, and later without any ROV in attendance.

- Simultaneous Operations (SimOps) on a tidal site are possible if suitably managed, for example, between a jack-up vessel and a supply vessel or a pair of DP vessels. SimOps require:
  - Early consultation with vessels masters and MWS;
  - Marine co-ordinators on each vessel;
  - Detailed passage management prior to, during, and after works are complete;
  - Transfer of information between vessels, ideally using a data link; however, expect this not to work and have contingencies in place.
- Weather forecasts which were marginal in terms of meeting the criteria for successful operations led to disagreements between MeyGen and the marine contractor as to the risk of starting an operation. Each party was not entirely aligned, or contractually incentivised at the outset, on the management of risks and rewards.
- In general, MeyGen noted that the level of buy-in from the vessel crew made a significant difference to achieving the expected programme.
- Whilst some vessels had a good (i.e. sufficiently fast and with sufficient bandwidth) satellite communication system, this was not the case on all vessels. The team solved this by also taking USB 'network dongles' which worked well at the MeyGen site.
- For future projects, MeyGen foresees that there are opportunities for savings to be made on the installation contract based on the learning from MeyGen Phase 1A. For example, with the knowledge it now has, MeyGen may be able to take more of the risks in-house and reduce the contingency put on the contract by the marine contractor.
- Significant savings can be made during installation by employing design and operational efficiency solutions aimed at reducing the installation time. This is due to the large costs associated with vessel rates, crew rates, and mobilisation costs coupled with the weather window availability,

3.16 ARRAY INSTALLATION

- MeyGen Phase 1A was originally planned with an expectation that all works would be conducted using DP vessels. This made it difficult to position the JUV to install the TSS around the cables (as these had been installed by the time the decision to use the JUV was taken).
- The installation (and retrieval) of multiple turbines was efficient as it made use of a mobilised vessel. However, these additional works placed increased demands on the project team within discrete neap tide windows. Removing the need for dry-mate cable works would significantly reduce the requirement for short duration operations.
- The project had expected to install turbines consecutively, and as a result the project had not purchased multiple assembly frames. In hindsight, additional frames should have been procured as a contingency against variation in the programme.
- The later turbines to be installed were being installed alongside turbines which were already in the commissioning and generation phases. These operations required detailed operational planning by the construction team to ensure that the works and existing assets were not placed at risk.
- For future projects, MeyGen foresees that there will be more opportunity to reduce (construction) costs through the application of operational learning on a site with more turbines (and TSS) being installed. MeyGen Phase 1A has benefitted from the learning achieved through multiple installations, however, the extent of this was limited as there were only four turbines. For sites with more turbines, the majority of the installations will benefit from the initial learning from the installation of the first few TSS and turbines.

3.17 ONSHORE WORKS

- Connecting to a remote point on the distribution network can be very challenging. This is particularly so during the winter months when offshore dynamics and onshore grid transients and outages are more significant. The testing and commissioning programme (for the onshore works) ought to recognise this increased likelihood of extreme conditions during the winter.
- The interface between the turbine supplier and the onshore works contractor, specifically relating to the onshore converters, proved complex. Although converters with extensive previous use for wind turbines were utilised, application-specific modelling and engineering work was needed to optimise the converter performance for tidal turbines. In the long term, there could be benefit from integrating the converter supply with the turbine supply contract.
- The remote location has made it critical to have a full-time local site manager, even though the original expectation was that there would likely not be the need for full-time site staff beyond the initial operations phase. It may also have been worth having a Senior Authorised Person (relating to electrical works) permanently on site during some of the construction phase, as the location made it difficult to get personnel when required. However, it is anticipated that staff requirements during the operations phase would be the same even for a substantially bigger array. The remote location also made communications very difficult, initially with no internet access and no mobile reception.

3.18 GENERAL OPERATIONS

- MeyGen found that the speed of information supply and responsiveness to technical queries was much slower for larger suppliers due to the corporate procedures and restrictions in place.
- Most Operations and Maintenance (O&M) contractors applied the same philosophy as for offshore wind in terms of attempting to maximise overall availability. However, in tidal energy, priority has to be given to maximising availability during times of peak flow. This was a novel concept to most O&M contractors, and therefore something they should be made aware of early.
- In terms of offshore operations, MeyGen recommends that no sea-fastening weld has leg lengths of more than 6mm, as this requires only a single pass rather than three. This saves time and cost as it limits the vessel port time during mobilisation.
- ROV video monitoring of the underwater components to date has revealed that:
  - biofouling is minimal on any surfaces oriented away from the sea surface (see Appendix A, Figure 1);
  - boulders have moved around the TSS (Appendix A, Figure 3);
  - rock bags have rolled, and
  - some cable bend restrictor bolts have vibrated loose.
- The operating costs are largely driven by the hardware and staff requirements during interventions. This is because large deck areas are required for turbine recovery/installation, and this translates directly into significant vessel and crew costs.

