Systems level considerations of NETs

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Points for discussion

- The mitigation potential of DAC vs CCU
  - Using both cost and energy per tonne CO₂ avoided basis
- What do NETs “do” in an energy system?
  - how might they be rewarded for this service?
- How do BECCS and DAC interact in a zero and negative emissions context?
  - under what conditions DAC will get deployed ahead of BECCS?
The mitigation potential of DAC vs CCU

a) Power-To-Fuel

- Water ($H_2O$) and hydrogen ($H_2$) are input.
- Direct air capture process captures $>95\% CO_2$.
- Methanol ($CH_3OH$) is produced.
- Methanol is used for fuel.
- Solar and wind energy are used.

b) Power-To-DAC

- Solar and wind energy are used.
- Direct air capture captures $>95\% CO_2$ from the atmosphere.
- Methanol ($CH_3OH$) is used for fuel.
- CO$_2$ is stored geologically.
The mitigation potential of DAC vs CCU

- There is a narrative of CCU as a tool to mitigate climate change
  - Hydrogenate CO$_2$ to produce liquid fuels
  - Use curtailed renewable energy for this purpose
  - This leads to avoiding the CO$_2$ otherwise associated with transport fuels
- Why not just use the same energy to operate a DAC plant?
  - Noting that a source of heat is also required
- Which is a better option?
How much curtailed renewable energy is available?

- At levels of renewable penetration less than 50 – 60% of peak demand, curtailment remains low.
- As grid operators become more experienced this will further reduce.
- iRES generators receive curtailment payments (~ $83-225/MWh) – this energy will not be available at zero cost.
Waste heat availability?

- Potentially significant levels of waste heat available
- Most “high grade” waste heat (> 700 K) available from solid waste streams
- Astute co-location of DAC processes could exploit this energy source
- Waste heat does not receive curtailment payments
  - Potentially low cost energy source?

Assuming the use of a KOH-based DAC process

DAC process taken from Carbon Engineering Ltd, 2015.
DAC provides superior mitigation service than CCU

- DAC consistently provides a superior climate change mitigation service to CCU
- As DAC processes improve, this gap is likely to widen
  - Improved catalysts don’t help CCU
  - Key driver is the cost of green $H_2$
What do NETs “do” in an energy system?

- The UK has a legally binding decarbonisation target for 2050
  - 80% reduction in total GHG emissions by 2050 from a 1990 baseline
- Predicated upon ~ zero carbon electricity grid
  - Electrification of heating and transport
- Also have an assumption of 50 Mt CO₂/yr negative emissions in this period
- What service do NETs provide in this system
  - And how might they be compensated?
## NETs description used in this work

### Subcritical-BECCS

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit size</td>
<td>500 MW</td>
</tr>
<tr>
<td>Economic Lifetime</td>
<td>30 years</td>
</tr>
<tr>
<td>Min./Max. Power Output</td>
<td>30-85 %-MW</td>
</tr>
<tr>
<td>CAPEX</td>
<td>1980 £/kW</td>
</tr>
<tr>
<td>Fixed OPEX</td>
<td>10 £/MWh</td>
</tr>
<tr>
<td>Variable OPEX</td>
<td>130-150 £/MWh</td>
</tr>
<tr>
<td>Start-Up Costs</td>
<td>250,000 £/h</td>
</tr>
<tr>
<td>*Efficient BECCS CAPEX is</td>
<td>2721 £/kW</td>
</tr>
</tbody>
</table>

### DAC

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity consumption</td>
<td>0.48 MWh/tCO₂</td>
</tr>
<tr>
<td>Heat consumption</td>
<td>1.69 MWh/tCO₂</td>
</tr>
<tr>
<td>Average Power Consumption</td>
<td>250 MW</td>
</tr>
<tr>
<td>Capture Capacity</td>
<td>1 MtCO₂/y</td>
</tr>
<tr>
<td>Min/Max. capacity</td>
<td>100%</td>
</tr>
<tr>
<td>CAPEX</td>
<td>7470 £/kW</td>
</tr>
<tr>
<td>OPEX</td>
<td>59 £/MWh</td>
</tr>
</tbody>
</table>

See Mac Dowell and Fajardy, ERL, 2017 for more detail on “efficient” and “inefficient” BECCS.
What do NETs “do” in an energy system?

**NETs description used in this work**

- **Miscanthus**: £49/tonne (wet mass basis)
- **Processing cost and personnel**: £15.2/tonne pellets
- **Annualised CAPEX**: £12/tonne pellets
- **Drying costs**: £2.66/tonne pellets
- **Conversion rate**: 83.7%
- **Miscanthus pellet price**: £88.4/tonne
Net zero without NETs?

• Absent NETs, generation capacity is very significantly expanded
• Costly!

Net zero without NETs?

- Reliance on iRE assets
  - Especially onshore wind
- Thermal asset utilisation factors are greatly reduced
  - $LF_{CCGT} < 10\%$ post 2035
- Implications for capacity market
  - Specific markets for other ancillary services?

