Change log (hidden)

Annex 1 Carbon dioxide rich side streams from sugar beet factories

This file calculates potential CO2 streams that could be used for utilization. The SuperPro sugar factory example was taken as a starting point (Intelligen, 2024).

Get libraries

Include << .\Libraries\Mw.mcdx

Include << .\Libraries\Vm.mcdx

Include << .\Libraries\Units.mcdx

Include << .\Libraries\Molecular formulas.mcdx

The following data were taken from the SuperPro Sugar beet example.

$\Phi_{mol} := 33.61 \cdot \frac{ton}{hr}$ mol = molasses

$f_{sucr\_mol} := 43.96\%$

$f_{non\_sucr\_mol} := 28.18\%$

$\Phi_{pulp} := 26.18 \cdot \frac{ton}{hr}$ pulp = Sugar Beet Pulp dry!

$\tau_{campaign} := 1920 \cdot \frac{hr}{yr}$ duration of campaign

The number of Sugar beet Factories needed to process sugar from NL agriculture is calculated in Annex 6

$N_{SBF} := 7.839$

It is assumed that molasses is fermented to produce ethanol. The production of ethanol and CO2 released from the ethanol fermentation is calculated from the sucrose content of molasses.

$\eta_{eth\_ferm} := 0.95$ practical efficiency compared to theoretical efficiency

$\Phi_{sucr\_mol} := f_{sucr\_mol} \cdot \Phi_{mol} = 14.775 \ \frac{ton}{hr}$

$C12H22O11 + H2O = 4\ C2H6O + 4\ CO2$ ethanol fermentation reaction

$y_{eth\_sucr\_th} := 4 \cdot \frac{mol}{mol}$ theoretical ethanol yield

$Y_{eth\_sucr} := y_{eth\_sucr\_th} \cdot \frac{Mw(ethanol)}{Mw(sucrose)} \cdot \eta_{eth\_ferm} = 0.511\ \frac{kg}{kg}$

$\Phi_{eth\_mol} := Y_{eth\_sucr} \cdot \Phi_{sucr\_mol} = 7.556\ \frac{ton}{hr}$

$y_{CO2\_sucr\_th} := 4 \cdot \frac{mol}{mol}$ theoretical CO2 yield

$Y_{CO2\_sucr} := y_{CO2\_sucr\_th} \cdot \frac{Mw(CO2)}{Mw(sucrose)} \cdot \eta_{eth\_ferm} = 0.489\ \frac{kg}{kg}$

$\Phi_{CO2\_mol} := Y_{CO2\_sucr} \cdot \Phi_{sucr\_mol} = 7.219\ \frac{ton}{hr}$

Sugar beet pulp is assumed to be digested to produce biogas. The yield of methane and CO2 is estimated from literature (Muzik et al., 2012).

$Y_{CH4\_pulp\_vol} := 330.9 \cdot \frac{liter}{kg}$ $\rho\_methane := \frac{Mw(methane)}{V_m(p_s, T_s)} = 0.716\ \frac{kg}{m^3}$

$Y_{CH4\_pulp} := Y_{CH4\_pulp\_vol} \cdot \rho\_methane$

$Y_{CH4\_pulp} = 0.237\ \frac{kg}{kg}$

$\Phi_{CH4\_pulp} := Y_{CH4\_pulp} \cdot \Phi_{pulp} = 6.201\ \frac{ton}{hr}$

The literature value can be checked assuming that the pulp contains only cellulose.

$C6H10O5 + H2O = 3\ CO2 + 3\ CH4$ Anaerobic digestion of C6 polymer

$y_{CH4\_pulp\_th} := 3 \cdot \frac{mole}{mole}$

$Y_{CH4\_pulp\_th} := y_{CH4\_pulp\_th} \cdot \frac{Mw(methane)}{Mw(pulp)}$

$Y_{CH4\_pulp\_th} = 0.297\ \frac{kg}{kg}$ Check OK! (Y_CH4_pulp_th should be larger than Y_CH4_pulp)

The methane content of biogas was taken from Hutnan et al. (2000)

$f_{CH4\_biogas} := 0.60$

$f_{CO2\_biogas} := 1 - f_{CH4\_biogas} = 0.4$

Carbon dioxide from pulp fermentation

$$Y_{CO2\_pulp} := \frac{Y_{CH4\_pulp}}{Mw(methane)} \cdot \frac{f_{CO2\_biogas}}{f_{CH4\_biogas}} \cdot Mw(CO2) = 0.433 \ \frac{kg}{kg}$$

$$\Phi_{CO2\_pulp} := Y_{CO2\_pulp} \cdot \Phi_{pulp} = 11.34 \ \frac{ton}{hr}$$

Total carbon dioxide production

$$\Phi_{CO2} := \Phi_{CO2\_mol} + \Phi_{CO2\_pulp} = 18.558 \ \frac{ton}{hr}$$ During campaign!

Both molasses and pulp could be preserved (and fermented/digested) over longer periods. If the production of CO2 is averaged over one year, the production rate is:

$$\tau_{campaign} = 80 \ \frac{day}{yr}$$ Campaign is less than 3 months per year!

Ethanol, methane and carbon dioxide from the Dutch sugar beet industry is calculated below (as reported in Table 3).

Ethanol fermentation

$$\Phi_{sucr\_mol} \cdot \tau_{campaign} \cdot N_{SBF} = 222.376 \ \frac{kton}{yr}$$

$$\Phi_{eth\_mol} \cdot \tau_{campaign} \cdot N_{SBF} = 113.731 \ \frac{kton}{yr}$$ $$\Phi_{CO2\_mol} \cdot \tau_{campaign} \cdot N_{SBF} = 108.645 \ \frac{kton}{yr}$$

Anaerobic digestion

$$\Phi_{pulp} \cdot \tau_{campaign} \cdot N_{SBF} = 394.032 \ \frac{kton}{yr}$$

$$\Phi_{CH4\_pulp} \cdot \tau_{campaign} \cdot N_{SBF} = 93.324 \ \frac{kton}{yr}$$ $$\Phi_{CO2\_pulp} \cdot \tau_{campaign} \cdot N_{SBF} = 170.671 \ \frac{kton}{yr}$$

Total

$$\Phi_{CO2} \cdot \tau_{campaign} \cdot N_{SBF} = 279.316 \ \frac{kton}{yr}$$

Literature

Hutnan et al., 2000 [27]
Intelligen, 2024 [26]
Muzik et al., 2012 [28]