3.19 HARDWARE

- One of the turbine types required backup power in the event of a power cut. The backup power was required to allow the user to continue to monitor the turbine, to ensure it remains at the required temperature, and to prevent the need for manual re-calibration of the pitch controllers. This requirement for backup power resulted in a number of associated issues. Firstly, it meant that a battery pack was required during ship transit. The battery pack required an earth connection which is not available on a vessel. As a result, the batteries were damaged, and this was not discovered until after deployment which resulted in a de-installation and re-installation being performed. Secondly, this type of turbine requires an onshore stand-by generator for use in the case of grid loss. The changeover between grid and stand-by generator and back to grid takes a substantial amount of time, resulting in a total of circa. 3 days downtime per year. Automating this process would increase availability but MeyGen would recommend that a simpler solution would be to specify that the turbine technology should not require backup power.
- MeyGen employed Fin Fan coolers in the onshore substation to cool water from the converters. The coolers met their design specification but caused corrosion of the printed circuit boards due the use of external air which, due to the proximity to the sea, was high in moisture and salt. It was found that this could be improved by re-circulating air within the building instead. Corrosion has also been an issue on other parts of the substation, such as its doors.
- Any feature that was required to latch or be secured underwater should include a visual indicator to ensure the arrangement is fully locked.
- MeyGen encountered fewer technical issues with the pitch system of those turbines employing an electrical pitch system in comparison to those with a hydraulic pitch system.

3.20 SUPERVISORY CONTROL AND DATA ACQUISITION (SCADA)

- MeyGen initially had problems with not being able to sufficiently remotely control the turbines and balance of plant aspects from their Edinburgh office location. This resulted in the need for frequent site visits by personnel which would not necessarily have been required under normal circumstances. Integrating most data feeds, including the protection system and those associated with substation facilities, into a tried and tested SCADA system early on would avoid this issue. A flexible system that allows addition of custom data streams is therefore recommended.
- The turbine suppliers' focus was, understandably, on the turbine itself, but this has meant that the development and supply of peripherals such as the SCADA software have been secondary. This has led to a number of teething problems with the SCADA systems. One of the two SCADA software systems in particular, is difficult to interrogate and extract data from. Since MeyGen does not have rights to the required software, it is unable to change the outputs without needing to revert to the supplier. The other turbine supplier's SCADA system did not originally include a data feed or functionality for control of the convertor. In hindsight it would have been beneficial to put more thought into the requirements of the SCADA system and the customer's ability to modify it during the contracting stage. The contracts should also define who the ultimate owner of the data is and how it should be archived to avoid data loss.
- MeyGen considers a key requirement of a SCADA system to be user-friendliness, in particular the ability to access key parameters and any faults/flags on a single page including those for balance of plant as well as for the turbines themselves. The system should also be able to distinguish between high and low-level warnings, and have the ability for the user to turn off low-level warnings if required. In addition, the SCADA system should be able to distinguish between normal operational status changes and faults, and allow easy and fast long-term data extraction for interrogation purposes.
- A meter should be installed within the turbine to avoid having to back-calculate the output from the converter.

3.21 ASSET MANAGEMENT

- The original maintenance strategy was to implement all maintenance activities recommended by the equipment suppliers. However, MeyGen has found that in some instances this is not cost effective at the scale of the current project so adjustments have been made accordingly.
- MeyGen have found that having a motivated and flexible local site manager is key to addressing any project related issues and thus keep operations going.
- The decision of which spares to hold in stock has been driven by a risk-benefit analysis based on lead times and costs for each component. Where possible, this was coupled with data from early learning on the required frequency of replacements. It may be advantageous to make the supply of spares part of the supplier contract or link it into the service supply agreement. MeyGen would be open to discuss an industry-wide spare pool of common components to keep costs down.
- The content of the condition monitoring reporting for both turbine types was not specified previously and the reporting therefore varies greatly between both turbine types. For example, this makes it difficult to accurately contrast measurements of flow, power and temperature. This could have been avoided by specifying the condition monitoring requirements during contracting.

