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REGENESYS UTILITY SCALE ENERGY STORAGE

Project Summary

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The work described in this report was carried out under contract as part of the DTI Technology Programme: New and Renewable Energy, which is managed by Future Energy Solutions. The views and judgements expressed in this report are those of the contractor and do not necessarily reflect those of the DTI or Future Energy Solutions.

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Exterior view of Regenesys Technologies Ltd pilot utility scale energy storage plant at Little Barford, Cambridgeshire, UK, July 2003.

Interior view of the plant – stream of XL modules.

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1 EXECUTIVE SUMMARY

THE COMPANY

Regenesys Technologies Limited ("RGN") (formerly Innogy Technology Ventures Ltd, “ITVL”) is a wholly owned subsidiary of RWE Innogy plc (“RWE Innogy”). RWE Innogy is one of the largest energy companies in the UK and, since May 2002, has been part of the German multi-utility RWE group of companies. Under RWE Innogy’s ownership RGN had progressed the Regenesys energy storage technology to its first full-scale demonstration plant and into the commercialisation phase.

THE PROJECT

In 2001, a proposal was put forward under the DTI’s New and Renewable Energy Programme, comprising of 4 work packages, which aimed to investigate and demonstrate the benefits that storage can bring to renewable generators. The total cost for this investigation of the Regenesys technology and demonstration at Little Barford was to be £1,962,916; the funding requested from the DTI was £881,458.

The programme of work would deliver a renewable-store-market interface that allowed renewable generators to optimise revenue under NETA. Whilst this programme concentrated in part on wind as the source of stochastic renewable energy, this work was applicable to the wider scope of renewables.

Technical difficulties and other issues in the development of the technology resulted in only half of the programme deliverables being completed. Some of these difficulties and issues are set out in section 5 of this report.

In 2003, RWE made the decision that RGN was not core business and that a partner should be sought to take the business forward (see section 4). A process to find a partner began in mid 2003. The process failed to secure a partner and so the decision was taken to close the business. Naturally this meant that the DTI Little Barford project could not be completed. It was agreed that this final project report should be written, summarising the work completed to date and explaining the current situation and the position going forward.

2 BACKGROUND TO THE PROJECT

THE COMPANY

Innogy Technology Ventures Ltd (ITVL) was a wholly owned subsidiary of Innogy Holdings plc (de-merged from National Power plc). ITVL was created as a vehicle to develop and exploit a revolutionary, electrochemical energy storage system that was branded Regenesys®. The Regenesys system offered great flexibility in its power and energy ratings. It would provide a high-speed response to requirements for the supply of real or reactive power and would be ideally suited to enabling the integration of intermittent renewable energy sources such as wind power onto the electricity grid system especially under the New Electricity Trading Arrangements (NETA).

ITVL had been developing Regenesys since the early 1990's and, at the time of the proposal of the project in question (2001) employed over 70 people. The technology was first proven viable on the laboratory scale and following this a pilot plant, Operations Training & Evaluation Facility (OTEF), was constructed in 1997. OTEF had a 1MW electrical capacity and was located at Innogy's Aberthaw Power Station.

Three generations of regenerative fuel cells were developed and operated at OTEF. These had increased in size and electrical output from 5kW to 10kW and now to 100kW. Much of the technology was covered by patent and patent applications held by ITVL.

Regenesys would be demonstrated at scale with the construction of Little Barford with 120 of the 100kW modules used.

THE PROJECT

The UK government is committed to renewable energy providing 10% of the UK electricity supplies by 2010. The best prospect for the UK to achieve this target is wind power. Wind is stochastic in nature and there are issues for such generators under the New Electricity Trading Arrangements (NETA).

Energy storage offers a way forward. It could enhance the value of energy produced, manage the NETA issues and aid in the connection of renewables to the system. However, until now, there has been no viable technology (apart from pumped hydro) that allows bulk storage of energy to be incorporated into a power system at the point of need. The Regenesys technology had the potential to meet this need.

A proposal was put forward under the DTI's New and Renewable Energy Programme, comprising of four work packages, which aimed to investigate and demonstrate the benefits that storage could bring to renewable generators. The total cost for this investigation of the Regenesys technology and demonstration at Little Barford was to be £1.96M with the DTI contribution requested at £0.88M The summary of costs and the work programme are shown in section 3.

