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# FIBRE CROPS FOR ENERGY PRODUCTION AND ENERGY SAVING

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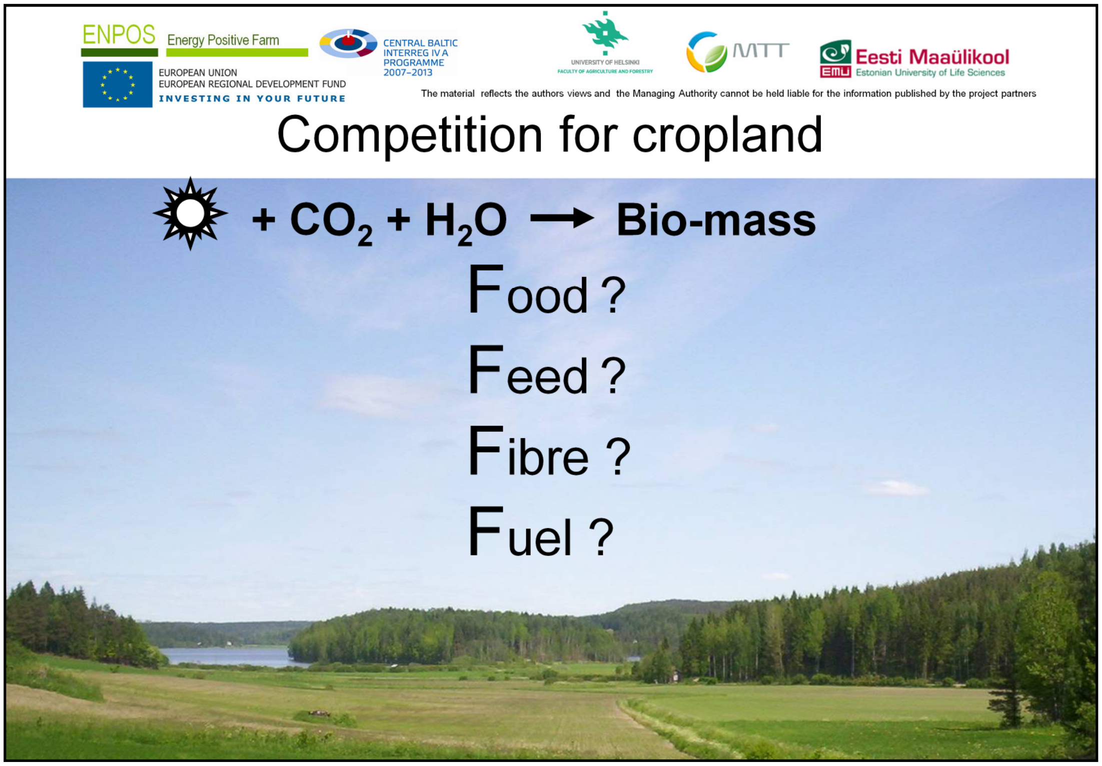
Energy crops are still considered as an important renewable energy source even though there are many doubts whether they may replace fossil fuels sustainably.




Energy crops do not only compete with food crops and feed crops, but also with fibre crops for industrial products.

The question whether the cure is worse than the disease emerged, when the awareness about environmental impacts of energy crop production especially in the tropics reached public awareness.

A living crop decreases the entropy of matter by the photosynthesis process generating beside carbon hydrates also more complex chemical compounds.

Therefore, many crops are used not only for food production but also as raw material for production of commodities.

This fact is often neglected in energy analysis of energy crops.

My thesis is:
The energy potential of fibre crops may be enhanced using them first as raw material for commodities before processing to fuel at the end of their lifetime.

Such a chain of usage trades off both, the low entropy of the fibre and the heating value of the fibre.

The thesis is verified here using reed canary grass as an example

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## Alternative A: production and the processing of RCG to fuel for heating.