3.22 HEALTH, SAFETY AND ENVIRONMENT

- MeyGen engaged with the Health and Safety Executive (HSE) and their Diving Inspectorate early in the project, and developed positive relationships with both parties which they are keen to foster.
- MeyGen split the installation contracts into onshore and offshore works and used two Principal Contractors. This appears to be contrary to the guiding principles of the Construction Design Management (CDM) Regulations where a single organisation should be in overall control. However, MeyGen judged that the skills required onshore were sufficiently different to those required offshore to justify this approach.
- MeyGen incurred significant time in reviewing, modifying and then agreeing contractors' Health & Safety and Environmental documentation.
- MeyGen found that the interpretation and working implementation of CDM Regulations varied greatly across the contractors (and their subcontractors) and it was difficult and time consuming to enforce a standard approach. MeyGen found that some issues had to be 'micro-managed' between MeyGen's contract managers and their respective contractors. This created another interface between MeyGen and its contractors, adding to the management burden. Once implemented, MeyGen found that a standardised approach was beneficial to the project.
- The above two points suggest that the supply chain generally still requires better engagement on Health & Safety and Environmental matters, and specifically on CDM. And also that Health & Safety and Environmental responsibilities and standards need to be defined very carefully at the contracting stage.
- MeyGen would have benefitted from implementing a common approach to recording Health & Safety statistics and information. This would have perhaps been easier than reviewing and monitoring each contractor's approach individually. A standardised system might include:
  - A standard reporting proforma;
  - An online data capture system;
  - Better defined contractual requirements, to ensure timely and accurate reporting.

- During the construction works there were two reportable incidents under RIDDOR; a diving equipment failure where the back-up system became faulty and the diver had to surface per emergency procedures (reportable by the contractor); and an incident when a person fell whilst building a crane (found to be as a result of the company not following their own procedures).
- The main source of other incidents was slips and trips on vessels, particularly when crews changed and a lesser experienced (in terms of the specific job) crew took over the operations. These incidents generally also concerned shore-based crew aboard the vessels at load-out, not whilst the vessel was offshore. There were also a number of incidents of damage to equipment, e.g. damage to a strop after snagging, but work was stopped before it could result in injury.
- On reflection, MeyGen has highlighted the following potential opportunities for improvement:
    - Reducing the number of crew transfers and mobilisation/demobilisation activities;
    - Using one vessel with an optimised deck layout, or if different vessels are required having kit 'boxed up' and ready to transfer onto the vessel;
    - Adopting a 'production line' approach when carrying out multiple installations (e.g. having individuals stick to the same specific role for each installation).
- Having two marine contractors working offshore required the role of the Principal Contractor on the offshore site to be clearly defined when the second offshore contractor became involved in the installation of the TSS.
- Handling cable tails on deck (for the dry-mate Andritz turbines), which could be under tension, increased risk compared to the use of wet-mate connectors.
- MeyGen is in discussion with other industry representatives on how best to use the gained experience to improve existing industry marine energy Health & Safety (H&S) guidance.

3.23 PERFORMANCE

- MeyGen recommends that, as part of the initial resource assessment, an ADCP is placed at the exact location of the proposed turbines, rather than in the vicinity, as this will provide certainty with regard to the environmental conditions the turbine will face. MeyGen also recommends designing the turbine and blades for a range of environmental conditions (for example turbulence intensity or flow speed) and not just for a particular small envelope. This will provide greater adaptability should the conditions be different to those expected.
- When providing availability figures, a distinction should be made between time-based availability and energy-based availability, with the latter being more significant as it is based on the availability during times of peak flow and thus energy and revenue. It should also be accepted that availability will invariably be higher during summer than winter months (MeyGen is currently achieving c. 90% availability in winter and 98% in summer).
- MeyGen attempted to conduct the power performance assessment according to the International Electrotechnical Commission Technical Specification (IEC TS) on Tidal Power Performance Assessment (IEC TS-62600-200), but in practice found that the required bed-slope conditions for ADCP placement could only be met on one side of each turbine. This, in conjunction with the excessive costs of deploying two bed-mounted ADCPs per turbine (i.e. 8 in total) led to the decision to place only a single ADCP on either the incident flood or ebb side of the turbine (whichever met the required seabed slope conditions). It is noteworthy that one of the ADCPs shifted during the survey, rendering the data unusable. The onboard nacelle and hub mounted ADCPs of one of the turbines was then used to develop a nacelle-to-hub ADCP relationship to arrive at hub-height velocities for the opposing flows and/or other turbines using their respective onboard nacelle ADCPs. This approach was not previously verified, but MeyGen concluded that the nacelle-to-hub shear exponent approach in this instance appeared to produce reasonable estimates of hub-height velocity from the nacelle-mounted ADCP when directly compared to bed-mounted ADCP data (where this was available).

