Bioenergy with carbon capture and storage (CCS)

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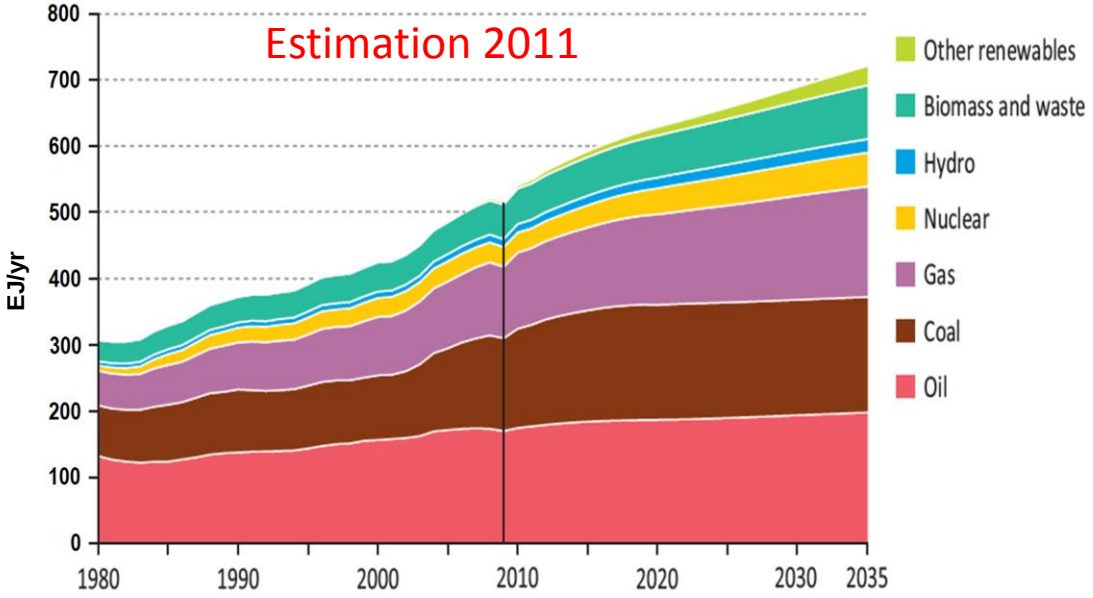
Understanding the climate effects of bioenergy systems,

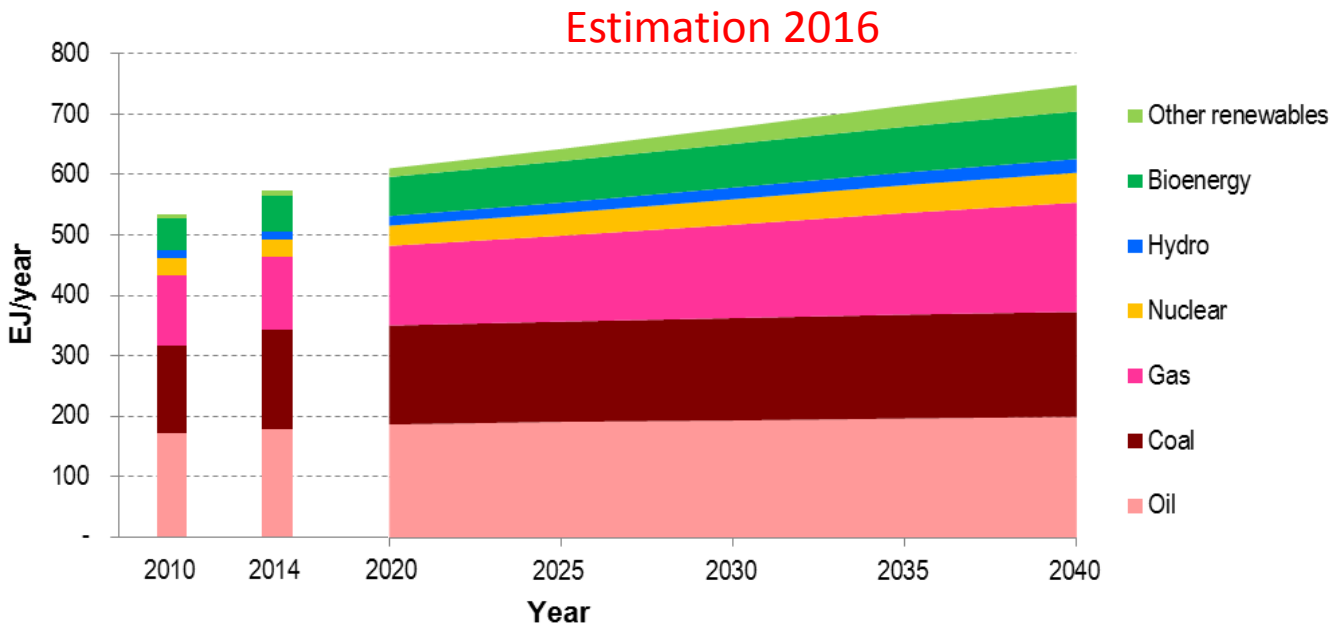
16 May 2017, Apollon Room, Chalmers Conference Center

IEA Bioenergy Task 38 and Chalmers University of Technology

Annual global primary energy use and trends (IEA)



