Bio-CCS: Early opportunities and incentives

Michiel C. Carbo

Oslo, Norway, 15 November 2011
“ECN develops and brings to market high-level knowledge and technology for a sustainable energy society”
R&D units

- Solar energy
- Biomass
- Wind energy
- Efficiency & Infrastructure
- Policy Studies
ECN in brief

- ECN is the largest independent Dutch energy research institute
- 140 M€/a turnover (2010, incl. nuclear R&D)
- 570 employees
- 600 scientific publications/reports each year
- 10 international patents each year
- Locations: Petten, Amsterdam, Eindhoven, Peking
- Integrated Bio-CCS R&D by units Policy Studies and Biomass, Coal & Environmental research
Biomass co-firing R&D (1)

Special reactor design: 1-2s residence times with only limited total reactor length

Probe measurements in power plants

Particle sampling probe

Fouling probe
Biomass co-firing R&D (2)

<table>
<thead>
<tr>
<th>Woody biomass</th>
<th>Agricultural residues</th>
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<tbody>
<tr>
<td>Mixed waste</td>
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</table>

- **Friable and less fibrous**
  - 19 - 22 MJ/kg (LHV, ar)
  - Hydrophobic
  - Preserved
  - Homogeneous

- **Improved fuel properties**:
  - Transport, handling, storage
  - Milling, feeding
  - Gasification, combustion
  - Broad feedstock range
  - Commodity fuel

- **Torrefaction and pulverisation**

- **Fuel powder**
  - Bulk density 650-750 kg/m³
  - Bulk energy density 13-17 GJ/m³

- **Fuel pellets**
  - Tenacious and fibrous
  - 10 - 17 MJ/kg (LHV, ar)
  - Hydrophilic
  - Vulnerable to biodegradation
  - Heterogeneous
Pre-combustion CCS R&D (1)

Ordinary water-gas shift:
\[ \text{CO} + \text{H}_2\text{O} \rightleftharpoons \text{H}_2 + \text{CO}_2 \]

Sorption-enhanced water-gas shift:
\[ \text{CO} + \text{H}_2\text{O} \rightleftharpoons \text{H}_2 + \text{CO}_2 \]

Feed:
- H\text{\textsubscript{2}}, CO, CO\textsubscript{2}, H\text{\textsubscript{2}}\text{O}, +CH\text{\textsubscript{4}}…

Sweep gas:
- CO\textsubscript{2} (+H\textsubscript{2}O…)

H\textsubscript{2}:
- Catalyst
- Sorbent
- Membrane

SEWGS
Pre-combustion CCS R&D (2)

VATTENFALL

Buggenum IGCC CO$_2$ capture pilot
Policy Studies CCS R&D

What happened in Barendrecht?
Case study on the planned onshore carbon dioxide storage in Barendrecht, the Netherlands

C.F.J. Poens, T. Hijmans, S. Breuning

CARBON DIOXIDE CAPTURE AND STORAGE

Technology Roadmap
Carbon Capture and Storage in Industrial Applications

Intergovernmental Panel on Climate Change
UNEP
IEA
UNIDO
Bio Energy & CCS (Bio-CCS)

- Conversion of biomass to electricity/heat/fuels/products combined with CO₂ capture and storage
- Bio-CCS potentially leads to negative CO₂ emissions, i.e. CO₂ uptake from the atmosphere through natural sequestration of CO₂ in biomass
- Offset of both historical and distributed CO₂ emissions
- Bio-CCS is indispensable to cost-effectively achieve most stringent global warming stabilisation scenarios
- Fossil fuel fired power plants with CCS ultimately only mitigate up to 80-90% of existing CO₂ emissions
ETP 2010: Electricity generation & CCS

CO₂ captured 5.4 Gt

- Coal: 86%
- Biomass and waste: 2%
- Natural gas: 12%

~ 110 Mton CO₂ captured by 2050

Source: IEA (ETP, 2010)
Roadmap: CCS in Industry (2011)

Five sectors:
- High purity sources
- Biofuels
- Cement
- Iron & Steel
- Refineries
Roadmap: Biofuel Projections