MeyGen concluded that using only a single ADCP on either the incident flood or ebb side of the turbine for a power performance assessment is difficult, but worked in this instance, due to the onboard ADCPs. Going forward, MeyGen is considering still using only a single ADCP per turbine for future power performance assessments. This would be placed perpendicular to the main flow direction, in line with the turbine, to allow it t o measure both the ebb and flood flows, albeit slightly offset spatially. MeyGen is in communication with the IEC TS-62600-200 Maintenance Team to feedback on their usage of the technical specification.

- MeyGen has found that system losses (as a percentage) vary with power so errors may be introduced if the power curve is measured at the turbine and system losses applied separately. The latest thinking is therefore that the most applicable power curve is that measured at the point of grid connection.

3.24 STAKEHOLDER AND ENVIRONMENTAL

- No conflicts have arisen with local stakeholders during the construction and operation of Phase 1A.
- A range of environmental monitoring activities have been completed including acoustic monitoring and tagging of marine mammals. Findings have not raised any concerns about the interactions with local wildlife. Associated publications can be found in Section 6.

4 ORIGINAL PROJECT BUDGETS

The total capital budget agreed at financial close in October 2014 was **£51.3m** and the operating budget was c. £1.4m/year. Figure 1 shows the split of the capital cost across a number of cost centres, and similarly Figure2 shows the split of the operating budget.

The capital budget also included some contingency, which has been spread evenly across all of the cost centres in **Figure 1**.