32 400 GJ/ha

Cultivation, transport, processing: 8.0 GJ/ha

Energy output 102 GJ/ha

6000 kg DM $ha^{-1}$, 17 MJ $kg^{-1}$ DM

Source: Lötjönen, T., Pahkala, K., Vesanto, P. & Hiltunen, M., 2009. Energy from field energy crops – a handbook for energy producers. Jyväskylä Innovation Oy, Jyväskylä, pp. 14-22.

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Alternative A includes the production and the processing of RCG to fuel for heating.

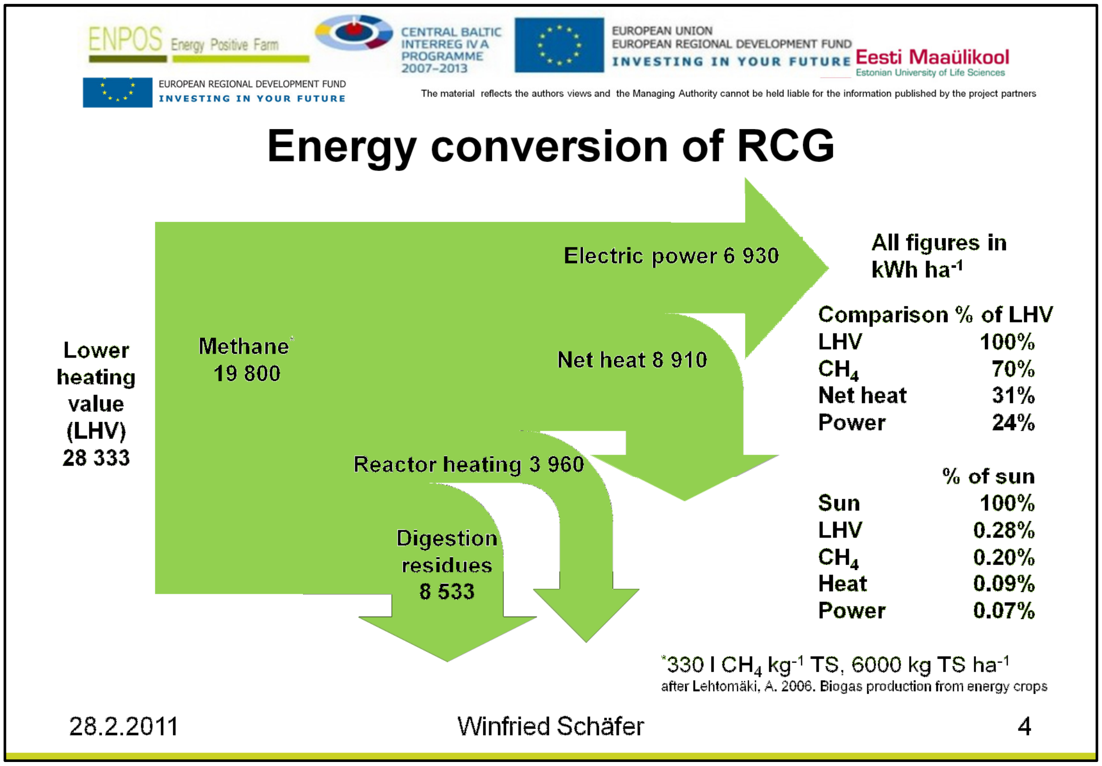
Energy input is 32400 GJ/ha solar energy and 8 GJ/ha fossil fuel and fertiliser for production 0,3% of energy input, (7,8)

Thus the EROI for heat production from RCG is 11.8 MJ $MJ^{-1}$ assuming a dry matter yield of 6 Mg $ha^{-1}$ corresponding to a gross energy yield of 102 GJ $ha^{-1}$.

However, this calculation takes into consideration only 8 GJ $ha^{-1}$ for fuels and fertilisers as energy input of RCG production.

If we estimate the indirect energy input for RCG production, the EROI may reach 6.2 GJ/ha.

