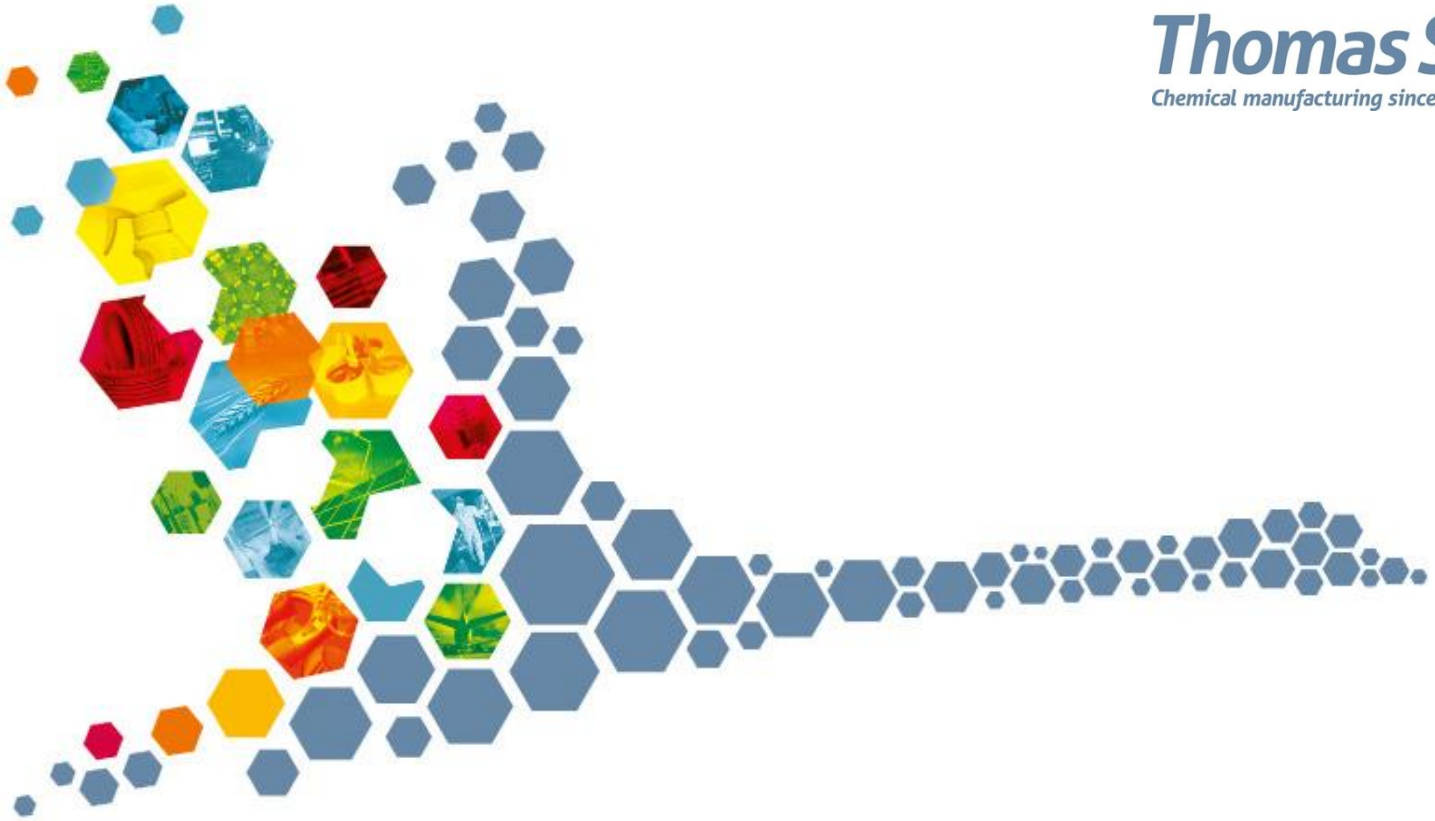
Thomas Swan

Chemical manufacturing since 1926



Leaders in Performance and Speciality Chemicals

Committed to Responsible Care

Sustainability in the Chemical Manufacturing Industry from an SME's perspective

Dr. Simon Grant

Technical Director

Thomas Swan & Co. Ltd

Thomas Swan

Chemical manufacturing since 1926

Thomas Swan
Chemical manufacturing since 1926

Agenda

- Introduction to Thomas Swan & Co. Ltd.
- A definition of “sustainability”
- Case studies
    - Energy Efficiency
    - Use of “green feedstocks” or “renewable feedstocks”
    - Super Critical Fluid Technology
- Conclusions

Thomas Swan & Co. Ltd.

