Steps to Green Hydrogen
Sustainable Scotland

Ian Williamson
Air Products

11th September 2008
Air Products Overview

• Global gases, chemicals, equipment and services provider
• Serving technology, energy, healthcare and industrial markets
• Industry safety leader
• $10 billion in sales
• Operations in more than 30 countries
• >20,000 employees
• Owns and operates over 700 plants
• Designed and built over 2000 plants
• Fortune 500 company
• Known for our innovative culture and operational excellence
The Leading Hydrogen Producer/Supplier Worldwide

- Air Products pioneered the first large scale production of liquid hydrogen for possible use as military aircraft fuel in the late 1950’s.
- Worldwide leadership position in third party hydrogen production and distribution > 50% market share

  - Safely operate more than 60 hydrogen production and processing facilities in several countries
  - Broad range of hydrogen supply modes and complete hydrogen technology
  - 15+ years building hydrogen fueling stations portfolio
  - Active in UK hydrogen arena, HFP, JTI etc
  - Driving advancement of the hydrogen fuel economy

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Drivers for alternatives energy supply are:

- Efficiency
- Independence
- Environment
- Sustainability
Air Products – 2008 UK

- Air Products awarded bus infrastructure contract
- Fuelling of 10 buses for 5 years in London
- LHY supply via a novel supply concept trailer, hydrogen will be green
Air Products – 2008 UK

• Infrastructure provider for Transport for London’s hydrogen bus project
  - Innovative new delivery concept
• Provided Hydrogen fueling station to Birmingham University
• Provided Hydrogen fueling station to Loughborough University
• Supplying hydrogen fueling infrastructure to Comhairle Nan Elian Siar
Flexibility in a Hydrogen Economy

**Energy source**
- Natural Gas
- Biomass
- Crops
- Organic Waste
- Renewables
- Wind, Wave, Solar
- Waste Materials
- Coal, oil
- Nuclear

**Hydrogen Production**
- Steam reforming
- Gasification
- Electrolysis
- Thermolysis
- Photolysis
- Off Gas

**Distribution**
- Pipelines
- Compressed gas trailers
- Cryogenic liquid tankers
- Ship
- Rail

**Storage**
- Metal tanks
- Composite tanks
- Metal hydrides
- Chemical Hydrides
- Carbon

**End Use**
- Vehicle fuel cell
- Stationary fuel cell
- IC Engine
- Portable fuel cell
Retail Fueling

IOC
India

BP
Singapore

Shell Hydrogen
Washington DC

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Some Air Products Fueling Stations...

- 80+ stations worldwide
- 50,000 + safe fuellings
- Standard and customized systems
- 200, 350 and 700 barg dispensing
Wind and Solar to Hydrogen
Wind to Hydrogen

- GAS NATURAL: Sotavento wind farm (60 Nm3/h H₂ production
PV to hydrogen

- Hércules project (Spain)
- Located at the site of a solar collector facility
- Transport application
- Converting a diesel car into a hybrid
- 8 companies participating, including Air Products

Acknowledgements:
Agencia de Innovación y Desarrollo de Andalucía (IDEA), and
Ministerio de Educación y Ciencia, both for their financial support
Hercules
Infrastructure Transition

TODAY

Hydrocarbon sourced infrastructure exists

- Global production: ~50 million tons/of H₂
- Industrial applications 5%
- Refinery/chemical applications 95%

PATHWAY?

Future

Revise energy Portfolio

Renewable, coal, nuclear, sourced H₂ for transportation sector
Infrastructure Transition

• Provide technologies which have utility today while positioning for the future
• Focus on a regional model with abundant H2 and population.
• Focus on mass transit in other urban areas.

Future Hydrogen Infrastructure will include:
- Pipeline delivered hydrogen similar to NG
- Multiple feed sources of hydrogen from:
  • Biomass
  • Geothermal
  • Wind
  • Solar
  • Nuclear
  • Coal
  • Methane reforming
- Delivered or distributed product in the outlying areas
Integrated Hydrogen Energy Station can provide a commercial transition

- High temperature fuel cells producing:
  - Heat
  - Power
  - Hydrogen

- Methane
  Anaerobic Digesters
  Landfill Gas etc.
Energy Station

Hydrogen Energy Station Vision
- High-Efficiency and Renewable -

Feedstock Generation
- Municipal Digester Gas
- Landfill Gas
- Ethanol / Agricultural Wastes
- Pyrolysis Gas
- Bio-Syngas / Syngas
- Vegetable Oils / Oils
- Other Methane Sources (e.g., coal-bed)
Comhairle nan Eilean Siar – Hebridean Hydrogen Park

Ruairi MacIver
Project Manager (Renewable Energy)
The Outer Hebrides

An island chain situated off the west coast of Scotland

<table>
<thead>
<tr>
<th>Island</th>
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<tr>
<td>Vatersay</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>26,502</strong></td>
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</table>

(Based on 2001 Census)
Outer Hebrides Infrastructure

Drivers

• Renewable Resource
• Grid Infrastructure
• All Energy Demand
• Imported Fossil Fuels
• Fuel Poverty

Energy Audit (2004)
>97% imported at +13% cost
Hebridean Hydrogen Park

Three distinct but inter-related phases:

Phase 1: Capacity building and skills development

Phase 2: Infrastructure and demonstration projects

Phase 3: Development of hydrogen markets
CnES Integrated Waste Management Facility

- Anaerobic digester
  - Capacity: 8,500 tonnes pa
  - Biogas production: 50 to 75 m³/h

- Biogas engine
  - Rating: 250kW
  - Run-time: 3-4 hours

- IWMF peak electrical load
  - ~110-120kW
  - Facility has spare electrical capacity
Hebridean Hydrogen Park
Phase 2: Infrastructure - H2seed (2007-08)

Electricity from biogas

H2 production - water electrolysis

Production: 5Nm³/h
Storage (buffer): ~22Nm³ at 30 bar
Storage (high pressure): ~65Nm³ at 420 bar

Application

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Hebridean Hydrogen Park
Phase 3: Growth - H2growth (2008-12)

• Encourage the development of a local hydrogen economy
• Extend range of application deployments
  - transportation
  - domestic
  - industrial
  \{ heating and power generation \}
• Establish hydrogen vehicle fleets
  - ICE & fuel cell
  - Private & commercial
• Use in marine vessels
• Develop local and export hydrogen markets
• Grid connected electrolysers for the active grid management
The Hydrogen Corridor

A joint initiative:
Scottish Hydrogen & Fuel Cell Association and Aberdeenshire Council

Tom Read
Chief Executive
Scottish Hydrogen & Fuel Cell Association
www.shfca.org.uk
Why Aberdeenshire?

• Aberdeenshire Council buses around 12,000 pupils to schools daily, the third highest number of any Scottish Local Authority.

• Over 1 million passenger journeys covering over 2.2 million miles are carried out on routes subsidised by the Council, making Aberdeenshire a significant player in the rural passenger transportation sector.
Scottish Hydrogen & Fuel Cell Association

- Set up in 2004 with 2 main tasks:
- Build representative body for the H & FC industries in Scotland
- Stimulate development of the H & FC industries in Scotland
- Now 60 member organisations
- Capability to deliver major projects in place
HyFuture 2008

• It is anticipated that the majority of hydrogen generated will be used in the transportation sector which is one of the highest contributors to CO2 emissions and poor air quality.

• Actions that encourage large-scale installation of renewables and demand for low carbon transport will support the commercialisation of renewable hydrogen.
Hydrogen Corridor

• A90 between Aberdeen and Peterhead
• Distance of 35 miles
• Corresponds to backbone of Energetica
• Early mover project to -
• Stimulate investment in hydrogen / fuel cell transport for Scotland
• Integral part of UK “Hydrogen Highway”
The Project Area
Project Partners

- Aberdeenshire Council
- Stagecoach Group
- Royal Mail Group
- BAA Scotland
- ASCO Group
- Scottish Power Renewables
- StatOil Hydro
- Air Products
- BOC Linde
- CENEX

- Intelligent Energy
- Axeon Holdings
- Proton Motor
- Alexander Dennis
- H2 Logic
- Amperor Europe Ltd.
- TUV NEL
- Gupta Partnership
- Green Urban Technologies
- Read Associates
# Applications

<table>
<thead>
<tr>
<th>Application Headline user</th>
<th>Examples of early actions</th>
<th>Vehicle</th>
<th>OEM (examples)</th>
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<td>Public transport</td>
<td>Stagecoach Group Aberdenshire Council</td>
<td>Coaches operating on A90</td>
<td>Alexander Dennis</td>
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<tr>
<td>Commercial vehicles</td>
<td>Royal Mail Group</td>
<td>Vans and small trucks</td>
<td>Proton Motor On-board APUs – Amperor Europe</td>
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<tr>
<td>Road freight</td>
<td>ASCO</td>
<td>Forklifts</td>
<td>H2 Logic / Amperor Europe</td>
</tr>
<tr>
<td>Aviation</td>
<td>BAA Scotland</td>
<td>Ground service vehicles &amp; passenger transport</td>
<td>Proton Motor On-board APUs – Amperor Europe</td>
</tr>
<tr>
<td>Off-road / leisure</td>
<td>Aberdeenshire Golf Resort developments</td>
<td>Golf buggies &amp; on site transport – ground maintenance vehicles and passenger vehicle Stationary applications in residential developments</td>
<td>H2 Logic / Amperor Europe / Intelligent Energy; Fuel Cell Scotland; MTU Fuel Cells; St Andrews Fuel Cells</td>
</tr>
</tbody>
</table>
Zero Emissions

$2H_2 + O_2 = 2H_2O$
Energy Crisis?

• There is no Energy Crisis.
• Hydrogen is all around us – it’s the stuff the oceans are made of.
• It’s the most abundant element in the universe.
• Scotland has the best wind and wave regime of any country in Europe = unlimited carbon free primary energy
Summary

• Small scale requirements will be met from various sources and with differing technology

• Air Products is leading the development of many greener hydrogen activities

• Scotland has a wealth of resources available to be positioned at the forefront of a renewable hydrogen economy

• The first projects and project concepts are emerging, political support needed to bring these to fruition.
Thank you
tell me more