Biogas Applications

Dr Stephen P Etheridge
Environmental Biotechnology Limited
Climate Change

- Climate is changing
- Not everyone agrees it is a result of human activity
- Carbon reserves being rapidly released into the atmosphere
Different countries release different amounts....

<table>
<thead>
<tr>
<th>Country</th>
<th>Consumption per person, kg coal equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>11,000+</td>
</tr>
<tr>
<td>Canada</td>
<td>10,000+</td>
</tr>
<tr>
<td>Australia</td>
<td>8,000</td>
</tr>
<tr>
<td>Germany</td>
<td>5,000</td>
</tr>
<tr>
<td>UK</td>
<td>5,000</td>
</tr>
<tr>
<td>France</td>
<td>5,000</td>
</tr>
<tr>
<td>China</td>
<td>1,000</td>
</tr>
<tr>
<td>Brasil</td>
<td>1,000</td>
</tr>
</tbody>
</table>
Kyoto Protocol

- 10% reduction on 1990 levels
- Can mean >30% reduction on current levels in some cases
- CDM important
- Not all non Appendix 1 countries agree with trading
- Value of credits?
Mitigation and Energy

Investment

Credits

1

21
Designers Responsibilities

- Understand the process
- Learn from mistakes
- Know the waste
- UK has bitter experience
Anaerobic Treatment

Waste + Heat (35°C/55°C)

90% COD Removal
ENDOTHERMIC

Low COD Effluent +
Biogas (65%CH₄ + 35% CO₂)

Energy Costs
Larger Reactors

Slow Growing Bugs...
No Sludge, COD to Biogas
Life and Death of a Microbe

Microbial Growth

Growth

Plateau

Extended Aeration

Activated Sludge

Death

Time
Optimum Digestion Temperatures

- **Psychrophilic**
  - Temperature: 35-37°C
  - Cattle Manure Seed

- **Mesophilic**

- **Thermophilic**
  - Temperature: 55°C

Microbial Growth vs. Temperature graph.
Simplified AD Process

Long Chain Organics

Acetogens

Volatile Fatty Acids

Methanogens

Methane + Carbon Dioxide

VFA Test < 3,000 mg/l

Methane %
What Wastes Can you Treat with AD?

- Sewage
- Animal Manures
- Industrial Effluents:
- Solid Wastes: MSW etc
- COD/N/P = 100/5/1

- Food Industry
- Paper & Pulp Industry
- Chemical Industry
- Pharmaceutical Wastes
- Petrochemical Wastes
- Steel Wastewaters
how do we realise the potential of biogas?
Monod Equation:

\[ \frac{dS}{dt} = \frac{kSX}{K_s + S} \]

- **S** - substrate concentration
- **X** - mass of microorganisms
- **k** - maximum rate of substrate utilisation
- **K_s** - half velocity coefficient

\[ \alpha \text{ Substrate} \]
\[ \alpha \text{ Bugs} \]
Biomass Retention

HRT - Hydraulic Retention Time
V - Volume
Q - Flow Rate

\[ \text{HRT} = \frac{V}{Q} \]

SRT - Solids Retention Time
Sr - Solids in Reactor
Se - Solids in Effluent

\[ \text{SRT} = \frac{S_r}{S_e} \]
Hydraulic Limitations

![Diagram showing WASHOUT at 5 days HRT (days)]
Digester Performance Curve

COD Organic Loading Rate (Kg COD/m^3/d)

COD Removal (%)

Lab Trials

- CSTR
- Anaerobic Filter
- UASB
- Expanded Bed

0  5  10  15  20  25  30

0  20  40  60  80  100
Laboratory Evaluation
Laboratory Evaluation
Define the Problem...
Waste Audit - Site Study

- Stream Identification
- Effluent Analysis
- Sampling
- Select the Right Process
  - Flow Proportional
  - Time Proportional
  - Spot
- Verification
Confectionery Plant
Flexible Liner Digestion Systems
Upflow Anaerobic Sludge Blanket (UASB)
Upflow Anaerobic Sludge Blanket (UASB)
IC Reactor
Expanded Bed Digester
CASE STUDY: Brewery and Soft Drinks Effluent