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Overview

- Performance and Speciality chemicals
- Independent for over 90 years
- £24.2m ($40m) turnover 2014/15
- 160 employees
- Exports 75% of turnover
- Breadth of capability, experience and expertise
- Dedicated to customer care excellence
- Reputation for innovation
- Commitment to the highest standards
- Offices in the UK, USA and China

Thomas Swan's Capabilities as an SME

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- Established manufacturing infrastructure:
  - Capital Engineering.
  - Quality Control.
  - Environmental Control.
  - Scheduling/Logistics.
  - Sales/commercial
- Regulatory Affairs:
  - Experts in nanomaterials
- Process Engineering:
  - Process design and piloting.
  - Flexible chemistries.
  - Proven scale-up experience.
- Research and Development
  - 8 patent applications since 2014
  - Strong links with Universities, CRO's
  - 8% turnover – commitment to R & D
- Underpinned by recognised accreditations:
  - ISO 9001.
  - ISO 14001.
  - OHSAS 18001.
  - Responsible Care.

Diversity across 3 Business Divisions

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Performance Chemicals

- Tyres & Rubber Additives
- Coating Additives & Leather Fungicides
- Household & Health Care

Custom Manufacture

- Contract & Toll
- Supercritical Processing

Advanced Materials

- Elicarb Carbon Nanotubes
- Elicarb Graphene
- h-BN

Thomas Swan's Capabilities as an SME

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Summary of chemistries performed on a commercial scale:

- Oxidation
- Chlorination
- Halogenation
- Nitration
- Alkylation
- Sulphonation
- Free-radical catalysed polymerisation
- Condensation polymerisation
- Chemical Vapour Deposition
- Condensation reactions
- Isocyanate
- pre-polymerisation
- Thiocyanation
- Esterification
- Amidation
- Hydrolysis
- Benzoylation
- Quaternisation
- Amination
- Friedel-Crafts Alkylation
- Diels-Alder reactions
- Isomerisation and Rearrangement reactions
- Reductions
- Diazotisation
- Cyclisation
- Grignard reactions
- Etherification
- Diazo Coupling
- Ester Exchange reactions
- Maleinisation

Thomas Swan's Capabilities as an SME

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Summary of unit operations performed on a commercial scale:

- Filtration
- Distillation
- Centrifugation
- Drying
- Exfoliation

Sustainability

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Sustainability – a definition from our perspective

- **Corporate longevity**
  - Commercial viability of new and existing products
  - Compelling value propositions for Thomas Swan, their customers and stakeholders
  - Continued focus on market-led innovation

- **Minimise the impact of our manufacturing activities on the environment**
  - Renewable raw material sources
  - Renewable energy sources

Case Study 1 – Energy Efficiency

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Three strategies used to increase the efficient use of energy on site:

- **Maintenance and heat recovery**: Good insulation and well maintained equipment will reduce heat losses
- **Reaction choice and conditions**: Chemistries performed at lower temperatures e.g. biosyntheses operate at near ambient temperatures
- **Heat and power source**: Generation of own electricity source instead of buying from the National Grid

Thomas Swan & Co. Ltd.