Cumulative global biofuel production (EJ)

- Hydrogen from biomass
- Biogas/BioSNG
- Biodiesel (Fischer-Tropsch)
- Biodiesel (oil seeds)
- Ethanol (ligno-cellulosic)
- Ethanol (cane)
- Ethanol (grains)

Sources: REN21 (2009) and IEA ETP (2010, BLUE Map scenario)
Roadmap: Bio-CCS projections (1)

CCS in 2020 (161 Mt CO$_2$/yr)

- 36.8% Gas (synfuels + hydrogen)
- 26.3% Biomass (synfuels + hydrogen)
- 17.4% Pulp and paper (biomass-based)
- 12.2% Iron and steel (biomass-based)
- 2.6% Chemicals (biomass-based)
- 1.8% Cement (biomass-based)
- 1.7% Iron and steel (fossil fuel-based)
- 1.8% Chemicals (fossil fuel-based)
- 1.7% Pulp and paper (fossil fuel-based)
- 0.5% Cement (fossil fuel-based)
- 0.3% Gas (synfuels + hydrogen)
- 0.4% Pulp and paper (fossil fuel-based)

Source: Carbo (2011) based on IEA ETP (2010, BLUE Map scenario)
Roadmap: Bio-CCS projections (2)

CCS in 2050 (4,032 Mt CO₂/yr)

Source: Carbo (2011) based on IEA ETP (2010, BLUE Map scenario)
Roadmap: Bio-CCS projections (3)

- H₂ & synfuels: 70%
- BioSNG: 17%
- Bio-ethanol: 11%

Source: IEA & UNIDO (2011)
Roadmap: Actions

- Create Bio-CCS stakeholder network
- Investigate impact of negative emissions accounting
- Implement policies that recognize Bio-CCS
- Scale-up and commercial-scale demonstration of biomass gasification, gas cleaning & treating and biofuel synthesis
- Expand number of bioethanol CCS demonstration plants
CCS today: mainly industrial CCS

- Natural gas processing with CO$_2$ storage in saline formations: In Salah, Sleipner & Snøhvit
- Natural gas processing with EOR: Shute Creek/Rangely
- SNG synthesis with EOR: Great Plains/Weyburn
- Bio-CCS:
  - Arkalon bioethanol plant (Liberal KS) with EOR in Booker TX (170-180 kT/a)
  - ADM bioethanol plant (Decatur II) with CO2 storage in saline formation (1 MT/a for 3 years)
Decatur Carbon Sequestration Project

- CO₂ captured at ADM ethanol plant and storage in saline Mount Simon Sandstone formation
- Why did this project go ahead where others did not?
  - Total cost: 164 M$; Total CCS: 2.5 Mtons
  - 66 $/ton or 49 €/ton CO₂ captured and stored

Source: ISGS (2011)
Policy incentives for Bio-CCS (1)

- EU Emission Trade Scheme (ETS):
  - Free allocation can be given to biomass CCS, but not to any electricity production (Tim Dixon)
  - Up to 97% biomass use; not 100%
- Potential role for JI and/or CDM in developing countries
- More clarity needed for negative emission accounting
- Biomass co-firing incentives vary by nation:
  Subsidies, feed-in-tariffs, certificates and biomass sustainability requirements
Policy incentives for Bio-CCS (2)

- Biofuels use mainly stimulated by mandates/targets
- Introduction of low-carbon fuel standards (US-RFS & EU-RED): minimum lifecycle GHG emission reduction for biofuels
- EU-RED:
  - 10% share 2nd generation biofuels in 2020
  - Minimum emission savings: 35% (2013), 50% (2017), 60% (2018)
  - Allows for subtraction emission reduction by CCS
Case Study: BioSNG

Natural gas in the Netherlands:
• 45% of primary energy consumption
• 135,000 km transportation grid
• 94% of all households connected

BioSNG:
• Ease of making distributed conversion more sustainable
• Possibility to decouple production and consumption
• Net CO$_2$ uptake from atmosphere possible through CCS
Natural gas production/consumption