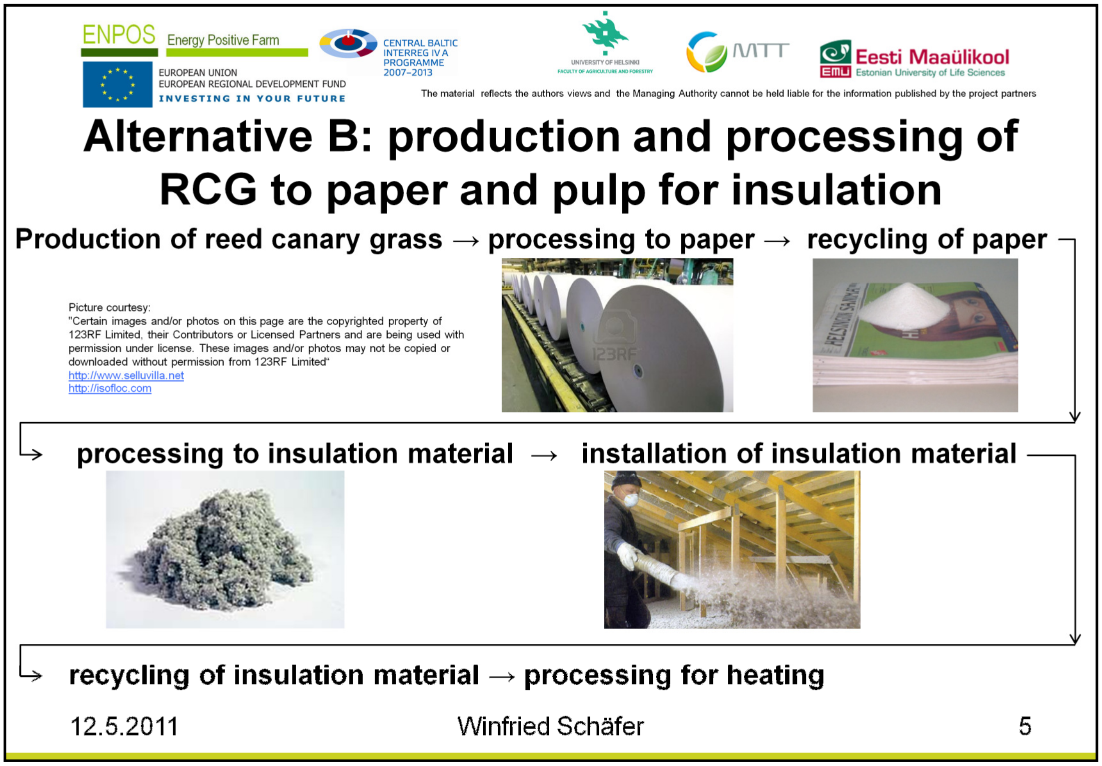
The realistic net energy gain is than about 88 GJ $ha^{-1}$.




If RCG would be used for biogas production, the energy gain may reach the half compared to burning.

Although biogas may replace fossil fuels for combustion engines the EROI would be too low to become a competitive alternative to fossil fuels.

The EROI of fossil fuels ranges between 10 and 20.