- **Problem**
  - Failed effluent treatment plant
  - Pressure from Water Company to reduce COD/SS
  - Very high Mogden charges
  - High variation in flow, COD, SS

- **Due to**
  - Plant corrosion
  - Poor design
  - Poor waste audit
CASE STUDY: Brewery and Soft Drinks Effluent

- **Solution**
  - Comprehensive waste audit (client owned)
  - Feasibility study
    - sewer or river
    - aerobic or anaerobic
    - new technologies/grants
  - New treatment plant
  - Novel heating and mixing system
  - THERMIE Grant
  - EBL design & project management
  - Client direct purchase of all equipment
Brewery Effluent

- 3,300 m$^3$ insulated Tank
- 600-700 m$^3$/d, COD = 3,000-6,000 mg/l
- >98% COD Removal
- Variable Volume Reactor (Monday = 1,800 m$^3$, Friday = 3,300 m$^3$)
- Stirred Tank Reactor
- Heated with Submerged Combustion
- Venturi Mixing
Submerged Combustion

Submerged Combustion

- 99% hot water

Boiler Use

- 60-75%
- 25-40% waste heat
Submerged Combustion

Diagram:
- Air
- Biogas
- Exhaust
- Digester
- Venturi
Venturi Mixing System
CASE STUDY:
Textile Industry Effluent

- Mill on Site for more than 190 Years (Part of Axminster Carpet Group)
- 140 Staff
- 2,900 tonnes Wool processed
- 2,000 tonnes Spun Yarn produced
- Lanolin wool grease and sheep dip pesticides in the fleeces
Buckfast Spinning Limited

- Buckfast Spinning has operated a flocculation effluent treatment process for 25 years
- Wool scouring and dyeing effluents combined to give overall discharge COD of 4,000 mg/l
Effluent Characteristics

- High COD (3,500 mg/l)
- Flow 420 m$^3$/d
- pH 6 - 8
- High Temperature Effluent (25-40ºC)
- Trace Organophosphate Pesticides
- Colour
- Grease, Dirt, Sweat Salts, Trace Sheep Dip, Oils, Dyes, Detergents
Pre-treatment of Effluent

- Effluent stored in Holding Tanks
- Pretreatment by Acid Cracking/Flocculation
- Effluent is Centrifuged and Resulting Sludge is Landfilled
- Final Effluent is Discharged to Sewer
- COD and SS Monitored
- 70% of COD is removed by Pretreatment
Problems

- £311,000 for Discharge of Effluent to Sewer in 1997 (23% increase in last two years)
- £113,000 for on-site Effluent Treatment in 1997 (excl. maintenance & parts)
- Pesticide Emissions at least < 8.0 ppb
- Future Direct Toxicity Assessment
- Sensitive Location
Pilot Plant

- Two 50m³ Reactors
- De-gas Tank prior to Discharge
- Flare/Boiler for Biogas Handling
- pH Control
- Gas Compressor for Mixing
Pilot Plant
Pilot Plant
Pilot Plant
Status and Objectives

- Biotechnology is the key to eliminating and degrading potentially harmful effluent

Future Objectives

- Demonstrate successful Treatment of Textile Effluent by Anaerobic Digestion
- COD Removal (>50%)
- Degradation of Toxic Organics and Pesticide (40-80%)
- Colour Reduction
CASE STUDY: Cassava Processing in Asia

**Problem**
- 6000m³/d effluent discharged to 72 open lagoons
- Massive methane emissions to atmosphere
- No energy capture

**Solution**
- New Flexible Liner Digester
- Third Party design, install, own operate
- Natural Gas to run plant
- Excess electricity to Grid
Cassava Delivery and washing

Digester Volume = 100,000m³
Washing and Processing
Flexible Liner Digester
Digester Volume = 100,000m³
Alkaline Hydrolysis