The project would directly meet the following DTI objectives:

- Development of new and renewable energy so that it can contribute in the competitive energy market
- Enable improved performance and/or cost reductions of wind energy
- Develop innovative technologies that facilitate an increased use of embedded generation while ensuring safe and secure network operation

The 4 integrated work programmes were

1) A system study – how energy storage could be expected to assist with the increase of market penetration of renewable generators, the added value benefits that energy storage provided to renewable generators and the benefits that on site energy storage could provide to renewable generators and the distribution networks.
2) Technical study – investigation into the connection of renewable generators and energy storage
3) Regenesys study – detailed investigation of the technology for this application and a small-scale demonstration.
4) Little Barford – the scale up and demonstration of renewable and energy storage at scale.

The programme of work would deliver a renewable-store-market interface that allowed renewable generators to optimise revenue under NETA. Whilst this programme concentrated in part on wind as the source of stochastic renewable energy, this work was applicable to the wider scope of renewables.

3 SUMMARY OF MILESTONES ACHIEVED

Milestone No.	Title	Due	Associated Payment	Completed
0.1	Final Project Report	30/09/03	£113,000	N
1.1	Background Study Report	31/08/01	£4,235	Y
1.2	Energy Balancing Report	30/11/01	£16,940	Y
1.3	Energy Arbitrage Report	31/03/02	£16,940	Y
1.4	Network Performance Benefits – Stage 1	31/08/02	£21,175	Y
1.5	Network Performance Benefits – Stage 2	30/11/02	£16,940	Y
2.1	Background Study Report	31/08/01	£4,235	Y
2.2	Wind Farm Network Improvement using Energy Storage	31/12/01	£21,175	Y
2.3	Wind Farm Power Quality Improvement using Energy Storage	31/05/02	£21,175	Y
2.4	Design of Plant Operational Controls – Stage 1	30/09/02	£16,940	Y
2.5	Design of Plant Operational Controls – Stage 2	30/11/02	£12,705	Y
3.1	Plant Operational Limits Report	30/09/01	£24,900	N
3.2	System Response	28/02/02	£41,500	N
3.3	Commissioning – Initial Report	30/09/01	£24,900	Y
3.4	Ops & Maintenance: Interim Report	28/02/02	£41,500	N
3.5	OTEF Final Report: Proving Trials & Commissioning	30/06/02	£33,200	N
4.1	Little Barford Commissioning Report	31/07/02	£225,000	N
4.2	Renewable Demonstration & Testing Report	30/06/03	£200,000	N
4.3	Visitor Centre	31/05/02	£25,000	N

The summary of milestones achieved is characterised by the distinction between academic studies and practical testing. Where studies were almost completely “paper-based” the milestones were achieved in a relatively straightforward manner. This applies to Work Programmes 1 & 2, as conducted by Dr Bathurst and Dr Zhan of the University of Manchester Institute of Science & Technology (UMIST). Whilst some of these studies did require the use of practical data, this was in the main sourced from existing facilities, such as the National Wind Power database.

Conversely, where reports were reliant on practical testing or commissioning of the Regenesys technology, whether at OTEF or Little Barford, the achievement of milestones was hampered by the various technical problems encountered, as outlined in section 5. The result was a series of delays, and an inability to complete all of the agreed reporting. On a positive note, testing at OTEF produced a sizeable amount of data which – while not capable of producing a full report to exactly meet the outstanding milestones – has been considered worthy of a separate report in conjunction with this final report.

4 LESSONS LEARNED

Regenerative Fuel Cell (RFC) Module

The RFC module is the 'heart' of the Regenesys energy storage system. The RFC module is where the process of changing electrical energy to a chemically stored energy (and vice-versa) takes place. Without a functioning RFC module it is not possible to operate the Regenesys system.

The RFC module is a proprietary product; designed, developed and manufactured by Regenesys Technologies Ltd (RGN). Many of the module components and their respective manufacturing processes have also been developed and are controlled by RGN.

There have been three generations of RFC module; the 'S' series, 'L' series and 'XL' series. The S and L series modules were developed to establish the concept of a bipolar reactor, to evaluate the use of injection moulding as a manufacturing process for the complex frame component and to test integral designs for module sealing which eliminated the need for additional 'O' rings.

There have been a number of technical problems associated with the development of the RFC module and while the module was greatly improved, long term testing of a module has not been achieved. The Little Barford plant would have rectified this.

The two work packages under the DTI project relating to the testing of the RFC Module are:

- DTI project work package 3 was the testing and characterisation of the XL module at OTEF.
- DTI work package 4 was based on the running of 120 XL modules at the Little Barford plant.