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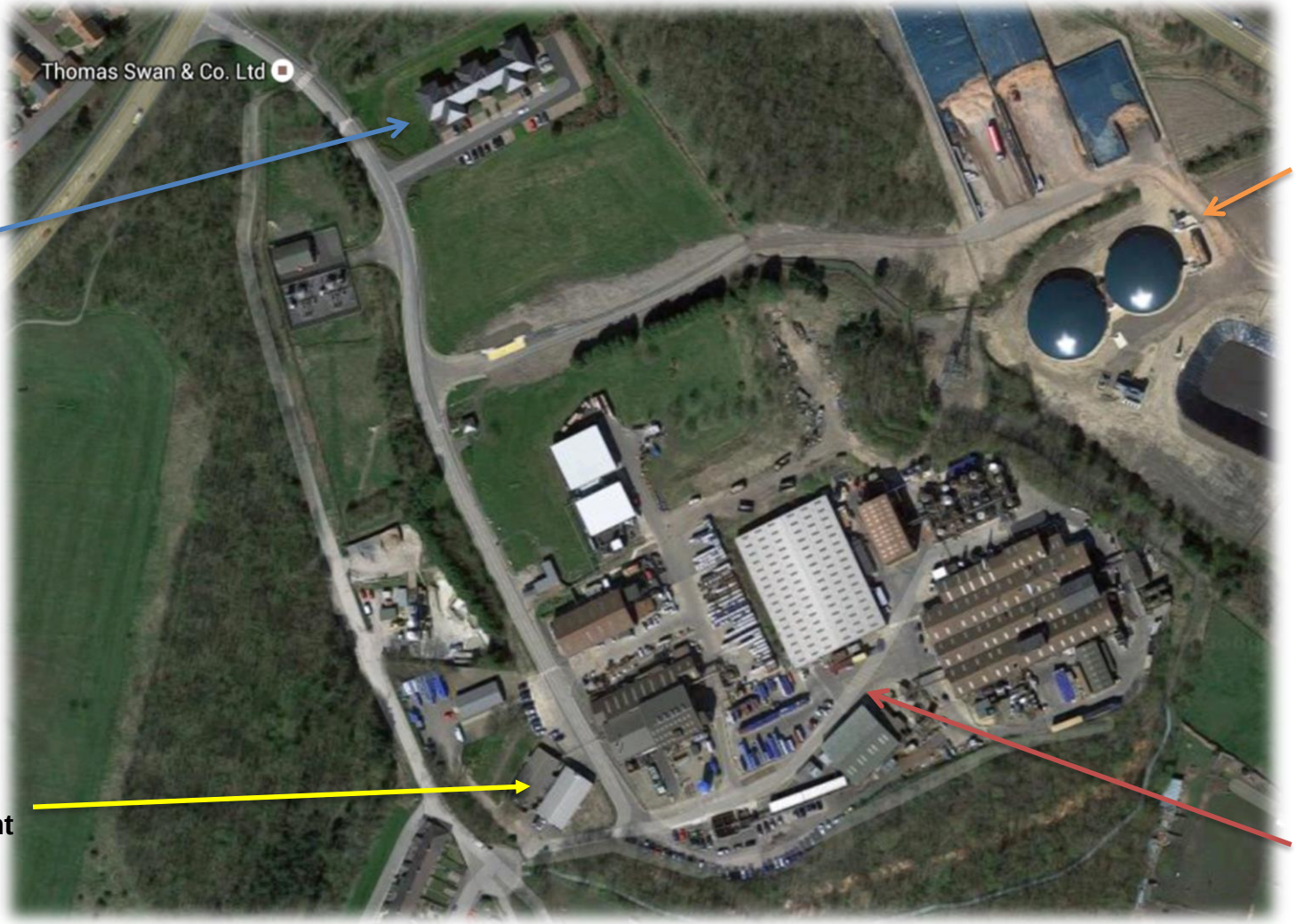