- pH14
- 150 °C
- 3 hours
- 4 bar
Centralised Digesters

- 20 years experience in Europe
- Well understood & proven in Denmark, Scandinavia & Germany
- 7 out of 20 biogas plants in Denmark take sewage sludge (1999)
- Track record of no disease spread (human or animal)
- Final Product is integrated into European “composting” networks
- Used to solve variety of waste management and public acceptance issues (e.g. Energy from Waste, landfill emissions, poor use of CHP, odours from spreading raw slurry, disposal of sewage sludge, food supply chain quality assurance)
Hashøj Biogas Plant (DK) - 140 tonnes/day – started operation 1994 (also takes Isopropanol & MSW fines from Copenhagen)
Hashøj Biogas Plant (1994)

- Digester 3000m³ operated at 37°C
- 10 pig farms + 6 cattle farms feed 100t/d manure (one vacuum tanker)
- Industrial and other waste (abattoir, grease traps, fish processors etc.) 38t/d
- Pasteurisation at 70°C (sterilised returned effluent)
- 2,200m³ gas storage
- Owned by cooperative, 17 members all stakeholders
- Electricity and hot water to two communities (38% of needs)
Kristianstad Biogas Plant (S) - 200 tonnes/day
- started operation 1996
(takes source separated kitchen wastes, manures)
Loick Digester
Loick Digester (2001)

- Digester 970m3 operated at 38°C
- 35t/d @ 14% TS biomass from 700 pigs, grease traps, food processing wastes, corn and rye silage
- 25-30 days HRT with 75% organic removal efficiency
- 2,640m3/d biogas to 249kWe CHP
Witte Digester (1998)
Witte Digester (1998)

- Digester 1206m³ operated at 42°C
- 16t/d @ 20% TS biomass from 80 cows, 1,100 turkeys, food processing wastes, fat, grease traps, vegetables
- 60 days HRT
- 2,000m³/d biogas to 3 x 110kWe CHP sets
- US$ 600,000 cost with 25% grant
- Revenue is US$12,000/month electric and US$1,000 fertiliser sales
- 7 year payback quoted
Holsworthy Plant, Devon
• 146,000 tonne/y of cattle, pig & poultry manure and food waste
• Manure from 30 farmers within approx. 5 miles radius
• Pasteurisation at 70°C for one hour
• Digestion (37°C) for 20 days HRT
• Gas production: 6 million m³ biogas (equivalent to 39m kWh)
• CHP provides on-site heat for treatment requirements
• Continual N, P & K monitoring for bio-fertiliser taken to supplying farmers
HOLSWORTHY BIOGAS - Flow sheet

- manure & waste
- Receiving tank
- Mixing tank
- Storage tank
- Desulphurisation unit
- Digesters
- Heat exchangers
- Pasteurisation tanks
- Distinct heating planned from 2002 / 2003
- Gas engines
- Electricity to the grid

Legend:
- substrate
- hot water
- cold water
- biogas

Reception Hall
The Process

- Totally enclosed (& pressurised) system after unloading
- Only manually controlled at point of ‘reception pit’ to ensure right mixture goes into ‘mixing tank’ via chopper pumps
- Automatic return (re-start) if parameters of ‘pasteurisation unit’ not reached
- Farmers usually operate 3 week no grazing system
- Constant Monitoring
Tankered Effluent
Barriers to Co-Digestion in the UK

- Complexity of legislation increasing
- Limited understanding by Regulators of relatively new concept
- Increasing requirements for involvement with farmers and monitoring of spreading practices
- UK has narrow focus on “composting” industry – poor awareness
- Physical contamination problems when using source separated kitchen wastes (MSW)
- Classification of what is a “waste” and when does it become a product
CASE STUDY: Baguio

Feasibility Study Funded by the UK Foreign & Commonwealth Office (FCO)

- Waste Study
- Site Review
  - Characterisation of Benefits
  - Collection
  - Impact on Local Community
- Design Options
- Selection, Costing and Funding
Irisan Dumpsite
<table>
<thead>
<tr>
<th>Waste Category</th>
<th>White Truck (kg)</th>
<th>Yellow Truck (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>37</td>
<td>146</td>
</tr>
<tr>
<td>Plastic</td>
<td>53</td>
<td>479</td>
</tr>
<tr>
<td>Rubber/Leather</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Vegetable/Organic Waste</td>
<td>4,564</td>
<td>1,193</td>
</tr>
<tr>
<td>Food Waste</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Glass</td>
<td>14</td>
<td>2</td>
</tr>
<tr>
<td>Metal/Tin Cans</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>Textile</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Inert</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wood</td>
<td>16</td>
<td>435</td>
</tr>
<tr>
<td>Special Waste/Fish &amp; Meat Waste</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4,696</strong></td>
<td><strong>2,287</strong></td>
</tr>
<tr>
<td>Bulk Density</td>
<td>470 kg/m³</td>
<td>229 kg/m³</td>
</tr>
</tbody>
</table>
Low Solids Digester Option