Year	2010	2014
Total (EJ)	**533**	**573**
	Distribution	**(%)**
Oil	32.4	31.2
Coal	27.3	28.7
Gas	21.4	21.1
Total fossil	**81.1**	**81.0**
Bioenergy	10.0	10.4
Nuclear	5.7	4.8
Other	3.2	3.8



Source: International Energy Agency (IEA), 2011. World Energy Outlook 2011
IEA, 2013. World Energy Outlook 2013;
IEA, 2012. *Key World Energy Statistics*
IEA, 2016. *World Energy Outlook 2016*

We compare climate effects of using coal or forest biomass for electricity production with and without CCS

We consider

- Annual CO_2 emission
- Annual change in CO_2 in the atmosphere
- Annual change in cumulative radiative forcing (CRF)
- Forest slash
- Forest thinnings
- Forest stumps

Anthropogenic climate change: Chain of events

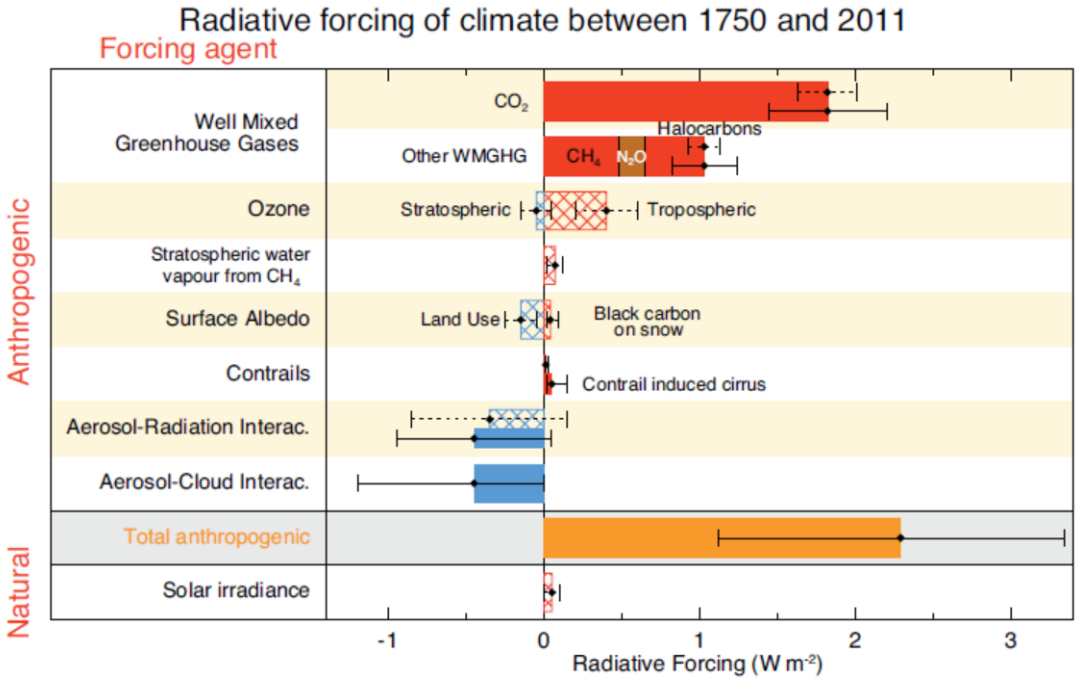
Human activities

- GHG emissions
- Albedo change
- Aerosols
- Ozone

Radiative forcing

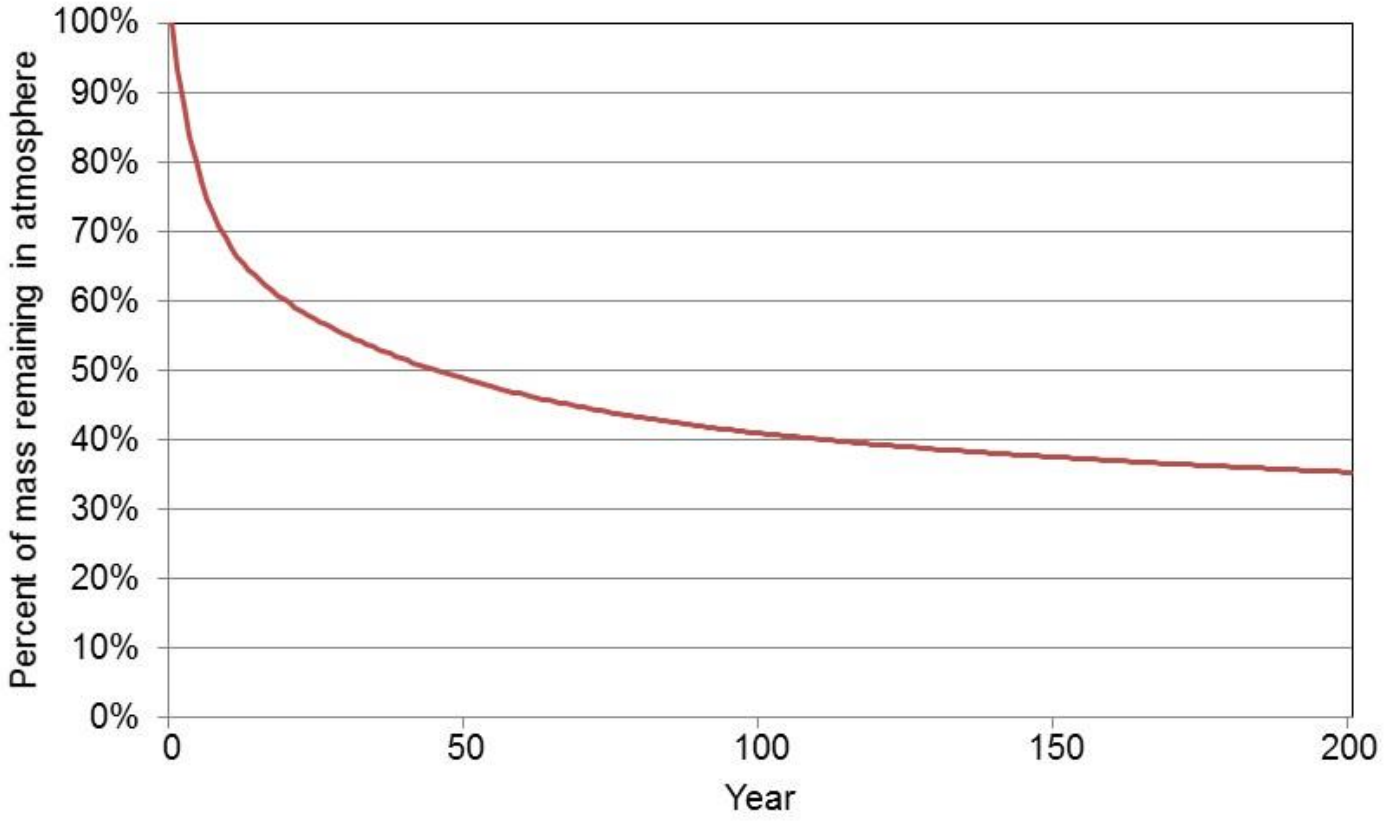
Mean temperature change

Physical, ecological, and social disturbances



(IPCC 2013)

Atmospheric decay of a unit pulse of CO_2



$$(CO_2)_t = (CO_2)_0 \times \left[0.217 + 0.224 e^{\frac{-t}{394.4}} + 0.282 e^{\frac{-t}{36.54}} + 0.276 e^{\frac{-t}{4.304}} \right]$$

(IPCC 1997, 2001, 2007, 2013)

Radiative forcing (W/m^2) due to CO_2 concentration change

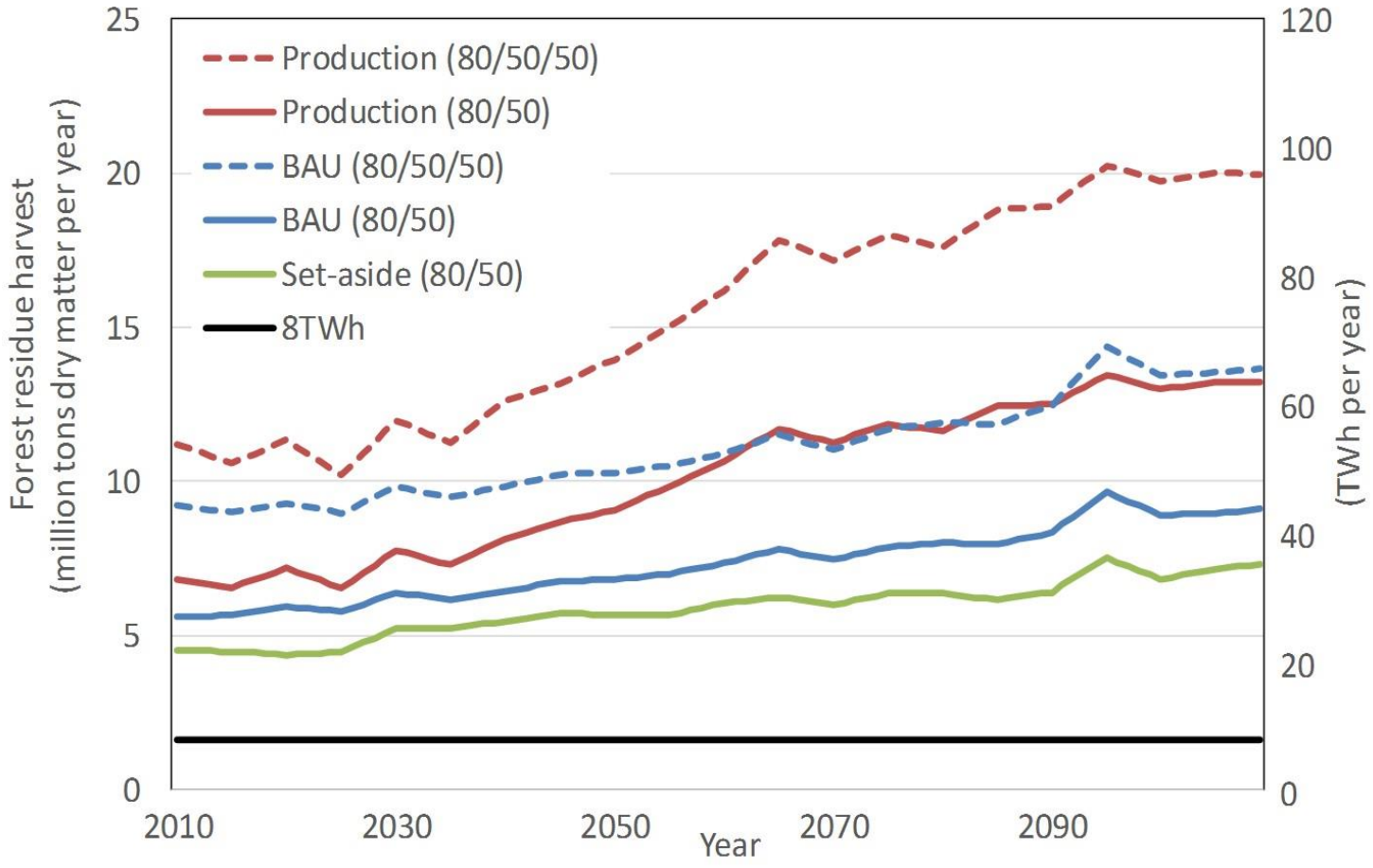
$$F_{CO_2} = \frac{3.7}{\ln(2)} \times \ln\left\{1 + \frac{\Delta CO_2}{CO_{2ref}}\right\}$$