Alternative B includes the production of RCG,

the processing of RCG to paper,

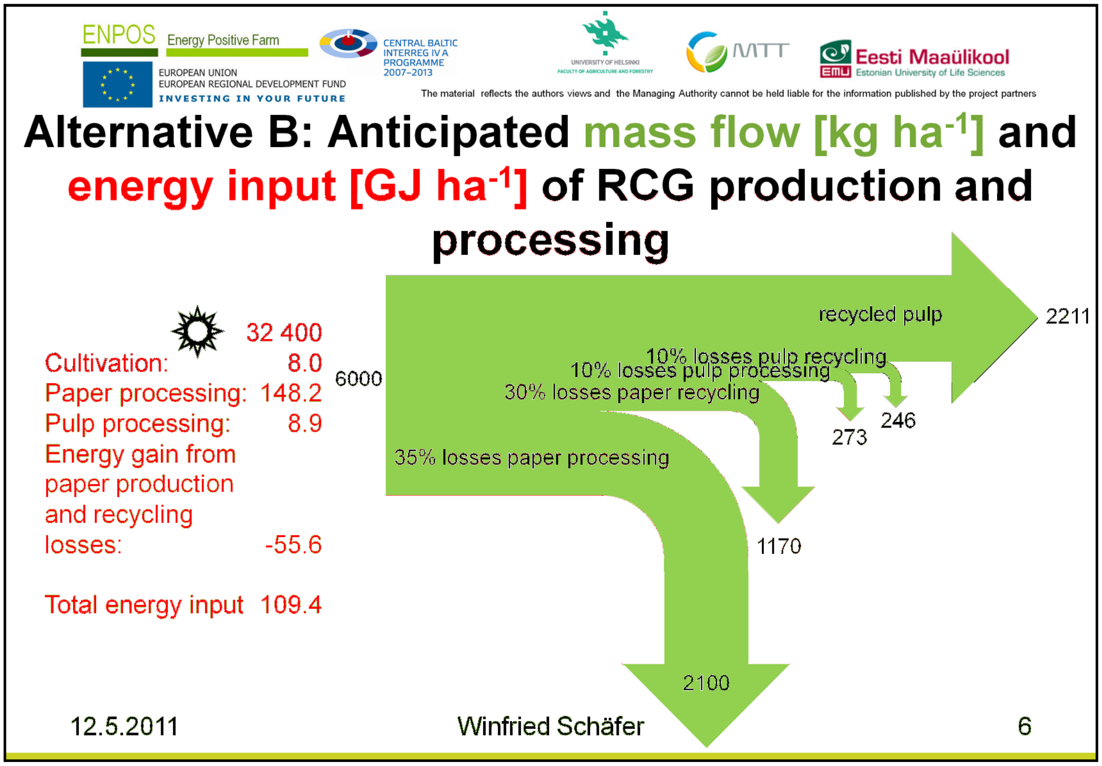
recycling of used paper,

processing of recycled paper to pulp as insulation material,

installation of pulp in buildings,

recycling of pulp,

and processing the residues to fuel for heating as in alternative A.