- Biogas: 1960 m³/d
- CHP: 160kWe
- Flare
- Solids Separator
- 25 t/d Wet Market Waste
- 1500 m³ Digester
- 20 m Feed Tank
- 3 m³/d Unthickened Sewage Sludge + 117 m³/d Sewage
- Solids: 10.7 t/d
- 3 m³/d Unthickened Effluent
- 120 m³/d Effluent
- Solids 10.7 t/d
High Solids Digester Option

- 1.2m³/d Thickened Sewage Sludge
- 25t/d Wet Market Waste
- 550m³ Digester
- 10m³/d Recycle Liquor
- 1960m³/d Biogas
- ± 160kWe CHP
- Flare
- 10m³/d Recycle Liquor
- Solids 10.7t/d
- 15m³/d Effluent
- Market Waste 10m³/d Recycle Liquor
- Solids Separator
Two Stage Digester Option

- Thickened Sewage Sludge
- 4 Concrete vessels or 20 Cargo Containers
- Solids 10.7t/d

- 1,100m Total Batch Reactor Volume

- 100m Storage Tank

- 200m UASB

- 160kWe ±

- Biogas 1960m /d

- Flare

- 10-20m /d Effluent

- Market Waste
Composting Digestate

Roofed Sludge Drying Area

- Air
- Mature Compost
- Digestate and Bulking Agent
- Aeration Pipework
- Condensate Trap
- Blower

Exhaust Air
Filter from Mature Compost
## Process Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baguio Wet Market Waste</td>
<td>14 t/d</td>
</tr>
<tr>
<td>La Trinidad Wet Market Waste</td>
<td>11 t/d</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>25 t/d</strong></td>
</tr>
<tr>
<td>Assumed average Bulk Density</td>
<td>470 kg/m³</td>
</tr>
<tr>
<td>Volume of waste per day</td>
<td>53.2 m³</td>
</tr>
<tr>
<td>Average Total Solids</td>
<td>26%</td>
</tr>
<tr>
<td>Average Volatile Solids</td>
<td>64%</td>
</tr>
<tr>
<td>Total Volatile Solids</td>
<td>16.64%</td>
</tr>
<tr>
<td>Projected Biogas Potential (at 65% CH₄)</td>
<td>1955 m³/d</td>
</tr>
<tr>
<td>Electrical Energy</td>
<td><strong>160 kWe</strong></td>
</tr>
<tr>
<td>Solid Digestate at 60% solids recovery</td>
<td>3,900 t/y</td>
</tr>
<tr>
<td>Compost including bulking agent</td>
<td>7,800 t/y</td>
</tr>
</tbody>
</table>
## Process Economics

<table>
<thead>
<tr>
<th></th>
<th>PhP (million)</th>
<th>£'000</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Revenues</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Tipping Fee</td>
<td>3.47</td>
<td>50</td>
</tr>
<tr>
<td>- Electricity</td>
<td>4.42</td>
<td>63</td>
</tr>
<tr>
<td>- Compost</td>
<td>8.18</td>
<td>117</td>
</tr>
<tr>
<td></td>
<td><strong>16.07</strong></td>
<td><strong>230</strong></td>
</tr>
<tr>
<td><strong>Operating Costs</strong></td>
<td>10.72</td>
<td>153</td>
</tr>
<tr>
<td><strong>Revenue</strong></td>
<td>5.3</td>
<td>230</td>
</tr>
<tr>
<td><strong>Total Project Costs</strong></td>
<td><strong>42.11</strong></td>
<td><strong>601</strong></td>
</tr>
</tbody>
</table>
Baguio Project Development