Anaerobic Digestion Power Plant

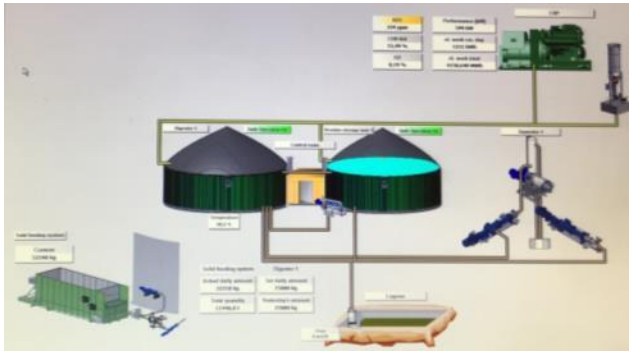
TSCL Anaerobic Digestion Power Plant

- Commissioned in 2015
- Owned by Generation X with funding provided by Ingenious Clean Energy
- 1MW output
- Combined heat and power plant
- 100% supply of the Thomas Swan manufacturing site electricity requirements

Additional

- Supplies electric car charging points at main office and security hut

Anaerobic Digestion Power Plant



Plant schematics

Generator

Generator house

TSCL Anaerobic Digestion Power Plant

- 100% supply of the Thomas Swan manufacturing site electricity requirements
- Biomass sourced within 10 mile radius
- Waste mass and liquor is collected and spread on the same farmers fields
- Waste heat used to heat the plant and water used on the plant

Case Study 1 – Energy Efficiency

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- Thomas Swan has own independent electricity supply that can provide 100% of current manufacturing requirements
- Have the capability to export excess energy to the National Grid at commercial rates
- Supply of hot water allows heating of reactors and heating of offices and buildings on our manufacturing site
- All of the feedstock for the AD plant is sourced within 10 miles of site
- Three harvests per year – feedstock stored on site
- “Waste” from the AD plant spread back on the land

Case Study 2 – Renewable Feedstocks

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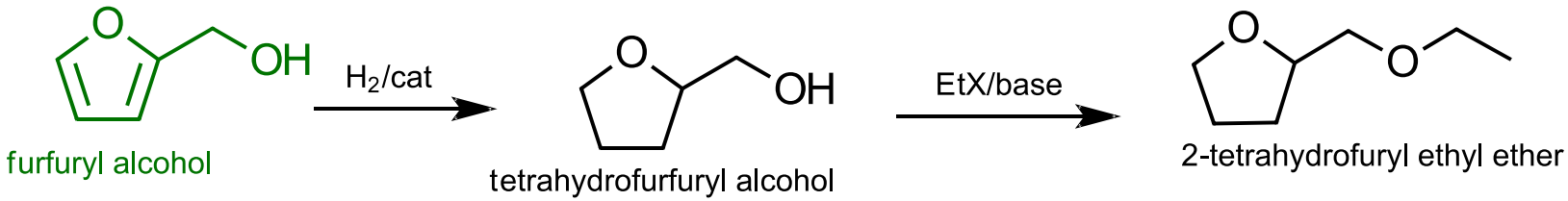
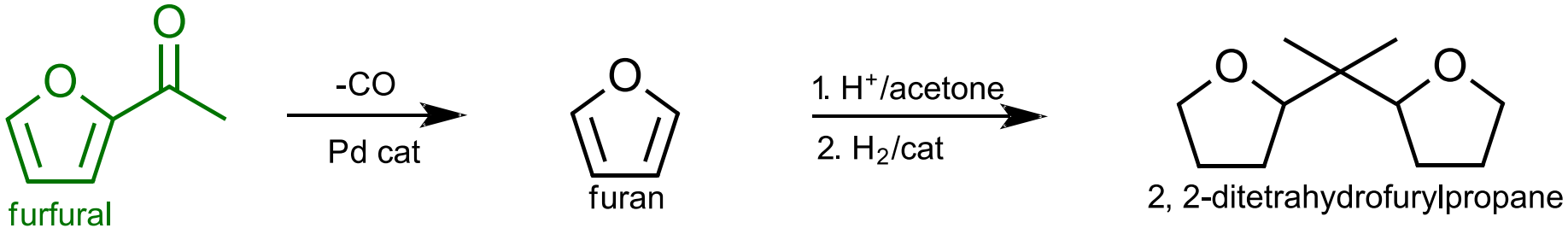
- Examples of new specialty chemicals that start from renewable feedstocks
- At Thomas Swan we manufacture the following molecules:





- Both products are “Polar Modifiers” used in Synthetic Rubber manufacture (anionic polymerisation of styrene and butadiene)
- Commercial sales of both products predicted to grow as synthetic rubber manufacturers invest in anionic polymerisation capacity

Case Study 3 – Super Critical Fluid Technology

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- Super Critical Fluid Technology (SCFT) ticks a lot of sustainability boxes:
  - Process Intensification
  - Green chemistry – replacement of traditional solvents
  - Catalysis
- Thomas Swan & Nottingham University collaborated on the development of SCFT from 1995 to 2003
- Target – continuous hydrogenation in $scCO_2$ using heterogeneous catalysis
- Work focussed on heterogeneous rather than homogeneous catalysis as the experimentation was simpler and scale up routes were more obvious
- Ambitious objectives were:
  - Development of technology for the hydrogenation of a wide range of functionalities, with high selectivity
  - Scale equivalent to tonnes per annum on laboratory scale
- If this proved to be successful, this technology would add new capability to Thomas Swan

Case Study 3 – Super Critical Fluid Technology

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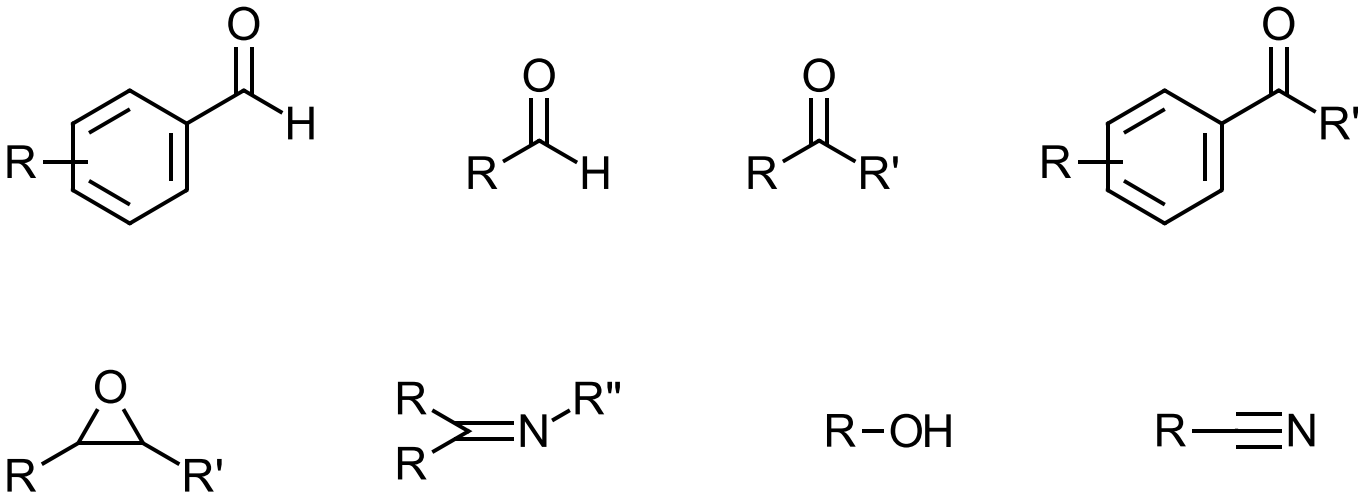
- Proof of concept work at Nottingham University:
  - Demonstrated the quantitative hydrogenation of cyclohexene
  - Demonstrated hydrogenation of the following functionalities:



  - Demonstrated that the technology can be used to perform Friedel Crafts alkylation, etherification, hydroformylation and base catalysed transesterification