Making DAC available reduces costs

- Thermal asset utilisation factors are increased
  - $\text{LF}^\text{CCGT} < 27\%$ post 2035
- Installed generation capacity reduced by a factor of 2.5
  - Cheaper energy services?

What do NETs “do” in an energy system?

Optimal system dispatch with DAC

- DAC requires 18 TWh of electricity in 2050
- Equivalent to a 3 GW power plant built to power DAC
  - Large in the UK!
- Note that the “cost optimal” solution chooses this – there is no requirement to do this

Key NET service: emission off-setting

• In a zero carbon system, NETs “mop up” the carbon emitted by (cheap) CCGTs
• This increases the LF\textsuperscript{CCGT}
  – NETs create value for unabated thermal assets
  – How to allow some of this to accrue to the NETs?

An alternative NET: BECCS

- BECCS is a preferable option to DAC
  - Further reduces TSC
  - If we start with BECCS available, DAC does not get deployed

What do NETs “do” in an energy system?

BECCS provides a similar off-setting service

• Similarly to DAC, BECCS also offsets the emissions from unabated thermal assets
• Also generates electricity…

Unpacking the service of NETs

What do NETs “do” in an energy system?

- NETs can create value in the energy system
- LF$_{CCGT}$ peaks owing to a phase out of coal

Making both DAC and BECCS available?

- Given the option of BECCS and DAC in a system, BECCS is a preferred choice.
- DAC needs to become significantly cheaper in both capex and opex terms to be attractive relative to BECCS.

Scope for cost reduction?

- The majority of DAC costs comes from capex
- Modular technology is amenable to cost reduction via mass production
  - Potentially easier for DAC than BECCS?
  - Modular BECCS for district heating-scale CHP?
# BECCS vs. DAC: Resource efficiency

<table>
<thead>
<tr>
<th>Target scenario</th>
<th>Miscanthus pellets (Brazil) – no LUC</th>
<th>Miscanthus pellets (Brazil) – LUC (cropland)</th>
<th>Willow pellets (US) – no LUC</th>
<th>DACS</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Removal target</td>
<td></td>
<td>3.3</td>
<td></td>
<td>3,320</td>
<td>$Gt_C/yr$</td>
</tr>
<tr>
<td>Nb units</td>
<td>3,700</td>
<td>5,400</td>
<td>6,800</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biomass use</td>
<td>10</td>
<td>15</td>
<td>18</td>
<td></td>
<td>$Gt_{DM}/yr$</td>
</tr>
<tr>
<td>Water use</td>
<td>5,900</td>
<td>8,590</td>
<td>42,000</td>
<td>negligible</td>
<td>$km^3/yr$</td>
</tr>
<tr>
<td>Energy use</td>
<td>-5</td>
<td>-26</td>
<td>22</td>
<td>81 – 274</td>
<td>$EJ/yr$</td>
</tr>
<tr>
<td>Land use</td>
<td>440</td>
<td>640</td>
<td>5,170</td>
<td>0.04 – 3.3</td>
<td>$Mha$</td>
</tr>
<tr>
<td>Nitrogen use</td>
<td>94</td>
<td>137</td>
<td>1,140</td>
<td></td>
<td>$Mt/yr$</td>
</tr>
<tr>
<td>Phosphorous use</td>
<td>76</td>
<td>111</td>
<td>220</td>
<td></td>
<td>$Mt/yr$</td>
</tr>
</tbody>
</table>

Source: Fajardy and Mac Dowell, Energy and Environmental Science, 2017
## BECCS vs. DAC: Resource efficiency

<table>
<thead>
<tr>
<th>Strengths</th>
<th>BECCS</th>
<th>DACS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Relatively resource efficient technology when deployed on marginal land,</td>
<td>1) Land and water requirements negligible compared to those of BECCS,</td>
<td></td>
</tr>
<tr>
<td>2) Can be an energy net producer,</td>
<td>2) Removes CO₂ right away,</td>
<td></td>
</tr>
<tr>
<td>3) Partly uses existing infrastructures,</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Weaknesses</th>
<th>BECCS</th>
<th>DACS</th>
</tr>
</thead>
<tbody>
<tr>
<td>4) High uncertainties around the LUC effects associated with the conversion of certain land types,</td>
<td>2) High energy requirement,</td>
<td></td>
</tr>
<tr>
<td>5) Can be an energy net consumer,</td>
<td>3) Need carbon neutral power to be carbon efficient,</td>
<td></td>
</tr>
<tr>
<td>6) High land and water requirements compared to those of DACS.</td>
<td>4) Geographical deployment constrained by renewable and storage (or utilisation) availability.</td>
<td></td>
</tr>
<tr>
<td>7) Can take 1 to 50 years to be negative.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Fajardy and Mac Dowell, Energy and Environmental Science, 2017
Conclusions

• DAC is technically, economically and environmentally preferable to CCU for carbon abatement
• There may be material levels of industrial waste heat available
  – The high grade heat can be hard-to-reach (solid waste streams)
• Both DAC and BECCS add value to electricity systems
  – They provide headroom for unabated thermal power plants
• With available options, BECCS looks preferable to DAC
  – Mass production of modular technologies combined with waste heat utilisation could challenge this