where CO_{2ref} = 400 ppmv

Assumes relatively minor marginal changes in CO_2 concentrations

(IPCC 1997, 2001, 2007, 2013)

Large potential harvest of forest slash, thinnings and stumps



8TWh: Annual harvest of 8 TWh of logging residues
80/50: Harvest of 80% of slash from final fellings and 50% from thinnings
80/50/50: Plus 50% harvest of stumps from final fellings

Based on: Gustavsson L., Haus S., Lundblad M., Lundström A., Ortiz C., Sathre R., Truong N.L., and Wikberg P.-E. (2017) Climate effects of forestry and substitution of carbon-intensive materials and fossil fuels. Renewable & Sustainable Energy Reviews , Vol. 67: p. 612-624.

1 MWh of electricity is produced annual for 40 years in a large stand-alone plant

Bioenergy system

- Forest biomass is harvested in central Sweden. Transported 100 km (truck) + 250 km (train) + 1100 km (ship) to harbour in Europe as chips

Fossil coal system

- Hard coal. Mining and transport emits 10% of combustion emission
- Forest biomass is not recovered and decays naturally

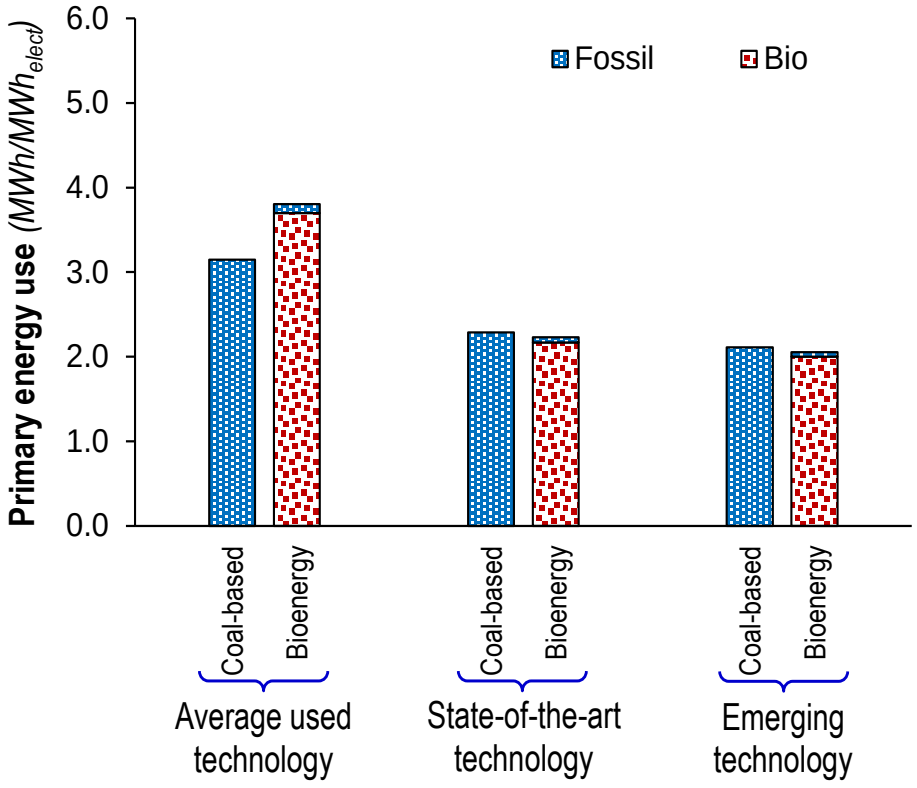
System with CCS

- Energy penalty is covered by fossil coal

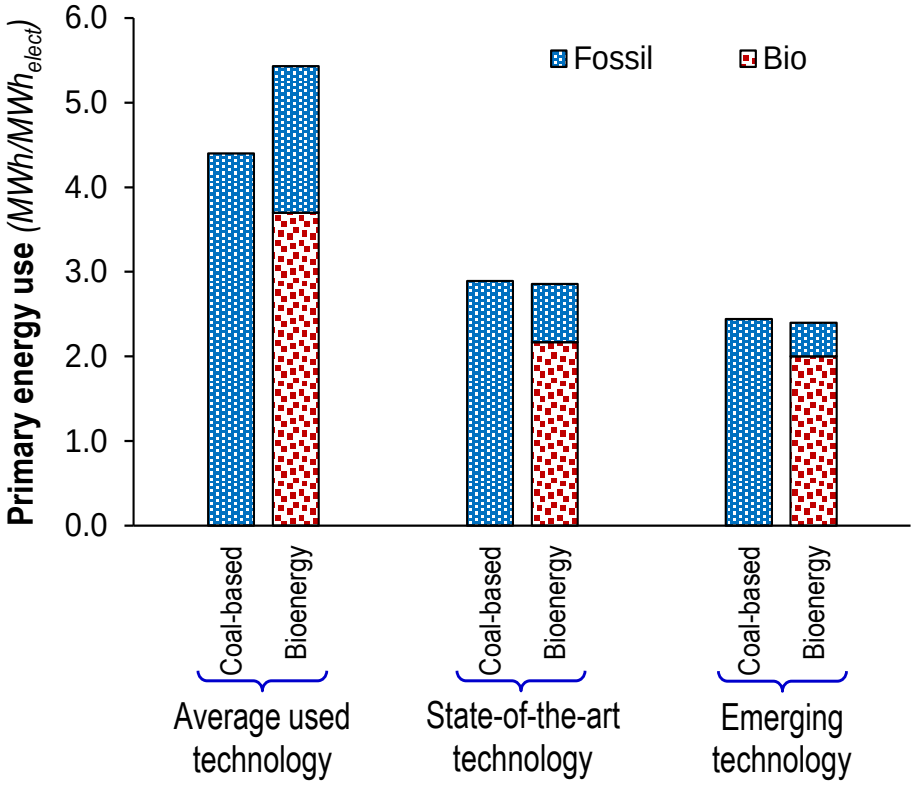
Selected technologies

Technology	Conversion efficiency (%)	
	Without CCS	With CCS
Average used technology in EU 2011		
• Coal	35	25
• Bioenergy	27	17
State-of-the-art technology		
• Pulverized Coal	48	38
• CFB Biomass	46	36
Emerging technology		
• IGCC Coal	52	45
• IGCC Biomass	50	43

Full primary energy use for generation of 1 MWh of electricity (fossil coal and forest slash)



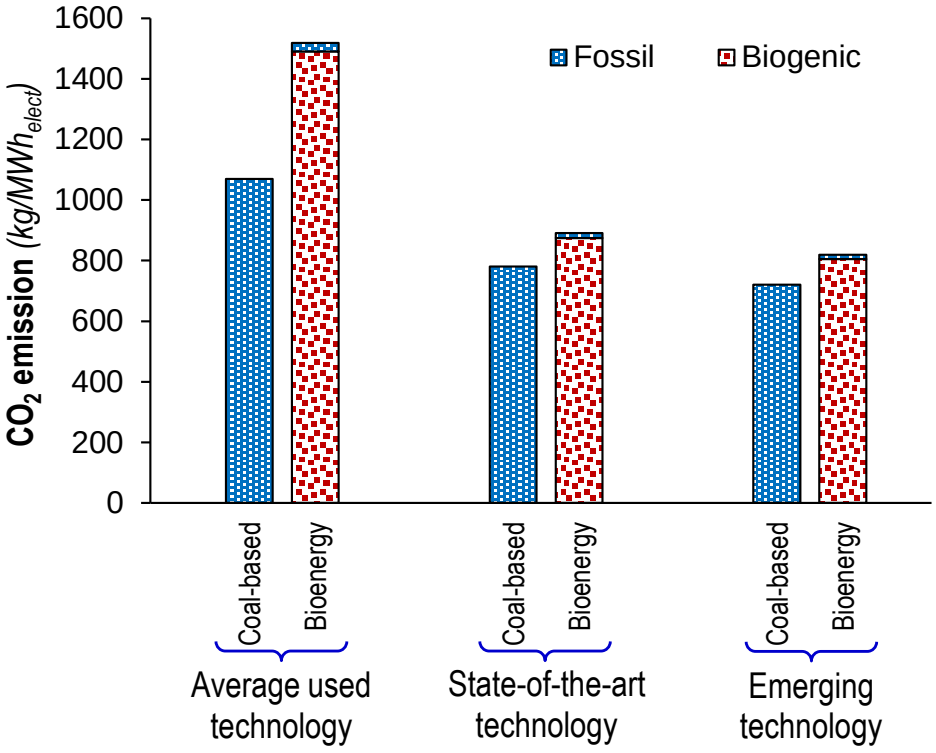
a) without CCS



b) with CCS

Based on Sathre, Truong & Gustavsson, 2017. Climate effects of electricity production fuelled by coal, forest slash and municipal solid waste with and without carbon capture. Energy 122, 711-723.

Fuel-cycle CO_2 emission including combustion for generation of 1 MWh of electricity (fossil coal and forest slash)



