

18th of March, 2010

Dr Christos Markides PhD (Cantab)
Lecturer (RCUK-Foster Wheeler Fellow) in
Clean Energy Processes

Mr Stephen M. Hargreaves

Chairman & CEO
International Innovations Limited (IIL)
Level 29, Chifley Tower,
2 Chifley Square,
Sydney,
NSW 2000,
Australia.

Dear Mr Hargreaves,


Based on the fact that we are trying to find a way to accelerate the development activities, please find attached to this cover letter an outline of a proposal for your consideration, focussed on the MOREAMPS system and involving a 24-month project for £670k, in which a team of dedicated Postdoctoral Researchers (RAs) will be working on various aspects of the technology simultaneously. Payment terms are annually in advance, hence: £280k at the start of the project for the first year, and £390k after 12 months for the second year. The anticipated kick-off date is estimated to be sometime before the 30th of June, 2010.

Please note that:

1. In order to keep the costs low, I have proceeded on the basis that we will get some support (in kind, in the form of equipment, etc.) from your development partners, Hydac and Honeywell.
2. A third Postdoctoral RA has been added to Phase 2 of the project, to work alongside the two RAs that will have joined the team from the beginning of the project. The purpose of the third RA is to accelerate this phase by assisting specifically with the optimisation of the MOREAMPS prototype. Referring to my previous proposals, dated 3rd of February, note that the increase in costs associated with the replacement of two PhD students with one additional RA, who is an experienced professional, is compensated by the focussing of our activities only on the MOREAMPS system, rather than both the MOREAMPS and the OTELLOTM. The inclusion of RAs in place of PhD students also makes the IP situation more straightforward.

You have permission to publish this proposal to your investors. I am sure that you are also eager to get things going and I look forward to your thoughts and comments. If you have any questions please do not hesitate to contact me. Specifically, if you require further details I will be more than happy to provide these.

Yours sincerely,



Dr Christos Markides

Product Development and Optimisation of a Working Prototype of the MOREAMPS Waste Heat Engine System

- INTRODUCTION AND BRIEF -

Parties

International Innovations Limited (IIL)

Dr Christos Markides (CNM), Department of Chemical Engineering, Imperial College London (ICL), UK

CNM Introduction

CNM obtained his BA with Honours, MEng with Distinction, MA and PhD from the University of Cambridge, where he was also an Engineering Fellow of Robinson College. He joined the Department of Chemical Engineering at Imperial College London in 2008 when he was appointed Lecturer in Clean Energy Processes. He belongs to the Energy and Fluid Mechanics research focus areas of the Department, and is collaborating closely with the multidisciplinary cross-faculty Energy Futures Lab of the College. He is also the joint Research Councils UK-Foster Wheeler Fellow.

CNM has expertise in the areas of fluid flow, heat and mass transfer, thermodynamics, mixing, combustion, dynamic system analysis and control, and experimentation. He has published more than 20 scientific articles in these areas. He is a Member of the Energy Institute, the Institute of Physics, the American Institute of Aeronautics and Astronautics, the Royal Aeronautical Society, the American Society of Mechanical Engineers, and the Combustion Institute.

CNM Background and Track Record

Previous to his appointment at Imperial College London, CNM co-founded and was the Technical Director of Thermofluidics Ltd, a spin-out company from Cambridge University Engineering Department. The objective of this effort was to realise, develop and commercialise a novel thermally-powered fluid pumping device without mechanical moving parts, capable of utilising low-temperature waste heat and solar energy. During his tenure as the Technical Director of Thermofluidics Ltd from 2005 to 2008, CNM was directly responsible for all development activities, including technology improvements and optimisation, as well as prototype development and scale-up.

This allowed Thermofluidics to prove successfully the concept of a 'two-phase thermofluidic oscillator' as applied to heat engine design. Following the successful proof of this unique concept, the resulting device was optimised to pump efficiently over large pressures by making targeted improvements to the effectiveness of key components. Specifically, these improvements allowed a thirty-fold enhancement in its pumping capability, from a pumping flow rate of 50 L/hr (from using approximately 50 W_t of heat) to 1500 L/hr (using approximately 1-2 kW_t of heat).

The work was initiated with the support of the UK Department of Trade and Industry, by means of a £120k R&D grant to develop early prototypes of the technology. This award culminated in a patent that is in the national phase in 10 regions: Europe, US, Japan, Korea, Australia, China, Israel, India, South Africa and Russia. As a follow-up, a further grant of total value £300k was awarded to Thermofluidics by the Carbon Trust for the purpose of building application-specific demonstrators.

In addition, as part of his work in the area of low-grade heat engines, CM initiated relationships and collaborations with many industrial, Governmental and non-profit organisations, including Honeywell, Vaillant, Bosch, Giannoni, Alfa Laval, the Technology Partnership, the Department of Trade and Industry, the East of England Development Agency and the Carbon Trust.

