

## Impact case study (REF3b)

<b>Institution: Robert Gordon University</b>
<b>Unit of Assessment: 15 General Engineering</b>
<b>Title of case study:</b> Eco-Friendly Optimisation of Ceramic Membrane Reactor for Monetising Stranded Natural Gas
<b>1. Summary of the impact</b> (indicative maximum 100 words)

Fifteen years of ceramic membrane research at Robert Gordon University and the applied development programme by the RGU spinout Gas2 Ltd have culminated in the development of the Gas2 pMR™ CPOX process and its new GTL reactor. This technology has captured the attention of major global energy investment company Lime Rock Partners for possible onshore and offshore deployment addressing the monetisation of stranded gas and to avoid flaring and venting of unwanted associated gas. The economic impact is £17.2 million in equity investment during 2008-2013 with concomitant impacts of new processes and employment opportunities at Gas2, with environmental impact for the oil & gas industry from eco-friendly handling of stranded natural gas.

<b>2. Underpinning research</b> (indicative maximum 500 words)
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Research on ceramic membranes has been conducted at RGU since 1998. A novel eco-friendly ceramic membrane process was developed for the processing and monetisation of stranded gas reserves with potential for environmental improvement [R1]. Refinement of membranes was carried out by assessing the impact of key operating variables on the effectiveness of various intrinsic membrane parameters, including permeability and selectivity to enable the comparative performance evaluation of the dense and porous membranes with more conventional contactors for gas separations and integrated membrane reactors. Comprehensive mathematical models were subsequently developed and applied to enable the identification of optimised operating parameters for downstream chemical catalytic processing [R2].

Major advances in adapting eco-friendly ceramic membrane technology for natural gas processing and gas-to-liquids production occurred during two PTDF-sponsored PhD projects (Olsen and Umoh) and two Scottish Enterprise Proof-of-Concept projects:

- *Novel Hybrid Inorganic Membranes in Natural Gas Processing* (2001-03) to prepare and test eco-friendly hybrid inorganic membranes for natural gas processing in marginal fields.
- *High density hydrogen production at 100% purity using a reconfigured multi metallic composite membrane reactor* (2002-04) provided a platform for the development of environmentally friendly multi-metallic membrane pathways to hydrogen production and fuel cell utilisation.

The conventional process for monetising stranded gas involves a multi-step indirect conversion of methane to higher molecular weight hydrocarbons ranging from liquefied petroleum gas (LPG) to paraffin waxes, often controlled to attain a maximum in the diesel range. The process is rather energy intensive and bulky, and suffers from scale-down problems, thus is unable to economically monetise stranded gas. In contrast, our eco-friendly ceramic membranes offer an advanced modulated variation of the entire process from the initial natural gas processing through to the gas-to-liquid unit itself, as shown in the following Figure 1:

### 1. Eco-friendly Hybrid Ceramic Membranes for Natural Gas Processing (CO<sub>2</sub> Capture)

Driven by the low carbon economy, the development of eco-friendly ceramic membrane system can simplify natural gas processing to enable subsequent utilisation due to their inherent thermo-chemical stability. (Gobina & Olsen [R3])

### 2. Eco-friendly Hybrid Ceramic Membranes for Synthesis Gas Production

Eco-friendly ceramic membranes are an interesting and promising way of producing low-cost synthesis gas (CO + H<sub>2</sub>) from feed of natural gas and oxygen/air, to give an H<sub>2</sub>/CO ratio ~2.0 which is optimal for on-site and distributed generation of synthesis gas. (Gobina & Olsen [R4])