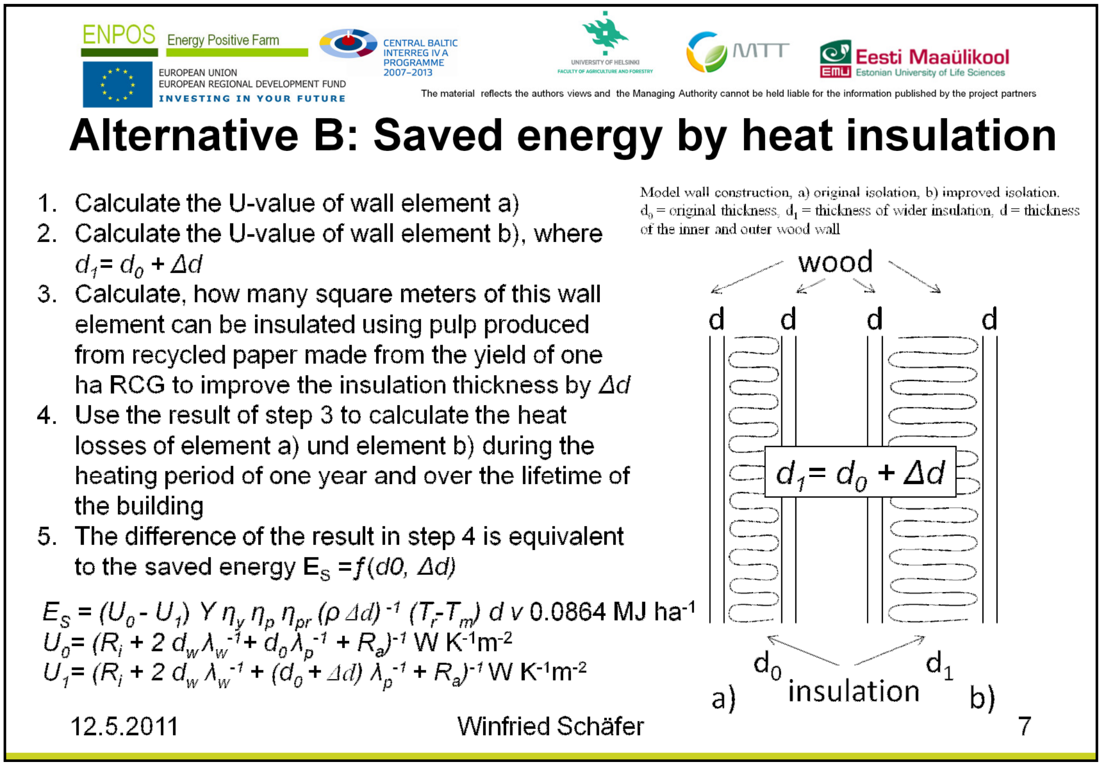

The fibre yield is processed to paper with a mean mass efficiency $\eta_y$ of 65%

The credit of lower process energy of paper production from RCG compared to pulp from wood is neglected.

The recycling efficiency $\eta_p$ of used paper is in Finland about 70%

And the mass efficiency $\eta_{pr}$ of processing used paper to pulp is estimated to 90%.

The heat value of the mass losses for pulp processing and recycling may compensate the energy demand for installation of the pulp as insulation material in buildings, recycling, and transport.




The figure shows a simple wall element made of two 22 mm thick wood walls filled with pulp insulation.

The U-value of the wall insulation declines widening the insulation thickness by the increment $\Delta d = d_1 - d_0$.

Therefore, the saved energy depends on both variables, the original insulation $d_0$, and the increment *Δd.*

The rationale for the energy saving calculation includes the following steps:

1. Calculate the U-value of wall element a)
2. Calculate the U-value of wall element b), where $d_1 = d_0 + \Delta d$
3. Calculate, how many square meters of this wall element can be insulated using pulp produced from recycled paper made from the yield of one ha RCG to improve the insulation thickness by $\Delta d$
4. Use the result of step 3 to calculate the heat losses of element a) und element b) during the heating period of one year and over the lifetime of the building
5. The difference of the result in step 4 is equivalent to the saved energy $E_S = f(d0, \Delta d)$

## Anticipated technical data input

| | |
|---|---|
| Yield of RCG | $Y$ = 6000 kg ha$^{-1}$ year$^{-1}$ |
| Thickness of wood | $d_0$ = 0.022 m |
| Thermal conductivity of wood | $\lambda_w$ = 0.14 W K$^{-1}$ m$^{-1}$ |
| Thermal conductivity of pulp | $\lambda_p$ = 0.041 W K$^{-1}$ m$^{-1}$ |
| External surface resistance | $R_e$ = 0.13 m$^2$ K W$^{-1}$ |
| Internal surface resistance | $R_i$ = 0.04 m$^2$ K W$^{-1}$ |
| Installation density of pulp | $\rho$ = 30 kg m$^{-3}$ |
| Mean temperature in Jyväskylä from September to May | $T_m$ = -0.87°C |
| Room temperature | $T_r$ = +20°C |
| Heating period | $d$ = 273 days year$^{-1}$ |
| Lifetime of pulp insulation | $v$ = 50 years |