IIL, MOREAMPS and OTELLO™ Background

The MOREAMPS and OTELLO™ thermal hydraulic generators are waste heat engine systems that are protected by patents owned by IIL. The systems can be used to recover waste heat in order to produce useful work and generate electricity. Both systems include a 'refrigerant circuit', which contains the working fluid (liquid-vapour) that undergoes a thermodynamic cycle, and a 'hydraulic circuit' that transforms the displacement work output from the pistons or accumulators in the refrigerant circuit to electrical power. The MOREAMPS system obtains its heat directly from the cooling water circuit and the combustion product exhaust gases of a conventional combustion engine, whereas the OTELLO™

system obtains its heat from a bath of hot liquid that acts as an intermediary heat store between the external waste heat source and the system. This is expected to render the MOREAMPS system more efficient than the OTELLO™. On the other hand, the OTELLO™ will be a more versatile system, in that it will be possible to adapt with greater ease to a more diverse range of waste heat sources. Both systems can also be powered by solar heat.

An advantage of the MOREAMPS and OTELLO™ systems is their use of standard components available from international suppliers such as Hydac (www.hydac.com) and Honeywell (www.honeywell.com). The MOREAMPS and OTELLO™ systems will be constructed entirely from off-the-shelf components. Using standard components lowers the overall cost, but also allows the warranties and replacement of parts to be covered by the suppliers. The heart of the systems are the 'pneumatic hydraulic accumulators' made by Hydac. Honeywell will supply valves, speed drives, controls, instrumentation and working fluids. Other suppliers will provide the fluid motors, Pelton or Francis turbines, governors, generators, etc.

According to www.internationalinnovations.com.au, IIL sold a license to B.I.G. Biogas Innovations (www.big-biogas.de), who built a 50 kW_e electrical power output OTELLO™ system in Germany in collaboration with IIL, with claims of 24% efficiency with waste heat temperatures of 72 °C. The Carnot efficiency (based on 20 °C heat sink) is 15%.

IIL engaged the clean energy commercial arm (www.newcastleinnovation.com.au) of University of Newcastle, Australia to predict the performance of a 1 MW power output OTELLO™ over a source temperature range of 120 – 200 °C. Typically, natural gas (primarily consisting of methane)-burning Stirling engines (e.g. www.whispergen.com), or spark-ignition internal combustion (Otto) engines (e.g. www.freewatt.com) have waste heat temperatures in the range 80 – 120 °C for the cooling water and 500 – 750 °C for the exhaust gases. Three working fluids were considered in this theoretical study: R245fa, R410a and CO₂, with cold sink temperatures of 25 °C, 25 °C and 20 °C respectively. Based on these preliminary calculations the *theoretical* efficiency of the OTELLO™ was found to be in the range 6.4 – 13.7% for R245fa, 3.4% – 12.2% for R410a, and 0.1 – 8.0% for CO₂.

Further Progress and Strategy Outline

IIL approached CNM at ICL to improve the theoretical efficiency of the MOREAMPS system, and to develop optimised working prototypes of this system for demonstration. ***As part of the interaction, CNM will also assist IIL with the scale-up of the technology at a later stage.***

IIL is interested in producing MOREAMPS units with power outputs of 100 and 200 kW_e for identified customers in Germany, including for example MWK Biogas (www.mwk-biogas.com) whose main product is a 1 MW biogas-fuelled engine-generator, comprising an internal combustion engine for power generation that rejects 1.2 MW_t of wasted heat. It is also interested in producing smaller MOREAMPS units with power outputs of 15 to 20 kW_e for other markets in potential collaboration with Infinity Turbine (www.infinityturbine.com).

The current document proposes a “first stage development plan” in this direction. The programme’s main objectives are: (i) to build, operate and optimise a lab-scale proof-of-concept MOREAMPS demonstrator that would substantiate a sound working principle for the system in the shortest possible time; followed by, (ii) using the knowledge gained in (i), to build a 20 kW_t working MOREAMPS prototype capable of providing information about the efficiency and performance of the final full-scale system.

With regards to (ii), a 20 kW_t thermal power input system will be more than capable of reducing engineering and development costs, but also investment risks, by supplying us with a reasonable estimate of the ultimate efficiencies, performance and capabilities of the final units, while greatly reducing time, cost and complexity at this early stage of development. The larger scale units can then follow. This process of up-scaling will also benefit directly from knowledge gained from the earlier prototypes, reducing the overall time required for final development and productisation.

The research programme proposed herein will conclude with a complete re-evaluation. If IIL judges that it wishes to proceed, a “second stage development plan” can be defined and initiated with the goal of up-scaling to an intermediate size (50 – 100 kW_t, and 200 or 300 kW_t) system within 1 – 2 years.

- FIRST STAGE MOREAMPS DEVELOPMENT PLAN OUTLINE -

Target Statement

Design, develop, build and optimise two working MOREAMPS waste heat engine systems, including: (i) a 5 kW_t heat input lab-scale proof-of-concept demonstrator; and, (ii) a 20 kW_t optimised prototype.