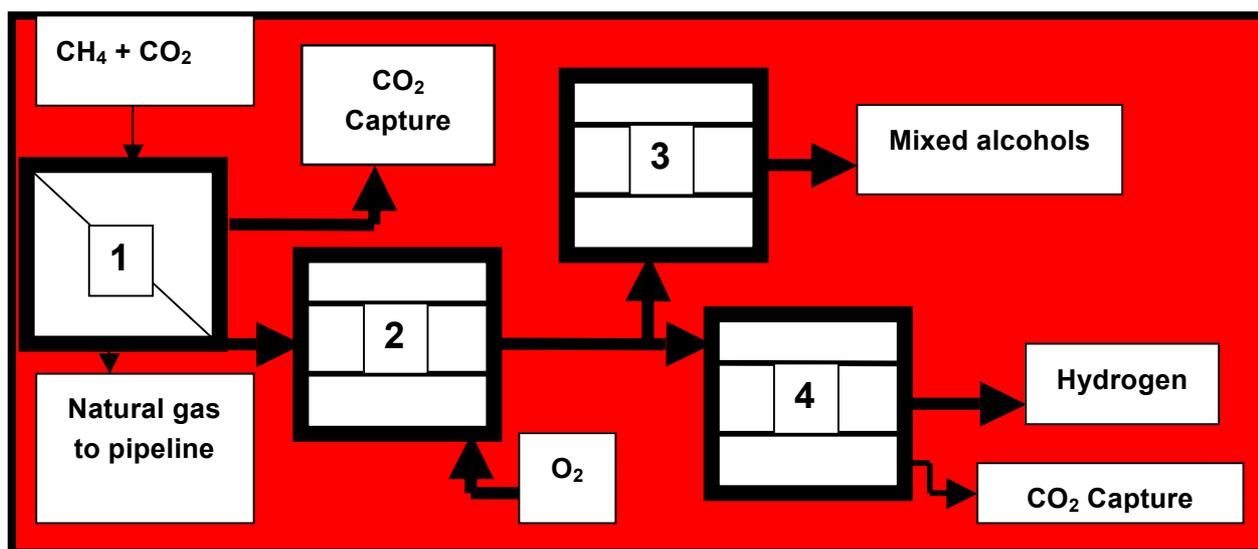
### 3. Eco-friendly Hybrid Ceramic Membranes for Fischer-Tropsch Gas-to-Liquids Production

One attractive option for monetising this gas is to use a low-pressure gas-to-liquids (GTL) process which can be integrated with the syngas process to enhance performance and significantly reduce costs of compression. (Gobina, Olsen & Umoh [R5, R6])

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**4. Eco-friendly Hybrid Ceramic Membranes for High-Density Hydrogen Production**

Eco-friendly multi-metallic hybrid hydrogen separation, recovery and production can offer an alternative pathway for syngas utilisation, and are of increased importance today due to a high demand for hydrogen as an environmentally clean fuel, and as a chemical constituent widely used in industrial processing. (Gobina & Chen [R7])



**Figure 1.** Eco-friendly ceramic membrane technology for stranded gas monetisation

**Research Grants**

- PTDF-funded Studentship, *Catalytic membrane reactors for synthesis gas production from natural gas via partial oxidation*, Susanne Olsen, 2001-2004.
- Proof of Concept Award (Round 2), *Novel Hybrid Inorganic Membranes in Natural Gas Processing*, Edward Gobina 2001-2003, £122k.
- Proof of Concept Award (Round 3) *High density hydrogen production at 100% purity using a reconfigured multi metallic composite membrane reactor*, Edward Gobina 2002-2004, £124k.
- PTDF-funded Studentship, *Direct synthesis gas conversion to alcohols and hydrocarbons using a catalytic membrane reactor*, Reuben Mfon Umoh, 2006-2009.

**Key Researchers**

Edward Gobina: Lecturer, Reader, Professor (1998->)

Barry McKenzie: PhD Student (2000-2009), Gas2 Ltd (2006->)

Susanne Olsen: PhD Student (2001-2004), Research Fellow (2002-2005)

Chee Chen: PhD Student (2004-2010), KTP Associate (2006-2008), Gas2 Ltd (2008->2011)

Reuben Mfon Umoh: PhD Student (2006-2009)

**3. References to the research** (indicative maximum of six references)

Key references are marked with an asterisk

[R1] Edward Gobina, Composite inorganic membrane for hydrogen separation: An evaluation of different substrate materials, in *Proceedings of the 16<sup>th</sup> Annual Membrane Technology/Separations Planning Conference*, Pages 178-184, Newton MA, 1998.

[R2]\* Edward Gobina, Inorganic membranes tackle oxo-alcohol synthesis gas production in a fluidized-bed reactor, *Membrane Technology*, Volume 2000, Issue 125, Pages 4-8, 2000. doi: 10.1016/S0958-2118(00)80210-4

[R3] Edward Gobina, "Hybrid Membrane" Patent Family WO02/074421, *Apparatus and Method for Separating Gases*, (File date 16-Mar-01), Publication date 26 September 2002.

[R4]\* Edward Gobina and Susanne Olsen, "Syngas Patent" Family WO2004098750, *Membrane apparatus and method of preparing a membrane and a method of producing hydrogen*, (File date 3-Apr-03), Publication date 18 November 2004.