Phase 1: 25t/d Wet Market Waste
Phase 2: +70t/d 50% Baguio MSW
Phase 3: +70t/d 50% Baguio MSW
MSW Treatment

Mixed Waste → Separation → Recycled Material

Separation → Composting

Separation → Anaerobic Digestion
Akras Herb & Essence Waste
Anaerobic Digestion of High Solids Wastes
Anaerobic Digestion of MSW
Overview of renewables support measures to date

- NFFO introduced in 1990 Electricity Act
- 5 Orders (& 3 in Scotland, 2 in NI)
- over 3600 MW contracted
- only 950 MW built so far
- low prices
- long period of consultation
- Start of Renewables Obligation
NFFO – non fossil fuel obligation

- Competitive tendering for banker-friendly contracts
- Bankers became familiar with renewables and NFFO contracts
- Supported range of technologies
- kick started industry & brought prices down
- but commissioning very slow
NFFO (1 - 3) and AD

- NFFO1
- 3 contracts awarded for AD projects (NI SG)  All commissioned.
  - 0.88 MW, Heathfield, Devon
  - 0.17 MW, Ham Sewage Treatment Works, Somerset
  - 3MW, Avonmouth Sewage Treatment Works, Avon

- NFFO2 & 3 No AD
**NFFO4, 6 contracts awarded for AD projects**

Status as of April 2002

- LRZ Ltd
  - **Eye Airfield**
    - 1.05
    - No PA made
  
- AGTEC Ltd
  - **Spalford ADS, Lincs**
    - 1
    - No PA made
  
  - **Whitchurch Hydro ADS, Shropshire**
    - 2
    - No PA made
  
  - **Hydro Leeming AD, N. Yorkshire**
    - 0.5
    - PA approved
  
  - **Hydro Seamer ADS, N Yorkshire**
    - 0.6
    - No PA made

- Holsworthy Biogas Company
  - **Holsworthy, Devon**
    - 1.43
    - Commissioned

**NFFO5 AD not eligible to enter**
Which RE sources are eligible?

- All non thermal RE sources (excluding hydro >20MW)
- Various restrictions on Biomass
- Where MSW is a fuel only gasification, pyrolysis or AD technology qualifies.
- With exception of certain hydro projects, nothing built before 1990, unless refurbished
- If it has a NFFO contract which was not terminated properly
- AD in - (provided OK re. bullet points 4 & 5)
<table>
<thead>
<tr>
<th>Biogas incentives in Germany</th>
</tr>
</thead>
<tbody>
<tr>
<td>● <strong>German Renewable Energy Act (1.4.2000)</strong></td>
</tr>
<tr>
<td>● <strong>Electricity 20 year min price</strong></td>
</tr>
<tr>
<td>● <strong>30% capital refund after construction (grant)</strong></td>
</tr>
<tr>
<td>● <strong>Long term soft loan</strong></td>
</tr>
</tbody>
</table>
Biogas incentives in Germany

- 150 developers and installers of new systems
- 1000 new plants installed
- > 2000 new jobs
- now stopped…
Germany

Biogas Development

No. Plants Installed

Installed Capacity


0 20 40 60 80 100 120 140 160

0 200 400 600 800 1000 1200 1400 1600 1800
## Biogas incentives in Germany

### Compensation in  Cent including 1% annual reduction

<table>
<thead>
<tr>
<th>Capacity</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
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<tbody>
<tr>
<td>Up to 500 kWe</td>
<td>10.1</td>
<td>10.0</td>
<td>9.9</td>
<td>9.8</td>
</tr>
<tr>
<td>Up to 5 MWe</td>
<td>9.1</td>
<td>9.0</td>
<td>8.9</td>
<td>8.8</td>
</tr>
<tr>
<td>Up to 20 MWe</td>
<td>8.6</td>
<td>8.5</td>
<td>8.4</td>
<td>8.4</td>
</tr>
</tbody>
</table>
Conclusions

- Technology available and developing
- Poor implementation – lack of understanding
- Needs careful incentivisation
- Barriers – public perception, scale, cost
- Developments – new forms of ownership, project development and operation
The End