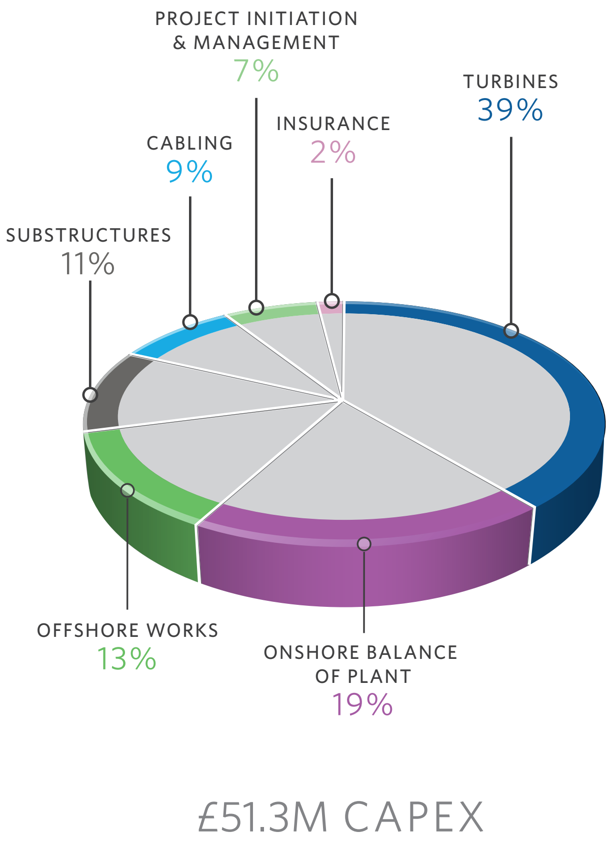

Figure 1: Capital expenditure breakdown

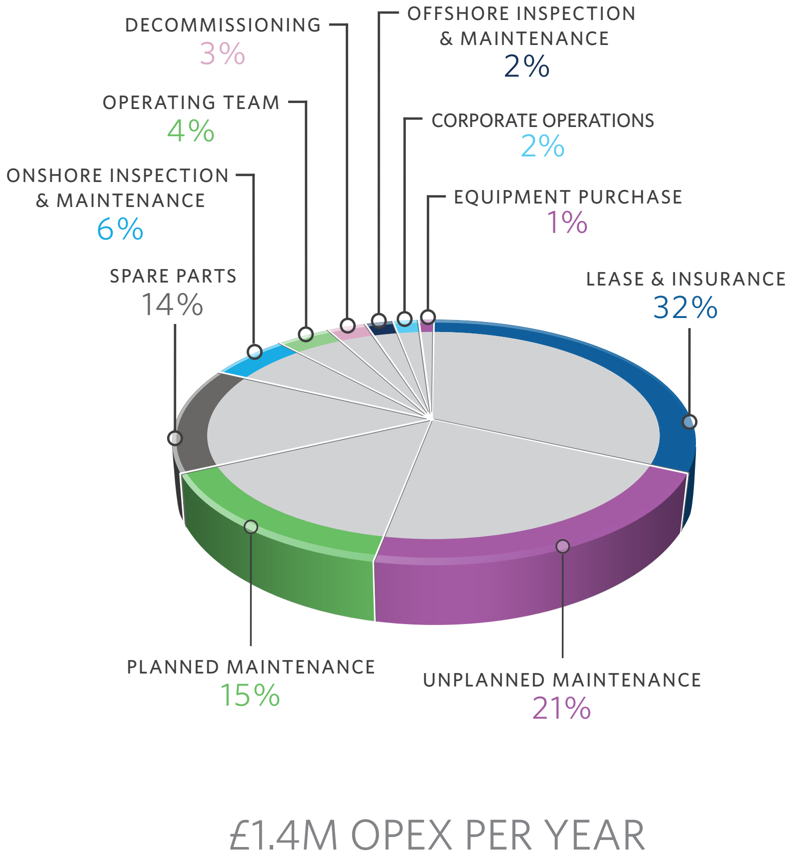

Figure 2: Operational expenditure breakdown

The above costs in **Figure 1** do not include costs incurred prior to financial close, such as the costs of project development, engineering and gaining consents.

5 ORIGINAL POWER PERFORMANCE ESTIMATE & LATEST FORECAST

MeyGen 1A exported 21GWh to the grid during its first 18 months of operations. The turbine details for the Andritz and Atlantis turbines are listed in Table 1 and Table 2 respectively.

ANDRITZ TURBINE CHARACTERISTICS	VALUE
Installed capacity	1.5MW
Rotor diameter	18m
Number of turbines in MeyGen Phase 1A	3

Table 1: Andritz Turbine characteristics

ATLANTIS TURBINE CHARACTERISTICS	VALUE
Installed capacity	1.5MW
Rotor diameter	18m
Number of turbines in MeyGen Phase 1A	1

Table 2: Atlantis Turbine characteristics

The contractual average coefficient of performance *(C_p)* is that calculated in order for the turbines to meet their target performance. This 'contractual *(C_p)*' estimate assumes that the *(C_p)* is constant from the cut-in velocity to the rated velocity (at which rated power is reached); the *(C_p)* between rated power and the cut-out velocity is not included in this calculation. This *(C_p)* accounts for all 'water-to-wire' losses up to the export terminals of the generator. It does not include for losses in the cables to shore, power converters, transformers or cables to the grid connection point.

The current best estimate of the 'actual *(C_p)*' for the Andritz turbines (averaged across the three turbines) is derived from the initial power curve tests under the turbine supply agreement, and is on the same basis as the 'contractual *(C_p)*.

The 'contractual energy yield' for MeyGen Phase 1A is taken from the turbine supply agreements. It represents the full 25-year project life, assumes a project-wide availability of 95%, and is based on the minimum performance metrics in the turbine supply agreements. The minimum performance metrics in the turbine supply agreements are based only on part of the turbines' overall power curve and do not include for the performance at relatively low and high flow rates. It was therefore anticipated that in reality the turbines would exceed their target performance and that the actual capacity factor would be significantly higher.

The current best estimate of the 'actual energy yield' for MeyGen Phase 1A is based on the full 25-year project life and a project-wide availability of 95%, but uses the validated tidal resource model (rather than the contractual tidal resource), actual turbine performance *(C_p)* and actual system losses.

The contractual and actual capacity factors at the export terminals of the generators and after all system losses are also shown.

The significant increase (of c. 21%) in the actual energy yield (and capacity factors) compared to the contractual energy yield (and capacity factors) is almost all (c. 95%) due to an improved (actual) flow distribution compared to that specified within the turbine supply agreements, with the remainder due to the improved (actual) (C_p) and reduced (actual) losses.

MEYGEN PHASE 1A CHARACTERISTICS	VALUE
Installed capacity	6MW
Number of turbines in MeyGen Phase 1A	4
Contractual lifetime energy yield (95% availability and all system losses)	370,000 MWh [6]
Actual lifetime energy yield (95% availability and all system losses)	450,000 MWh [7]
Project Life	25 years
Contractual (C_p) (all turbines)	0.38
Actual (C_p) (all turbines)	0.41
Contractual capacity factor (100% availability at generator terminals, from Turbine Supply Agreements)	33%
Actual capacity factor (100% availability at generator terminals, from turbine supply agreements)	40%
Contractual capacity factor (95% availability and including all system losses, from turbine supply agreements)	28%
Actual capacity factor (95% availability and including all system losses, from turbine supply agreements)	34% [8]

Table 3: MeyGen Phase 1A characteristics

6MW
Project Size

34%
Capacity Factor

25
OPERATIONAL YEARS

450GWh [7]
Lifetime Energy Yield Forecast

0.41
POWER COEFFICIENT

95%
AVAILABILITY

[6] Value quoted to two significant figures to preserve confidentiality.