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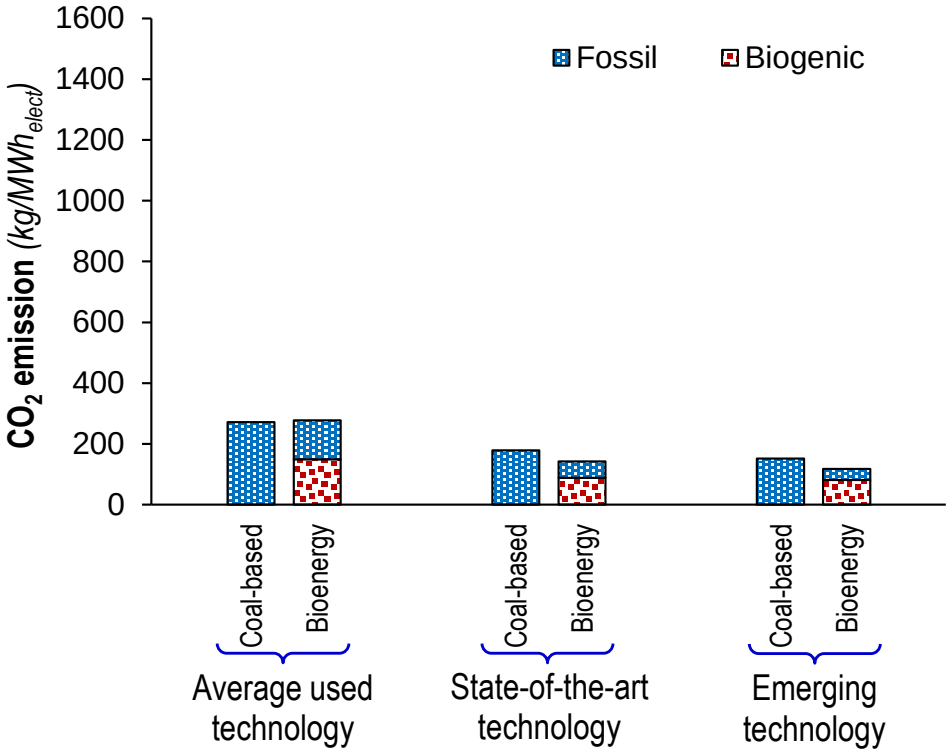

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CO_2 emissions from decay of forest biomass (slash) left in forest

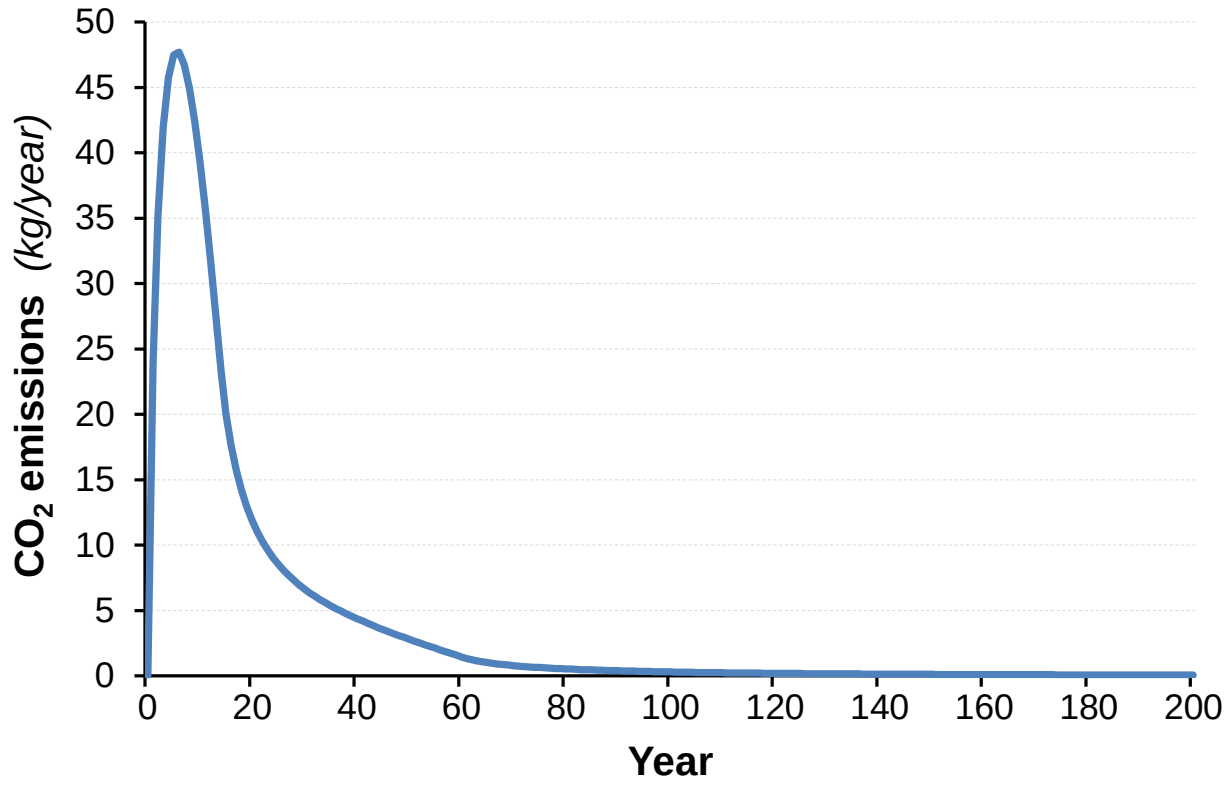
Using the Q model: slash decomposes continuously at specific rates in time that depend on the quality of the litter. Used parameters are given below.