The physical size and volume manufacturing potential of the XL module was key to the cost reductions targeted to bring the Regenesys technology to market. Driven by the value of time to market, development of the XL module was started in parallel with full validation of the design concepts under test in the smaller reactors. This risk was judged to be manageable based on the results to date.

Manufacturing processes for the S and L series modules were not suitable for the physical scale and volume requirement of the XL module. In most product development projects, it is possible to prototype components before committing to investment in bespoke manufacturing plant. However, in the case of the RFC module, because of the relationship between component specification and the novel manufacturing processes required, prototyping was only possible in limited instances – a component produced via a different manufacturing route would not have been representative of the actual design.

This forced the parallel development of novel, large scale manufacturing processes with the design of the RFC module, increasing complexity and risk. This also increased the cost and timescale associated with design and process modifications, since they were implemented into volume manufacturing processes. Hence the scope of the XL development programme included the development of proprietary large scale manufacturing processes to deliver modules for the demonstration plants.

The development period for the RFC module was extended due to number of design and manufacture problems. Whilst some problems were anticipated, the aggregate timescales required to find appropriate solutions caused significant delays to the overall programme for development of the technology. Changes had to be carefully considered and 'small investigative developments' were not always possible.

Specific problems experienced with the XL module are detailed below.

<u>Module sealing</u>

The hydraulic integrity of a module is paramount. It is critical for a module to seal as leaks can result in a release of Bromine and H2S, which would be unacceptable for a commercial product. Long term testing of the module also requires good hydraulic integrity to be maintained throughout the test period.

Poor initial tooling manufacture coupled with a design requirement for tight manufacturing tolerances were major factors. The fundamental seal design was also modified a number of times and ultimately delivered excellent sealing performance.

<u>End bipole failures</u>

The end bipoles experience greater stress than the other bipoles and although the design mitigated this to some extent, this was the predominant failure mode throughout the testing programme. Iterative improvements in materials, design and manufacture did extend module life, but as further testing was not possible once a component had failed, this was a significant limitation on the testing time possible.

<u>Electrode Fracture</u>

The electrode component has the lowest strain to failure of the components within the module and hence acts as the weakest mechanical link. Extensive development of materials, design and manufacturing was required to minimise the stress on the electrode and maximise its ability to operate under this level of stress. Significant progress was made although further development was required to achieve the design lifetime of 15 years.

Lessons Learnt on the RFC Module

Scope of development programme

The development of a major new industrial technology is by definition complex and broad in scope. Management of development risk within such a project is critical. Limiting the scope of specific development programmes can enable early testing in specific areas and it is this functional testing of a product which greatly accelerates a development process by increasing learning and providing feedback on materials, design and manufacturing.

Due to limited testing of S and L modules, and the need to develop both the large-scale design and manufacturing processes in parallel, the XL development programme took on a very broad scope. This broad scope required progress in each of a number of parallel development routes to deliver progress with the headline product (i.e. testing time on the full scale module). This resulted in a complex and high-risk technology development step.

Reduction of the scope of this programme and the identification of alternative routes to achieve progress with the headline product testing while still addressing development issues would have reduced this risk profile and provided earlier feedback and opportunity for risk management.

Management Process

An early review of the management process for development of the module could have helped in managing the risk as described above. Although it is important to recognise the difference between product and technology development, increased use of industry best practice in product development could have been investigated further.

Resource Level

One possible area of benchmarking would have been the level of resource and experience required to deliver a development step of this complexity and risk. The scale up in resource within the Regenesys business occurred after key decisions on the design and process routes for the XL module. Greater resource and experience at these early stages may have limited the number of problems carried into the more expensive scale up phase and facilitated the concurrent development paths which characterised the programme.

Concurrent Development

Parallel engineering was applied to reduce the development time for the XL module. This approach requires discipline in establishing and communicating specifications in order to ensure the overlap between programmes is constructive. Greater rigour in the use of specifications and control processes would have yielded more benefit from this approach.

Risk Management

The XL programme did contain a small number of high risk development steps such as the elimination of 'O' rings in favour of integrated sealing. Although ultimately a highly successful design solution was implemented, the problems encountered before developing this were a major hurdle in achieving test time on the product.

Fuller development and testing of S and L series designs would have reduced the risks of the XL programme. Smaller scale developments of the volume manufacturing processes required for the XL module would have further limited the scope and risk of the XL programme. Although ultimately this may have been the lowest cost route for the technology programme, it should be noted that this would have extended the timescales for development of the technology, an important consideration in any R&D investment.

LITTLE BARFORD CONSTRUCTION

Little Barford was the first of kind Regenesys plant that was to be a demonstrator of the Regenesys Technology at utility scale.