Case Study 3 – Super Critical Fluid Technology

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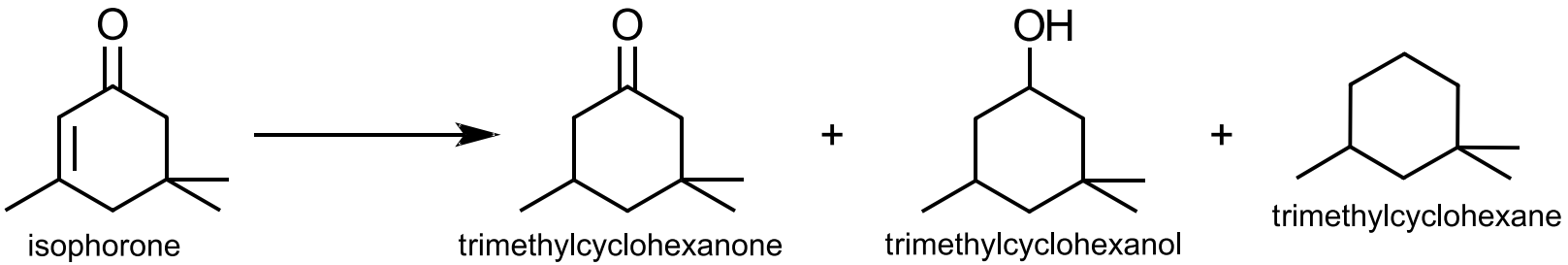
- Identified a model compound for the commercial scale trials
- The molecule chosen needed to have commercial interest



- Hydrogenation of isophorone to trimethylcyclohexanone
- Industrial use of trimethylcyclohexanone requires high purity
  - Conventional hydrogenation produces trimethylcyclohexanol and trimethylcyclohexane as by-products
  - To obtain high purity trimethylcyclohexanone requires careful distillation as the starting material and products have similar boiling points. This adds to both cost and environmental impact of the conventional route

Case Study 3 – Super Critical Fluid Technology

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- SCFT plant designed and commissioned in 2002
- The multi-purpose plant design allowed the ability to change the catalyst to suit the chemistry
- The first reaction that was run was the hydrogenation of isophorone
- The following table details the analysis of trimethylcyclohexanone made using SCFT compared to the customer specification

Specification	Customer	TSCL SCFT
Colour (Hazen)	10 max	< 10
Assay (%)	99 min	99.4
Trimethylcyclohexanols (%)	1 max	0.03
Isophorone (%)	0.4 max	0.08
Acid value (mg/KOH g-1)	0.1 max	0.08

Case Study 3 – Super Critical Fluid Technology

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Super Critical Fluid Technology (SCFT) had eliminated the requirement for further purification of trimethylcyclohexanone after hydrogenation

A technical success story – that resulted in the winning of the Industrial Innovation Team Award for Nottingham University and Thomas Swan in 2003

Case Study 3 – Super Critical Fluid Technology

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- Super Critical Fluid Technology (SCFT) where are we today?

- SCFT plant is not currently operational
- Thomas Swan have the capability to perform SCFT
- There is no current commercial advantage for Thomas Swan in using this green technology for the manufacture of specialty chemicals at present

Conclusions

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In terms of sustainability for Thomas Swan as an SME in Specialty Chemicals Manufacturing:

- We believe that we have a business model that will allow Thomas Swan to grow in the Specialty Chemicals market. This is based on
  - Market-led innovation for new product development; ensures that there is a compelling value proposition for Thomas Swan, our customers and stakeholders – commercial viability is essential
  - Minimising the effect of our manufacturing activities on the environment - AD plant
  - Practical adoption of sustainable and green chemistry principles where possible – use of renewable feedstocks and the learning gained from SCFT

Offices

United Kingdom

Thomas Swan & Co. Ltd.
Rotary Way
Consett
County Durham
DH8 7ND
UK

Tel: +44-1207-505-131
Fax: +44-1207-590-467

United States

Swan Chemical Inc.
136 Ridge Road
2nd Floor
Lyndhurst
New Jersey
07071
USA

Tel: +1-201-729-1400
Fax: +1-201-729-0763

China

Thomas Swan (Shanghai) Co. Ltd.
Room 607
Building B
Rainbow Centre
No. 3051, Hechuan Road
Minhang District
Shanghai
201103
China

Tel: +86-21-3472-0232
Fax: +86-21-3472-0231

www.thomas-swan.co.uk

Thomas Swan
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