PJ/y natural gas (EU25)

- **consumption**
- **production**

European Union 25

sources: BP (history), IEA/2006 (projections)
Current status BioSNG

• Güssing (Austria): 1 MW\textsubscript{SNG} pilot plant (existing)
• GoBiGas (Götenburg, Sweden) commercial plant: 20 MW\textsubscript{SNG} (2012) & 80 MW\textsubscript{SNG} (2016)
• HVC & ECN (The Netherlands) commercial plant: 8 MW\textsubscript{SNG} (2014)

All based on indirect biomass gasification:
- Carbon conversion 100%
- N\textsubscript{2}-lean product gas
- High initial CH\textsubscript{4} content
Engineering for 12 MW$_{th}$ Bio CHP plant
BioSNG plant layout

MILENA gasifier

Producer gas

OLGA tar removal

Further gas cleaning

Methanation

BioSNG upgrading

Steam

Flue gas

Riser (pyrolysis)

Downcomer bed material & char

Char combustion

Biomass

tars

S

Cl

CO₂

CO + 3 H₂ → CH₄ + H₂O

CO₂ + 4 H₂ → CH₄ + H₂O

40% C

BioSNG

H₂O production

20% C

100% C

40% C

100% C

40% C

H₂O production
CO₂ uptake during BioSNG production
Assumptions (1)

- Plant size $\sim 500 \, \text{MW}_{th}$ input
- Plant simulated using AspenPlus V7.1
- Costing:
  - Early 2010
  - Greenfields, overnight
  - $N^{th}$ plant, North-western Europe
Assumptions (2)

- Gasification pressure: 7 bara
- TCI: 1,100 €/kW_{SNG}
- O&M: 5% of TCI
- Other fixed cost: 2% of TCI
- Return on Investment: 12%
- Interest: 5%
- Biomass price (dry): 4 €/GJ
- Electricity price: 0.05 €/kWh (14 €/GJ)
- CO₂ emission natural gas combustion: 55 kg/GJ
## Economic analysis (1)

<table>
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<tr>
<th></th>
<th>Annual Cost (M€/yr)</th>
<th>Cost (€/GJ)</th>
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<tbody>
<tr>
<td>TCI</td>
<td>55.2</td>
<td>3.50</td>
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<tr>
<td>Biomass</td>
<td>89.7</td>
<td>5.69</td>
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<tr>
<td>Electricity</td>
<td>10.9</td>
<td>0.69</td>
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<tr>
<td>O&amp;M</td>
<td>28.6</td>
<td>1.82</td>
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<tr>
<td>Other fixed cost</td>
<td>11.4</td>
<td>0.73</td>
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<tr>
<td>Total cost</td>
<td>195.8</td>
<td>12.42</td>
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<tr>
<td>Result</td>
<td>13.5</td>
<td>0.86</td>
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<tr>
<td>Revenues</td>
<td>209.4</td>
<td>13.28</td>
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</tbody>
</table>
Economic analysis (2)

- BioSNG with CCS @ 13.3 EUR/GJ
- BioSNG w/o CCS @ 12.2 EUR/GJ
- Natural Gas @ 7.5 EUR/GJ
- Diesel @ 11.5 EUR/GJ

Conclusions

- Incremental cost for CO$_2$ capture and storage is low for biofuels production; CO$_2$ separation equipment implemented regardless of application CCS
- CCS retrofitting in biofuels production is straightforward
- CO$_2$ avoidance costs for biofuels & CCS competitive with CCS in fossil fired power plants; net water production
- Accounting for net CO$_2$ uptake from atmosphere lowers avoidance costs and accelerates deployment
- Commercial-scale demonstration of biomass conversion technologies needed
Questions

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Publications: www.ecn.nl/publications

Fuel composition database: www.phyllis.nl

Tar dew point calculator: www.thersites.nl

IEA bioenergy/gasification: www.ieatask33.org

Milena indirect gasifier: www.milenatechnology.com

OLGA tar removal: www.olgatechnology.com

SNG: www.bioSNG.com and www.bioCNG.com