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- [R5]\* Susanne Olsen and Edward Gobina, GTL synthesis gas generation membrane for monetizing stranded gas, *Membrane Technology*, Volume 2004, Issue 6, Pages 5-10, 2004. doi: 10.1016/S0958-2118(04)00161-2
- [R6] Edward Gobina and Reuben Mfon Umoh, "Fischer Tropsch" Patent Family WO2009037469, *Process and apparatus for the production of alcohols*, (File date 21-Sep-07), Publication date 26 March 2009.
- [R7] Chee Chen and Edward Gobina, Ultra-thin palladium technologies enable future commercial deployment of PEM fuel cell systems, *Membrane Technology*, Volume 2010, Issue 3, Pages 6–13, 2010. doi: 10.1016/S0958-2118(10)70054-9

**4. Details of the impact** (indicative maximum 750 words)**Context**

Between 30% to 60% of the world's natural gas (6,186 trillion cubic feet (TCF)) is classified as "stranded", meaning that it cannot be used locally or transported economically to other markets. As a result the natural gas is often flared causing economic waste and environmental concern. One way of utilising "stranded" gas is to convert it into synthesis gas (Syngas), that in turn can be converted using Gas to Liquids (GTL) technology into fluids that can be readily pumped through the same pipelines as the produced oil. In addition, there are still large amounts of undiscovered gas (4,133 TCF) that could be produced by using GTL technology. New methods to convert natural gas to liquids enable producers to transport gas more easily and economically from previously inaccessible areas. However, 38% of the world's stranded gas fields cannot be monetised using current large footprint GTL systems [I1.../stranded\_gas].

**Pathway to Impact**

Ceramic membrane research at RGU, combined with experience of process intensification through eco-friendly reactors, led to the foundation of the spinout company Gas2 Ltd by RGU in 2005, to commercialise eco-friendly ceramic membrane technology through the development of Syngas and Fischer–Tropsch (FT) technologies. The eco-friendly ceramic membrane technology can be streamlined into modular reactors and reconfigured to monetise small reserves of "stranded" gas that cannot support traditional large-scale GTL technology [I1 Timeline, I2].

A Knowledge Transfer Partnership (KTP 001658) between Gas2 and RGU (2006-2008) successfully built, tested and optimised a working, multi-tubular, miniature, industrial, eco-friendly, ceramic membrane prototype, producing high quality Syngas at variable ratios, using an input of air/oxygen and natural gas only [I3].

In early 2008 Gas2 secured an exclusive licence for the development of the Syngas and Fischer-Tropsch technologies from RGU [R4, R6]. A significant estate of granted and pending patents in multiple territories has subsequently been established around the Syngas and Fischer-Tropsch technologies [I1 Timeline].

**Reach and Significance**

The eco-friendly ceramic membrane technology captured the attention of major global energy investment company Lime Rock Partners for possible onshore and offshore deployment, to monetise stranded gas, and to avoid flaring/venting of unwanted associated gas. The optimised prototype fortified Gas2's global competitive position, with the result that in February 2008 Gas2 was able to attract an inward capital investment of £10 million from Lime Rock Partners (USA) and a private investor syndicate to finance the commercialisation of the technology [I4].

In February 2010, the achievements of the KTP partnership between RGU and Gas2 were recognised with the Best Knowledge Transfer Partnership for Scotland award [I5].

Gas2 was awarded a further £1.7 million in 2010 to make out-of-the-laboratory slip-stream testing of the optimised ceramic membrane prototype system. Gas2 has, and continues to support the exploitation of RGU intellectual property in the Syngas and Fischer-Tropsch patent families. During 2010 and 2011, Gas2 established a laboratory Syngas programme at the specialist petrochemical research Wilton Centre in Cleveland to extend their Syngas test capability while further laboratory work and computerised modelling continued in the Aberdeen laboratory [I2]

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Gas2 secured a further £5.5m in February 2012 to further the development of the next generation of GTL technology, including the construction of a pilot reactor plant on a 0.4 acre site at the Wilton Centre in Cleveland. Gas2 is developing a catalytic ceramic-based porous membrane (pMR™) that is used in its GTL technology, to combines gas reforming Syngas reactors and fluid forming Fischer-Tropsch reactors to create liquid hydrocarbons [I6].

