NWaste2H2:

Decreasing $N_2O$ and $CO_2$ emissions from WWTP by co-reforming of the biogas and digestate liquor

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Integration of Chemical, Biochemical and Thermal Processes

A joint AD Network/Supergen Bioenergy Event, Birmingham, 6th Feb 18
N2Waste2: H₂ Production by Reforming Bio-methane with Nitrogen Rich Waste Streams (Significant Carbon and Nitrogen emissions reductions from synergies of SMR, AD and WWTP)

EP/R00076X/1 start 18 Sept 2017 end 17 Sept 2019 £ 202,491


Additional funding: EP/L014912/1, MSc/PhD scholarship via EPSRC Centre for Doctoral Training in Bioenergy (Leeds)

Research topic actually started with PhD project (Oliver Grasham) in June 2015
Motivation

Decarbonising energy intensive industries by:
- Process intensification measures
- Identifying potential synergies for GHG emissions mitigation
- Demonstrating techno-economic-sustainability
- Quantifying benefits to the UK and wider world.

Industries whose GHG this project addresses:
- Pairing of water treatment and production of bio-H2.
Disadvantages:
- GHG emissions at denitrification stage (CO₂, N₂O)
- SMR furnace (CO₂)
- No heat integration
- Plant double size, space availability

Advantages:
- Mature technologies, reliable
- Use of clean water on site for SMR
- Plants can be run independently

CONCEPT
H₂ from SMR of biomethane
Using conventional separate AD / SMR processes
Advantages: Denitrification throughput is greatly reduced,
  • In particular $\text{N}_2\text{O}$ emissions are avoided (GWP of 270 -20 years)
  • Energy requirement is less
  • Waste heat from SMR can be used in increasing AD biogas yield

Disadvantages:
  • SMR has to operate on impure steam feed
  • Digestate liquor/urine would need to undergo pretreatment and concentration.
  • Unknown effects on SMR catalyst
HOST PLANTS ASSESSMENT

WWTPs

556 AD plants in the UK (March 2017)

FOOD WASTE

PROCESS WASTE

AGRI WASTE

CROPS

AD PLANT

Capacity: $32.5 \times 10^6$ tpa (wet)

BIOGAS

DIGESTATE
HOST PLANTS ASSESSMENT

65% CH₄/25% CO₂ (vol.)

Biogas upgrading +90% CH₄ → BIOMETHANE → NWaste2H₂

DIGESTATE → Decanter centrifuge → L-fraction → Ultrafiltration → SOLID-FREE LIQUOR

BIOGAS
USE OF HYDROGEN

- Chemical feedstock
- Gas network injection
- Stationary FC
- CHP
- Transport (FC, mixtures, etc.)
UK DEPLOYMENT

- TECHNO-ECONOMIC SCREENING
  - ENERGY AUDIT
  - LIFE CYCLE ASSESSMENT
  - FINANCIAL VIABILITY
Work since EPSRC award:

- Investigation of UK sites suitability (host plants assessment)
- Investigation of UK end users
- Consultation with project partners
- Optimisation of the plant design (Aspen Plus): process refined, alternative layouts explored:
  - Combined NH₃ Recovery and H₂ Production
  - Combined NH₃ Recovery & Solid Oxide Fuel Cell Model
- Experiments of feasibility of co-reforming CH₄ and aqueous ammonia solutions in the lab
Results so far...

Preliminary techno-economic assessment of NWaste2H2
- Early version of Aspen Plus model of SMR integrated to Esholt WWTP
- Promising results, included in EPSRC case for support

### Table 1. Electricity production breakdown

<table>
<thead>
<tr>
<th></th>
<th>CURRENT BIOMETHANE -CHP</th>
<th>PROPOSED HYDROGEN - FUEL CELL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>QUANTITY /DAY</strong></td>
<td>7,000 kg CH₄</td>
<td>2,534 kg H₂</td>
</tr>
<tr>
<td><strong>LHV (MJ/KG)</strong></td>
<td>50</td>
<td>119</td>
</tr>
<tr>
<td><strong>CHEMICAL ENERGY CONTENT (MJ)</strong></td>
<td>350,000</td>
<td>302,000</td>
</tr>
<tr>
<td><strong>ELECTRICAL OUTPUT KWH</strong></td>
<td>34,000</td>
<td>41,800</td>
</tr>
</tbody>
</table>
Esholt WWTP Case Study
Background

Treats sewage from equivalent 760,000 people

CHP unit
• 35% elec efficiency
• ~40,000 kWh electricity per day

AD produces:
• ~8,235 kg CH₄ per day

Recycles ~660,000 L digestate liquor per day
Combined NH₃ Recovery and H₂ Production

- CH₄: 343 kg/hr
- H₂O: 831 kg/hr
- NH₃: 39 kg/hr
- Conc: 47 g/l

Recovered NH₃ Stream

- H₂O: 27,537 kg/hr
- NH₃: 50 kg/hr
- Conc: 1.8 g/l

H₂: 108 kg/hr
Combined NH₃ Recovery & Solid Oxide Fuel Cell Model

- **Biomethane**: CH₄ 343 kg/hr
- **Air**: 31,858 kg/hr
- **Recovered NH₃ Stream**: 41.4 kg/hr
- **Upstream S:C of 2.5**
- **Digestate Liquor**: H₂O 27,537 kg/hr, NH₃ 50 kg/hr, Conc 1.8 g/l
- **Flash**: H₂O 951 kg/hr, NH₃ 41.4 kg/hr, Conc 43.5 g/l
- **54.3 MWh/day**
- **0.45 Efficiency_{elec}**
Esholt WWTP: Energetic Implications

<table>
<thead>
<tr>
<th></th>
<th>Current Bio-methane - CHP</th>
<th>Proposed SOFC System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical Output (MWh/day)</td>
<td>40</td>
<td>54</td>
</tr>
<tr>
<td>N-diversion energy Savings</td>
<td>-</td>
<td>3.8</td>
</tr>
<tr>
<td>(MWh/day)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy used in SOFC process</td>
<td></td>
<td>1.9</td>
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<tr>
<td>(MWh/day)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total WWTP Elec Consumption</td>
<td>60</td>
<td>58.1</td>
</tr>
<tr>
<td>(MWh/day)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net Consumption (MWh/day)</td>
<td>20</td>
<td>4.1</td>
</tr>
</tbody>
</table>
H₂ POTENTIAL

2 % of UK’s domestic NG

30 % of UK’s merchant H₂

Every AD plant in the UK fitted with Nwaste2H2 technology
Experimental Set up

Packed bed reformer rigs (PI lab, Leeds)

Nickel based steam reforming catalysts (TST Ltd):
18 wt% NiO/α-Al₂O₃, 15 wt% NiO/CaO.Al₂O₃

Honeycomb Monolith Rhodium catalysts (TST Ltd)
1 wt% Rh / γ-Al₂O₃ washcoat on cordierite
1wt% Rh – 3 wt% Ce / γ-Al₂O₃ washcoat on cordierite
Video explainer of NWaste2H2
1st Prize winner of IChemE Special Interest Group 2017
https://www.youtube.com/watch?v=0bZ8B3iPRw0&t=177s

Acknowledgments

EPSRC

EP/R00076X/1 NWaste2H2

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THANK YOU