Parameter	Description	Value
q_{0n}	Initial quality of needles and fine roots	1.01
q_{0w}	Initial quality of woody litter	1.0
ε_{11}	Speed of substrate quality decreases by decomposers	0.36
B	Steep of decomposer growth rate changes with substrate quality	7
e_0	Microbial decomposer growth efficiency	0.25
u_{00}	Parameter for decomposer growth rate	0.0855
u_{01}	Parameter for decomposer growth rate	0.0157
fC	Carbon concentration in decomposer biomass	0.5
$t_{maxbr+tops}$	Time for total invasion of branches and tops	13

- Q-model is a decomposition model based on continuous quality theory
- Decomposes fractions of material with specific initial quality during time
- Requires annual litter production and temperature input

  Rolff, C., Agren, G.I., 1999. Ecological Modelling 118, 193-211

CO_2 emission from natural decay of 932 wet kg of forest slash (needed to produce 1 MWh of electricity - state-of-the-art technology)



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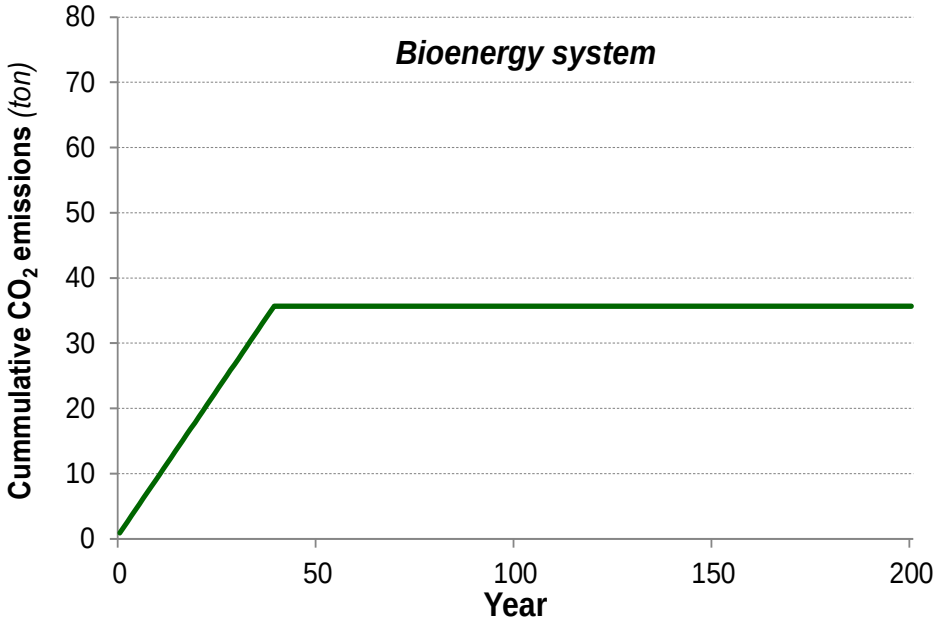
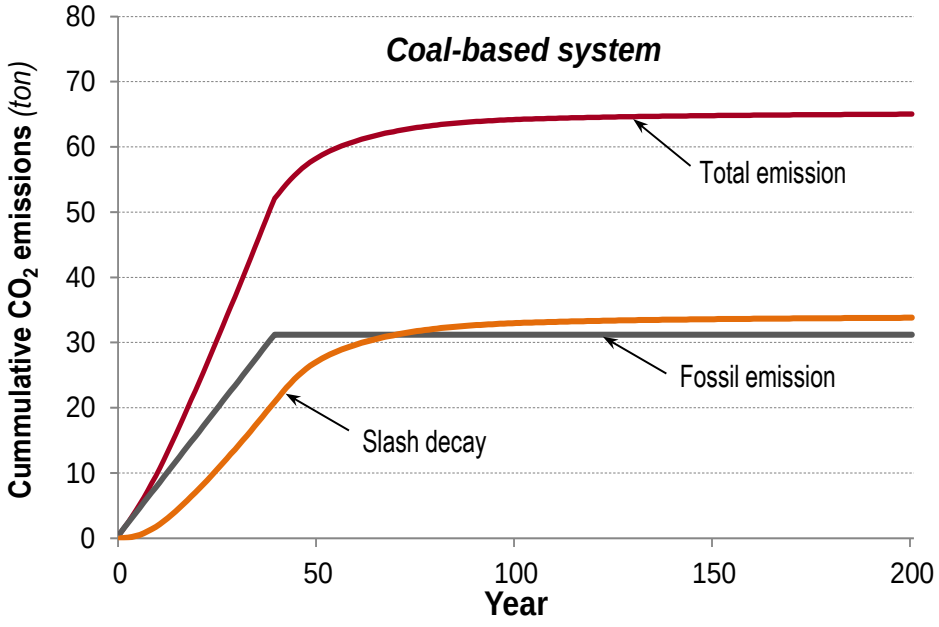
Cumulative fuel-cycle and combustion CO_2 emissions