The plant design was for 120 RFC modules to operate with 1800m3 of each electrolyte. The plants intended power output was to be 12MW (peak output of 15MW) with an energy capacity of 120 MWh.

Tank Issues

The problems with the main tanks were the most significant cause of delay from the original contract programme. All other events were subsumed within the tank issue programmes. A factor for the significant impact on programme caused by the tank issues was that any failure during a hydraulic test had an associated empty and fill time with the test liquid. Additionally the interactions between repeat annulus tests and the necessary holding of main tank test water until the annulus tests were complete. The time for a main tank fill and empty was totally dependent upon the available water supplies and discharge routes rates (kg/hr). This was a site-specific programme and costs constraint. At Little Barford empty times were constrained by local environmental consents issues and operational constraints. Fill times were constrained by local supply constraints. Some 11 days (2 weeks) to fill and empty a tank were required followed by clearing of water for inspection.

Initial construction periods for the tank and original roof design were met (some 4 months). Further impacts were as follows:

Bromide Tank Roof Change
There was an issue with the material specification for the original tank construction which required the bromide tank roof to be changed. This event resulted in the extension of programme of some 7 months to design and install the replacement roof.

Subsequent cracking of the PVDF roof lining segment welds resulted in inspection, redesign and repair of these joints adding some 3 months.

Commissioning Problems
A Bromide tank overpressure event occurred when annulus levels exceeded the inner tank levels during a drain down. This event required significant inspection, design review, procedure examination of weld methods and analysis, to determine that repairs were adequate. Significant enhanced inspection and re-weld techniques were required to determine that the plate liners welds were in a satisfactory condition. The Bromide tank rework added some 5 months to the programme including testing of annulus seal repairs.

Polysulphide Tank
In parallel with the Bromide roof modifications a number of wall\floor joints failed under hydraulic test. These repairs and tests (5 including original test) were conducted over a period of 6 months.

The design solution of a tank lining was conceived and implemented over a period of 5 months. Leaks were then detected and the tank had to be drained. A further comprehensive review of installed designs and assessments lead to design changes and modified installation techniques. The modifications were completed in 4 months.

<u>Regenesys system</u>

The balancing system for the Regenesys Technology was in its early days of development and was unproven at plant scale. The original concept was to move the prototype balancing system being built at the OTEF test facility to Little Barford after it had been proven at scale. The OTEF balancing system encountered many problems as knowledge of

the chemistry improved resulting in the Regenesys system becoming more complex than first envisaged.
There was additional expense and delay to the programme while a suitable balancing system was designed and installed.

LESSONS LEARNED ON THE LITTLE BARFORD PLANT

Risk Assessment

During the design phase of the project detailed engineering risk assessments were carried out. With hindsight, the original tank designs were unsuitable for the application and this was not highlighted as a major concern during the risk assessment process. Considerable modifications had to be made resulting in lost time and excess cost. It is vital that in any project that the importance of up-front design is recognised. It is during the early design and development that the future spend is committed while actual spend is low. Any changes early on then have minimal cost and programme implications associated with them but can make huge difference to out-turn costs and delivery of a project.

Commissioning

It is vital that for all activities a risk assessment and method statement are produced, not only for Health and Safety reasons but to also consider any possible implications. Local management instructions for draining the tank and annulus at different rates should perhaps have been more rigorously applied.

Scale up

- The Regenesys technology had been tested at lab. scale and was in the process of being proven at pilot plant scale. Driven by the value of time to market, development of the XL module was started in parallel with full validation of the design concepts under test in the smaller reactors. This risk was judged to be manageable based on the results at that time. However the risk of this co-development was greater than expected.

5 CURRENT STATUS OF REGENESYS TECHNOLOGIES LTD, AND THE RATIONALE FOR CLOSURE

Introduction

Regenesys Technologies Limited ("RGN") is a wholly owned subsidiary of RWE Innogy plc ("RWE Innogy"). RWE Innogy is one of the largest energy companies in the UK and, since May 2002, has been part of the German multi-utility RWE group of companies. Under RWE Innogy's ownership RGN had progressed the Regenesys energy storage technology to its first full-scale demonstration plant and into the commercialisation phase. However, in 2003 RWE decided that RGN did not fit with RWE's core business and that a partner should be sought to take the business forward.