[7] Value quoted to two significant figures to preserve confidentiality.

[8] The significant increase (of c. 21%) in the actual energy yield (and capacity factors) compared to the contractual energy yield (and capacity factors) is almost all (c. 95%) due to an improved (actual) flow distribution compared to that specified within the turbine supply agreements, with the remainder due to the improved (actual) C_p and reduced (actual) losses.

6 PROJECT PUBLICATIONS

6.1 PUBLISHED

Blaxland D., Johnson F., Macfarlane D.M., & Robinson N.J., 2019, Cost reductions through smart transportation and installation engineering – experience of the MeyGen Tidal Array, Proceedings of the 4th International Conference on Offshore Renewable Energy, Glasgow, UK

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6.4 PHD THESES

Joe Onoufriou. Harbour seals in a tidal stream environment: movement ecology and the effects of a renewable energy installation. Submission date 28th November 2019.

APPENDIX A - BACKGROUND

A.1 BACKGROUND

MeyGen PLC (MeyGen) is a Scottish-registered company established in 2010 for the purpose of developing the MeyGen Tidal Energy Project. MeyGen was awarded an Agreement for Lease for the Inner Sound tidal development site on 21st October 2010 by The Crown Estate. The Inner Sound Agreement for Lease is for 398MW of installed tidal stream energy capacity and will be consented in two separate phases.

Phase 1 (86MW) has already been consented. The Phase 1A 6MW demonstration array (comprised of four 1.5MW tidal turbines) reached financial close in 2014, and is now fully constructed and operational. There is a further 80MW of consented capacity in Phase 1, and an overall total of 392MW of further development capacity (beyond phase 1A) in the MeyGen project. Phase 2 will increase the installed capacity to a total of 252MW, the extent of the currently secured grid connection capacity. Phase 3 will then require an additional expanded grid connection to build the project out to the full site capacity of 398MW.

Phase 1A of the MeyGen project is partly funded through a £10million grant from the Department for Business Energy and Industrial Strategy (BEIS) under the Marine Energy Array Demonstrator (MEAD) Fund. The remainder of the funding is from SIMEC Atlantis Energy, and The Crown Estate (Scotland), Scottish Enterprise's Renewable Energy Investment Fund, and Highlands and Islands Enterprise (together with BEIS, referred to within this report as the 'Funders'). One of the requirements of the BEIS grant contract is that MeyGen considers the experiences from the MeyGen Phase 1A project, which may be useful to the wider tidal industry through a series of 'lessons learnt' workshops, and that the results of these workshops are disseminated for the benefit of the wider tidal energy industry, hereafter called tidal industry.

There have been three such lessons learnt workshops, some with preceding project internal workshops to help inform the lessons learnt workshops, each representing the main stages of the Phase 1A project.

- The first lessons learnt workshop covered the period from financial close to the end of the design phase;
- the second lessons learnt workshop to the end of the construction phase, and;
- the third lessons learnt workshop to the end of the initial operational phase.

After each of the first two workshops a lessons-learnt report was created and made publicly available, disseminating the results. This third and final, publicly available, report includes the findings of all three workshops and thus supersedes the first two reports.

A.2 DESCRIPTION OF THE PROJECT

A full description of Phase 1 of the Inner Sound project can be found on the Wave and Tidal Knowledge Exchange Network in document MeyGen Phase 1 Environmental Impact Assessment–MeyGen non-technical summary.

Phase 1A has deployed four turbines, three manufactured by Andritz Hydro Hammerfest (Andritz) and one by SIMEC Atlantis Energy (Atlantis). All the turbines are upstream, three-bladed, horizontal-axis machines, fully submerged and mounted on gravity-base foundations resting on the seabed. Each turbine is connected to shore by its own cable to a single onshore converter/grid connection station. The onshore station includes power converters for each turbine and the connection to the local electricity distribution network.

Phase 1A is the UK's first MW-scale tidal array and has successfully exported 21GWh to the grid to date with an average turbine availability of c.95% during its operational phase. MeyGen Phase 1A will be followed by Phase 1B (also known as Project Stroma), which will connect two additional Atlantis AR2000 turbines via a new subsea hub to a single power export cable which will then be connected via the MeyGen substation to the National Grid. Phase 1C will add a further 49 turbines (73.5 MW) at the MeyGen site.