Overriding Development Objectives

The design areas, scientific/research and experimental-development aims are:

1. Determination of capabilities, and optimisation of thermodynamic cycle
2. Selection of optimal working fluid(s)
3. Analysis of heat transfer limitations and alleviation of such effects
4. System construction, testing and optimisation
5. Characterisation of real efficiencies and performance, and improvements to basic design

Further specific objectives include:

1. Identification of preferred heat sources and specification of heat source temperatures, which will be used to focus on the selection of the optimal working fluid.
2. Consideration of the design of the accumulators (geometry, materials and fluids) for maximum power generation while taking heat transfer into effect, and balancing between the heat gained from the exhaust gases and that gained from the cooling water. Also, design and optimisation of the two separate heat exchangers.
3. Design and optimisation of the interfaces between the various off-the-shelf components, and any effects on the behaviour and performance of the overall system.

Programme and Methodology

A. PHASE 1: 5 kW_t Heat Input Proof-of-Concept MOREAMPS Demonstrator

Description:

- System components:
 - In addition to the thermodynamic and hydraulic circuits, the system demonstrator will not include a turbine or electric generator.
- Heat input:
 - Heat will be taken from a hot liquid stream (representing an engine cooling circuit), as well as a hot gas stream (representing combustion product exhaust gases). The system will be optimised for a hot liquid stream of 100 °C, and a hot gaseous stream of 600 °C, though the performance will be evaluated over a range of hot liquid and gas stream temperatures (i.e. 80 – 120 °C and 500 – 700 °C respectively).
- Heat rejection:
 - The ambient temperature will be 20 – 25 °C.
- In all cases, the power output and efficiency will be established by direct measurements on the hydraulic power in the hydraulic circuit.

B. PHASE 2: 20 kW_t Heat Input Optimised MOREAMPS Prototype

Description:

- System components:
 - In addition to the thermodynamic and hydraulic circuits, the system prototype will include a turbine and an electric generator.
- Heat input:
 - Heat will be taken from a hot liquid stream (representing an engine cooling circuit), as well as a hot gas stream (representing combustion product exhaust gases). The system will be optimised for a hot liquid stream of 100 °C, and a hot gaseous stream of 600 °C, though the performance will be evaluated over a range of hot liquid and gas stream temperatures (i.e. 80 – 120 °C and 500 – 700 °C respectively).
- Heat rejection:
 - The ambient temperature will be 20 – 25 °C.
- In all cases, the power output and efficiency will be established by direct measurements on the electric generator.

Phase 1: Personnel, Duration and Costs

Associated Personnel:

1 x Principal Supervisor (CNM)
2 x full-time dedicated Postdoctoral Research Associates
1 x part-time expert Consultant
1 x part-time workshop Technician

Duration: 9 – 12 months

Costs (with Justification): £280k

Personnel £90k; Instruments, Equipment, Consumables and Materials £60k;
Workshop, Technicians and Subcontracted charges £50k; Support and Overheads £80k

Phase 2: Personnel, Duration and Costs

Associated Personnel:

1 x Principal Supervisor (CNM)
3 x full-time dedicated Postdoctoral Research Associates
1 x part-time workshop Technician

Duration: 12 – 15 months

Costs (with Justification): £390k

Personnel £140k; Instruments, Equipment, Consumables and Materials £90k;
Workshop, Technicians and Subcontracted charges £70k; Support and Overheads £90k

Total Project (Phases 1 & 2) Duration and Costs


Time: ~ 24 months

Costs: £670k (Personnel £230k; Instruments, Equipment, Consumables and Materials £150k;
Workshop, Technicians and Subcontracted charges £120k; Support and Overheads £170k)

Notes:

1. *To reduce costs, it was assumed that development partners Hydac and Honeywell will be able to assist by offering accumulators and control systems at reduced or no cost.*
2. *Also, in order to accelerate the development activities, a third Postdoctoral Research Associate (RA) has been added to Phase 2 of the project, to work alongside the two RAs that will have joined the team from the beginning of project. The purpose of the third RA is to assist specifically with the optimisation of the MOREAMPS prototype.*

Overall Workplan

Activities/Targets	Month							
	1-3	4-6	7-9	10-12	13-15	16-18	19-21	22-24
PHASE 1								
A1. Theoretical determination of capabilities & cycle optimisation	Analysis/ Modelling							
A2. Working fluid selection, and heat transfer considerations	Analysis/ Modelling							
A3. Design, orders, construction & manufacturing		Design/ Orders	Development/ Prototyping					
A4. Efficiency evaluation and improvements			Experimental					
A5. Presentation of a 5 kW_t working MOREAMPS demonstrator								
PHASE 2								
B1. Further improvements to cycle/system					Analysis/ Modelling			
B2. Design & orders				Design/ Orders				
B3. Construction & manufacturing					Development/ Prototyping			
B4. Efficiency evaluation & improvements						Experimental		
B5. Presentation of a 20 kW_t optimised MOREAMPS prototype				