I used the following data for the calculation:

| | |
|---|---|
| Yield of RCG | 6000 kg ha$^{-1}$ year$^{-1}$ |
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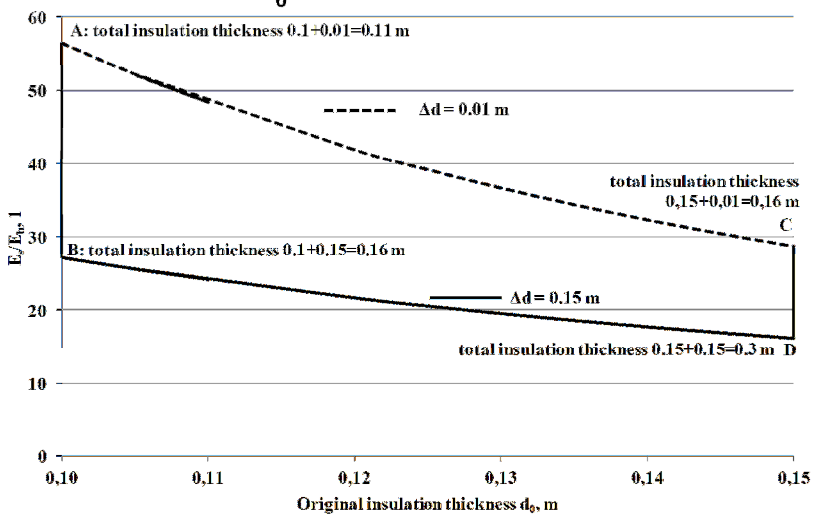
**Ratio between saved energy $E_s$ by insulation improvement and heat gain $E_h$ of burning RCG as a function of the original insulation thickness $d_0$ and the insulation thickness increment *Δd***




Saved energy ranges between 5.22 TJ/ha at A and 1.43 TJ/ha at D

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The saved energy of alternative B is expressed as a function of the original insulation thickness and the insulation thickness increment *Δd* as parameter.

The original insulation thickness $d_0$ may e.g. range between 0.1 and 0.15 m.

Then the area enclosed by the points ABCD embraces the energy saving potential widening the insulation thickness by 0.01 (dotted line) to 0.15 m (solid line) resulting in a final insulation thickness between 0.11 and 0.3 m.

It is evident, that the energy saving efficiency of widening insulation thickness is lower when the original insulation $d_0$ is wider and vice versa.

Within the anticipated boundaries of insulation thickness the saved energy ranges between 5.31 TJ/ha at point A and 1.52 TJ/ha at point D,

this is 16 to 56 more than the heat produced by burning RCG.

## GHG mitigation potential

| Process | $CO_2$ equivalents | Mass kg $ha^{-1}$ | kg $CO_2$eq. $ha^{-1}$ |
|---|---|---|---|
| *RCG heat production* | 0.015 kg $CO_2$eq. $MJ^{-1}$ heat | 6,000* | 1,530 |
| *paper production* | 1.1 kg $CO_2$eq. $kg^{-1}$ paper | 3,900 | 4,290 |
| *pulp production* | 0.2 kg $CO_2$eq. $kg^{-1}$ pulp | 2,808 | 491 |
| ***Total emissions*** | | | **6,311** |
| | | **Total savings** | |
| ***Replaced fuel*** | | **min at point D** kg $CO_2$eq. $ha^{-1}$ | **max at point A** kg $CO_2$eq. $ha^{-1}$ |
| *Light fuel oil* | 86 g $CO_2$eq. $MJ^{-1}$ | 125 108 | 452 437 |
| *Natural gas* | 69 g $CO_2$eq. $MJ^{-1}$ | 98 064 | 358 032 |
| *District heating* | 61 g $CO_2$eq. $MJ^{-1}$ | 86 654 | 318 205 |
| *Electric power* | 190 g $CO_2$eq. $MJ^{-1}$ | 282 305 | 1 001 165 |