A.3 LESSONS LEARNT PROCESS

MeyGen held a project internal lessons learnt workshop covering the period from financial close to the end of the design phase. It was facilitated by an independent third party, the Offshore Renewable Energy Catapult. The workshop included key members of the MeyGen team to provide a broad range of experience and expertise. The findings of the workshop were captured by the facilitator and were documented in the first public-domain lessons learnt report that was initially prepared by Black & Veatch (the Funders' Technical Advisor since financial close) for MeyGen and the Funders for comment. The report also included additional input from a separate lessons-learnt workshop which was held between MeyGen, the Funders and Black & Veatch.

For the period between the end of the design phase and the end of the construction phase, MeyGen held a series of project internal lessons-learnt workshops with several of its contractors. These workshops were followed by an internal workshop with the MeyGen team. These findings were then shared at a workshop facilitated by Black & Veatch and its contents captured in the second public-domain lessons learnt report.

For the period from the end of the construction phase to the completion of the first 18 months of operation, MeyGen and Black & Veatch held a joint lessons-learnt workshop.

The contents of all these workshops are captured in this third and final public-domain report, which supersedes the two previous reports. In addition, information on the budgeted project costs, comparison against actual expenditure to the project, and project performance based on the latest forecast are summarised in this report.

APPENDIX B - SURVEY IMAGES

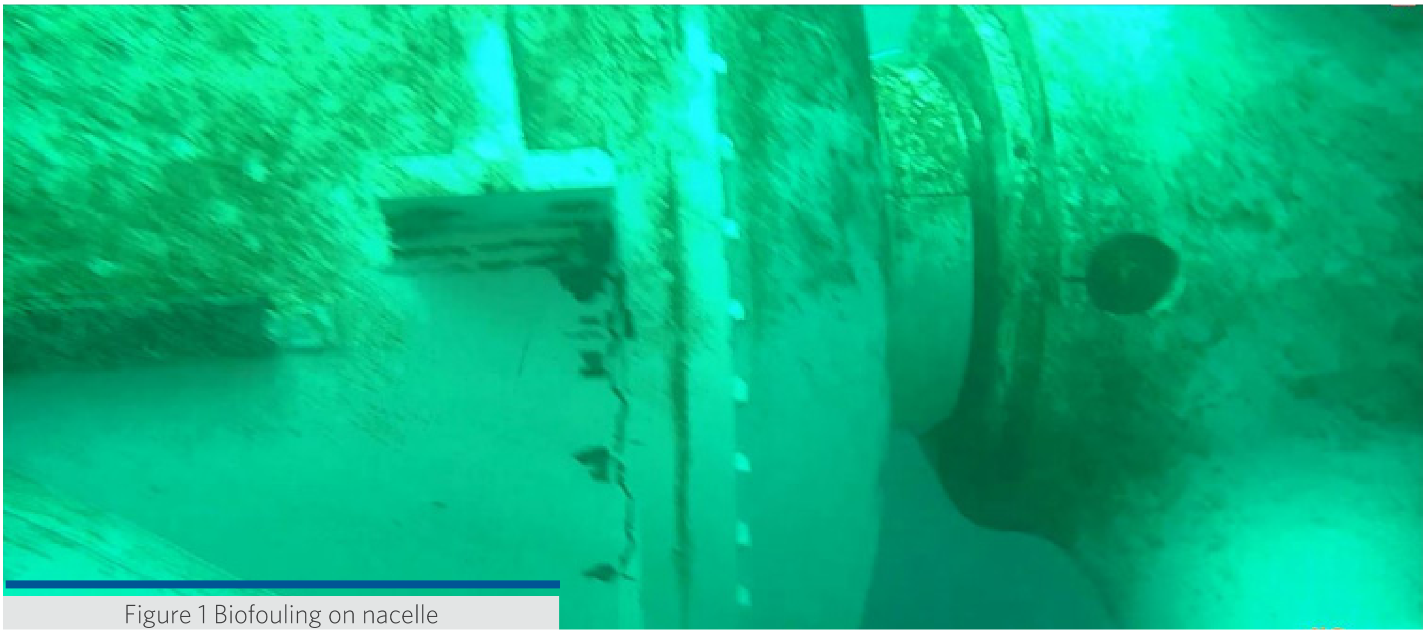

Figure 1 Biofouling on nacelle

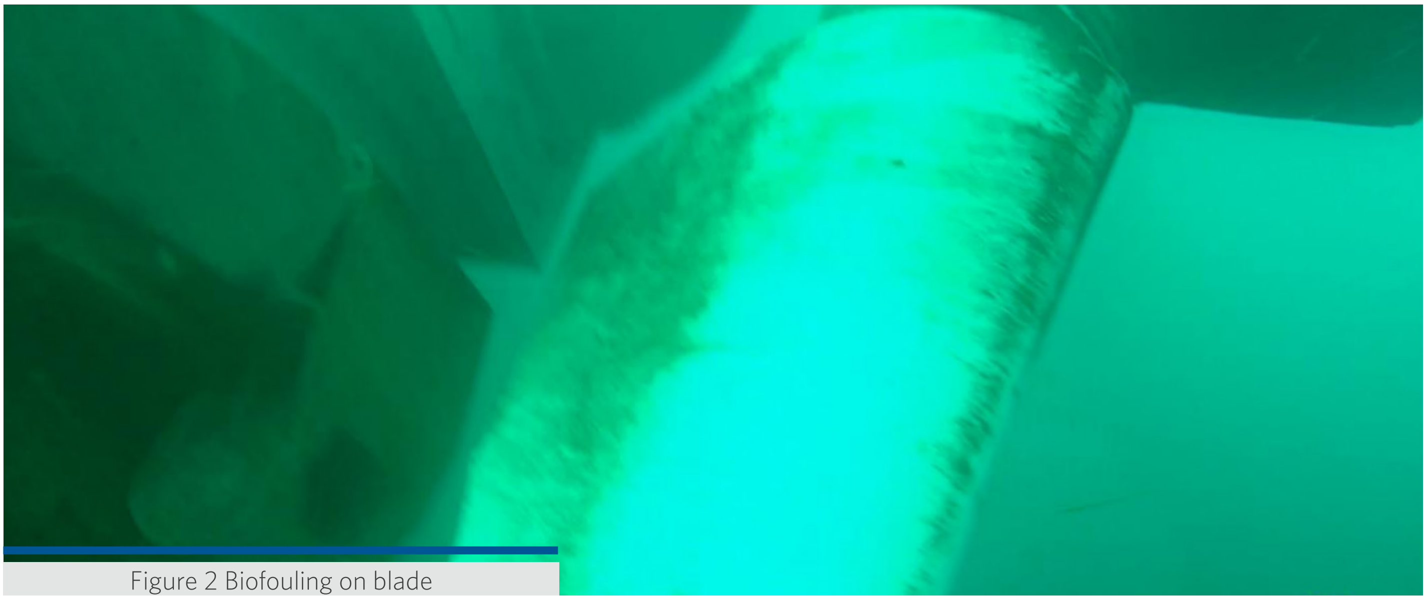

Figure 2 Biofouling on blade

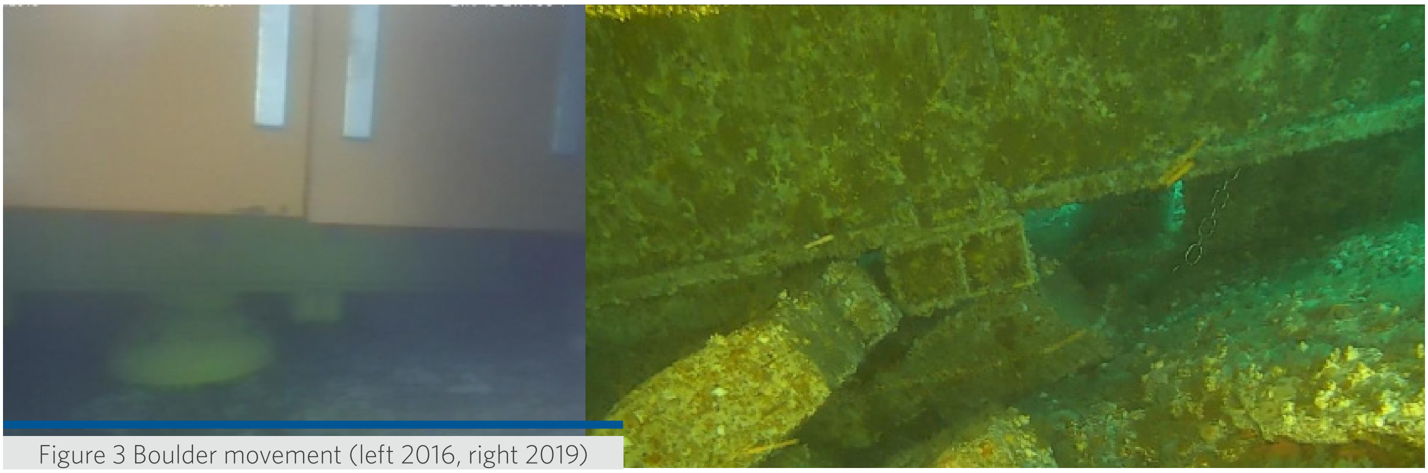

Figure 3 Boulder movement (left 2016, right 2019)

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