RWE Innogy intended to transfer management control of RGN by means of a share sale to an investor whose core competencies were better aligned with the commercial exploitation of a major new power sector technology. Key elements of such a sale were to have been future funding of the business by the new investor and a purchase consideration reflecting the long-term value of the Regenesys technology. Interested parties were invited to submit binding bids based on the information contained within an Information Memorandum.

Business Opportunity

RGN provided a potential investor with a major business opportunity by making bulk energy storage available to the electricity supply chain. The supply chains for many other commodities are regulated by storage media like reservoirs, tanks and warehouses that balance supply and demand and optimise the overall efficiency of the supply chain. In contrast, commercial utility-scale electricity storage has been very limited so far. RGN had developed the concept of an "Electricity Warehouse®" equipped with the Regenesys technology to help overcome this limitation. Based on the displacement of new capacity alone, RGN estimated that there was a potential market opportunity for electricity storage of at least 10-15 GW per annum.

RGN aimed to supply utility scale storage solutions to customers based on the unique patented electrochemical Regenesys technology. RGN was making progress towards the reduction of the unit cost of these utility scale plants, through technology improvements.

Discussions with potential customers confirmed that the market opportunity for storage was significant at prices of £700/kW and below. Assuming the Regenesys technology reached a level of maturity in the next decade with prices of £500/kW it was estimated that RGN could penetrate the market with sales of approximately 5 GW per annum.

Key Investment Considerations

The key investment considerations were:

- Large global market opportunity with high barriers to competitor entry;
- Unique and patented technology;
- Potential to capture multiple electricity storage value streams including ancillary services, load shaping, arbitrage and power quality;
- Compelling business strategy enabling gradual market entry at the earliest opportunity;
- Recognised brand name in the development of bulk electrical storage technology that would have been reinforced following successful commissioning of the UK demonstration plant at Little Barford;
- Highly skilled scientists, engineers and management; and
- Established relationships with suppliers.

Technology

The key technical considerations of the Regenesys technology were:

- Proven electrochemical technology;
- Modular plant design (>5 MW);
- Low cost commodity materials that are commonly used in the chemical industry;
- Electrolytes comprising two low cost chemicals;
- Off the shelf membranes similar to those used in the chlor-alkali business;
- Utility scale demonstration plant constructed and some initial commissioning completed; and
- Performance improvement targets identified and being delivered.

It should be noted that the Regenesys technology was quite different from primary fuel cells. The Regenesys technology stored energy in the multiple MWh range with power ratings of 5 MW and upwards and was developed for utility scale electricity applications. It operated with a reversible process by which electrical energy was converted into chemical potential energy by “charging” two liquid electrolyte solutions and subsequently releasing the stored energy on discharge.

Intellectual Property

The Regenesys technology was well protected by a large number of patents registered in the most relevant markets. RGN holds 30 active patents or patent applications in countries in which RGN considered such protection to be necessary for the future development of the Regenesys technology, including the US, Japan, China, Canada and Europe. RGN had applied for and had granted patents in all the fundamental technical areas. With the closure of RGN, RWE will retain these patents.

Cost Reductions

The Little Barford Regenesys plant was a first-of-kind plant and as with all first-of-kind demonstrations the costs were high. The costs were high for a number of reasons, namely unforeseen technology problems due to the innovative nature of this technical demonstration plant, but also because a first-of-kind plant tends to be over engineered to allow the technology to be fully tested and characterised. The cost of future plants can be significantly reduced through improvements in the fundamental technology as well as the plant, but also through reduced specification and economies of scale. It is still RGN’s belief that the cost reductions identified earlier are realistic.

Long Term View

One important milestone towards full commercialisation was the commissioning of the initial 2.4 MW stream of the five stream 12 MW plant at Little Barford. This was expected to attract international attention from utilities, energy users, policy-makers and the media. A similar plant was under construction at Columbus in the US. The Columbus, Mississippi plant would have been both proof-of-concept and a showcase located in the important North American market.

The interest in electricity storage among policy-makers and industry experts is growing. The US Department of Energy now sponsors 28 storage-related research, development and demonstration projects. The Electric Power Research Institute has recently established a “Target” for electricity storage to which more than 20 utilities have subscribed. The US Federal Energy Regulatory Commission released its draft of a standard market design with a specific call for the development of new technologies capable of solving grid congestion and constraint problems. European governments have set challenging targets for increasing the penetration of renewables and development of new technology to enable this is both being encouraged and supported financially.

Currently the only viable utility scale energy storage technology is pumped hydro, which is itself constrained to certain geographies. There remains a significant market opportunity for a flexible utility-scale energy storage technology that provides the benefits of pumped hydro economically.