* heating value: 17 MJ $kg^{-1}$

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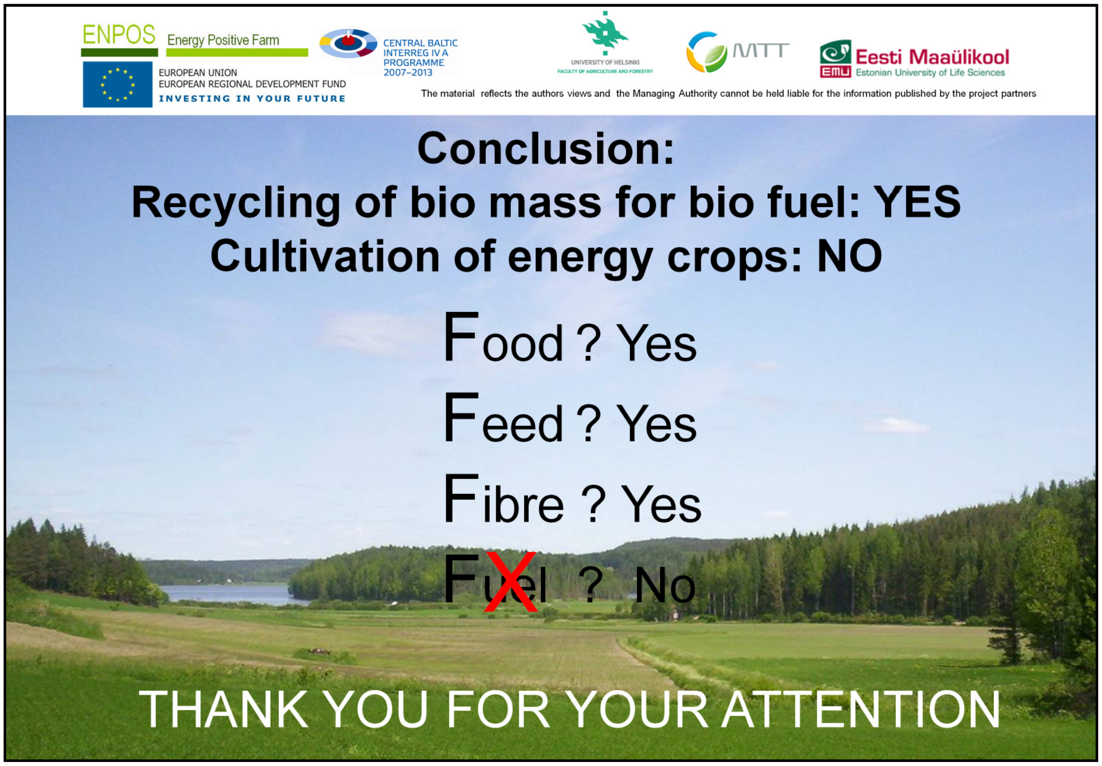
The results of emitted and saved $CO_2$ equivalents is given in this table.

Depending on the kind of replaced fuel used for heating, the $CO_2$ mitigation burning RCG instead of fossil fuels ranges between 4 and 16 Mg $CO_2$eq. $ha^{-1}$

RCG used for insulation material may reduce $CO_2$ emissions from 86 to 1001 Mg $CO_2$eq. $ha^{-1}$, this is up to 75 more than the mitigation achieved by burning RCG depending on the replaced fuel used for heating.




The calculation example shows clearly that fibre crops should first be used as feedstock for industrial commodities before the residues are converted to energy at the end of the lifetime.

Producing a table from a tree and burning the residues and the table at the end of its lifetime renders the same energy gain as using the tree for firewood only.

Because of the second law of thermodynamics, decrease of entropy without energy input is impossible.

Only the photosynthesis process, powered by sun energy, guaranties low entropy products for humans and animals.

Thus, fibre crops processed and used as insulation material render an excellent example of high energy efficiency.

The reason, why energy crops are recently used for fuels only, may be explained by agricultural subsidy policies, ignoring basic thermodynamic laws, and neglecting both indirect energy input and external cost of energy crop production.

Anyway, the energy return on investment of fossil fuels is still higher and therefore $CO_2$ mitigation using renewable energy sources is more expensive for the time being.