*“Gas2 has a new technology that has the potential to fundamentally disrupt the gas-to-liquids market. The global demand for new solutions is vast and the ability of Gas2 to secure this level of funding in today’s economic climate is a powerful indicator of confidence in the company and the potential of its technology.”*

Saad Bagach, Lime Rock [I6]

*“We are entering a new and exciting phase with the build of the pilot plant which will validate on a larger scale the commercial viability of the Gas2 process. We have a unique technology and process, and the commercial prize is great for a successful outcome.”* Mike Fleming, Gas2 [I6]

In July 2013 Gas2 was on track with development of the next generation GTL technology and test results from its pilot reactor plant at Wilton are encouraging. The Gas2 Syngas reactors have been commissioned and are operating successfully, producing upper quartile gas conversions in a single pass and through-puts within a narrow 2:1 hydrogen to carbon monoxide output ratio. The Fischer Tropsch (FT) reactors were commissioned during summer 2013. [I7]

The number of posts at the Aberdeen laboratory peaked at 9 people, including KTP associate Chen and PhD student McKenzie. February 2012 funding ultimately resulted in 16 posts within Gas2 in Aberdeen plus the creation of 5 operative positions at the Cleveland pilot plant site [I2].

Gas2 continues to protect its IP developed from the Syngas and Fischer-Tropsch technology with new patent applications related to its pMR™ CPOX process and new generation GTL reactors based on pMR™ porous membrane cores [I8, I9]. The Gas2 approach offers great potential for working very efficiently at low and medium gas pressures and at high single pass conversion rates resulting in radically lower CAPEX and OPEX and significantly smaller footprint than conventional GTL solutions. [I1.../intellectual-property, I1]

*“Gas 2 has a unique technology and process with the potential to fundamentally disrupt the current gas-to-liquids market.”*

Mike Fleming, Gas2 [I7]

Each funding round has assisted Gas2 to move towards commercialisation of the technology in the form of compact reforming and FT reactors. These reactors will be marketed on a global basis as the core chemical processing within small and medium scale GTL plants. It is envisaged such plants will be built by consortia involving Gas2, natural gas field operators, and engineering companies licensed to exploit the RGU/Gas2 IP portfolio. It is estimated that a 1000 barrel per day plant deploying Gas2 technology for stranded gas monetisation will convert around 10 million cubic feet of natural gas per day into synthetic crude oil, which is cleaner than its naturally occurring mineral-based equivalent [I2].

<b>5. Sources to corroborate the impact</b> (indicative maximum of 10 references)
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- [I1] [www.gas-2.com](http://www.gas-2.com) including <http://www.gas-2.com/applications/stranded-gas/>; Timeline at [www.gas-2.com/about/](http://www.gas-2.com/about/); [www.gas-2.com/gtl-technology/intellectual-property/](http://www.gas-2.com/gtl-technology/intellectual-property/)
- [I2] Co-founder and Managing Director, Gas2 Ltd. Letter describing Gas2 and the economic impact of the investments to commercialise the technology.
- [I3] <http://info.ktponline.org.uk/action/details/partnership.aspx?id=1658>
- [I4] [www.heraldscotland.com/gas2-secures-pound-10m-growth-capital-investment-1.875754](http://www.heraldscotland.com/gas2-secures-pound-10m-growth-capital-investment-1.875754)
- [I5] [www.ktponline.org.uk/assets/Uploads/eTransfer\\_Issue18.htm](http://www.ktponline.org.uk/assets/Uploads/eTransfer_Issue18.htm)
- [I6] [www.heraldscotland.com/business/company-news/gas2-raises-55m-in-bid-to-develop-greener-technology.16735913](http://www.heraldscotland.com/business/company-news/gas2-raises-55m-in-bid-to-develop-greener-technology.16735913)
- [I7] [www.gas-2.com/2013/07/gas-to-liquids-technology-plant-on-target/](http://www.gas-2.com/2013/07/gas-to-liquids-technology-plant-on-target/)
- [I8] Patent WO2011083332, *Apparatus and method for adiabatic methane conversion*, Quintero, Diaz & Banister, Gas2 Ltd, (File date 7-Jan-11), Publication date 14-Jul-11.
- [I9] Patent WO 2013008020, *Isothermal reactor for partial oxidation of methane*, Banister, Gas2 Ltd (File date 12-Jul-12), Publication date 17-Jan-13.