1 MWh of electricity is produced annual during 40 years without CCS





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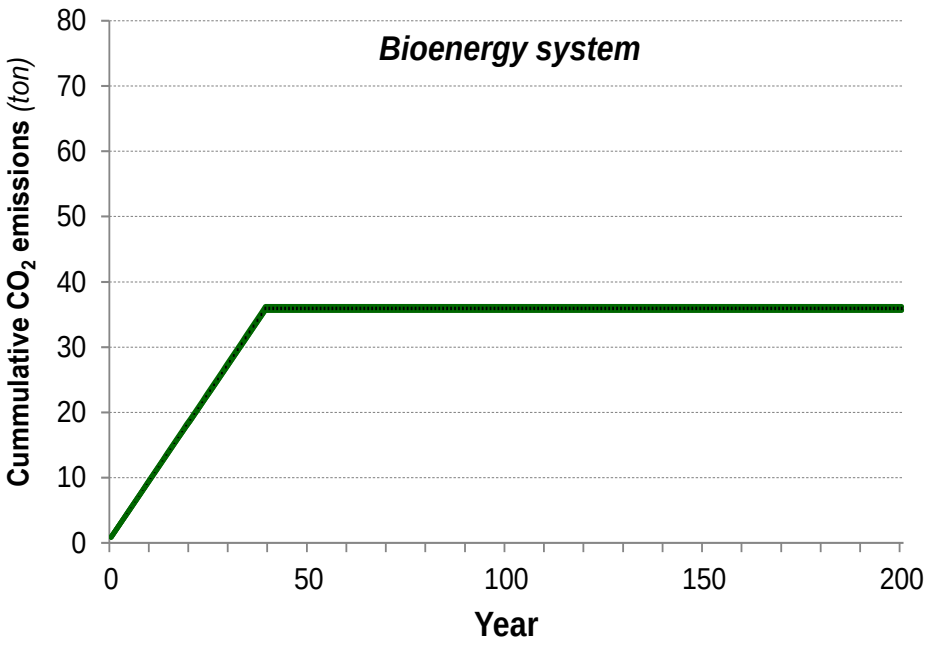
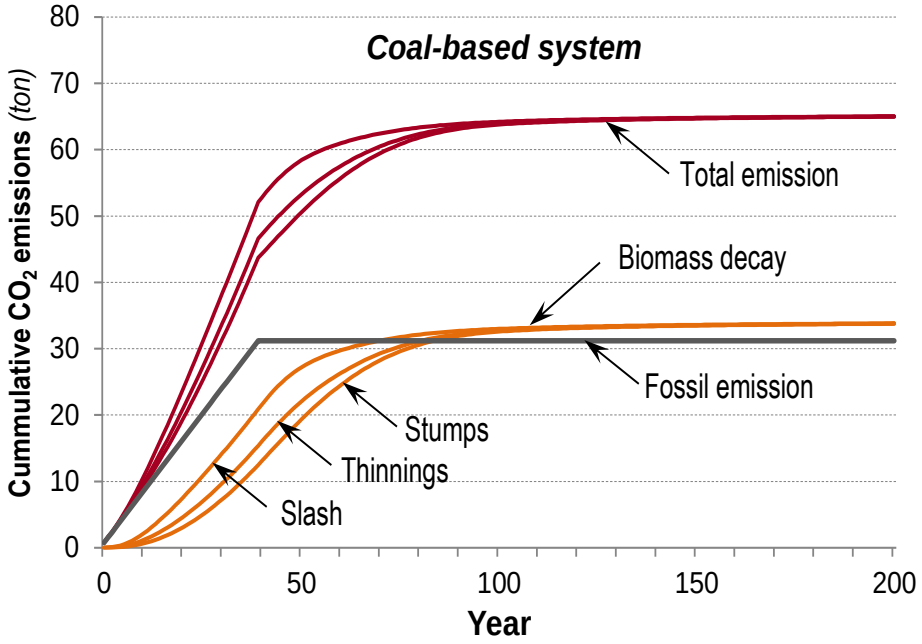
Cumulative fuel-cycle and combustion CO_2 emissions
1 MWh of electricity is produced annual during 40 years without CCS

In the bioenergy system, the difference between slash, stumps and thinnings is difficult to se





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Cumulative fuel-cycle and combustion CO_2 emissions

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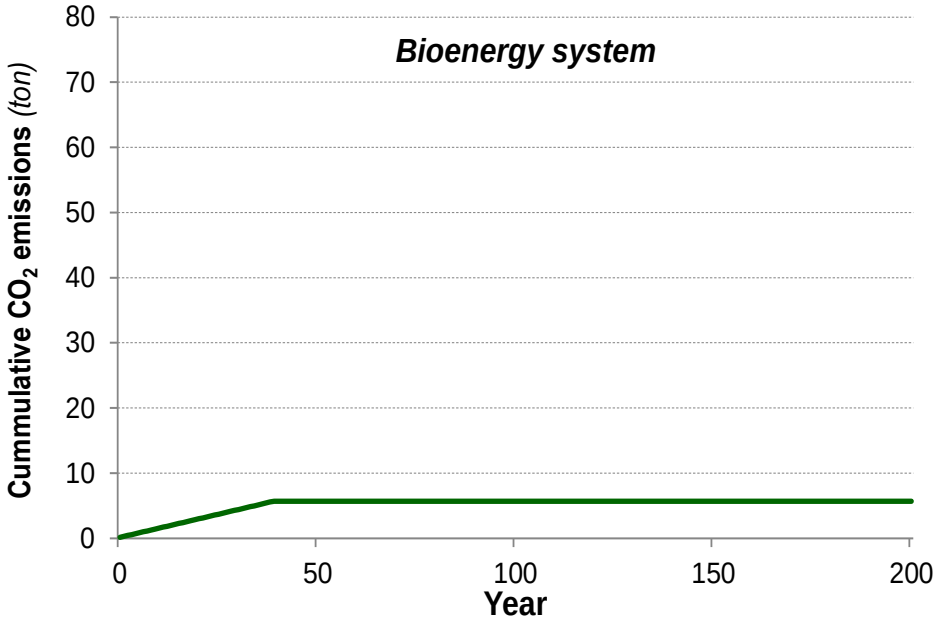

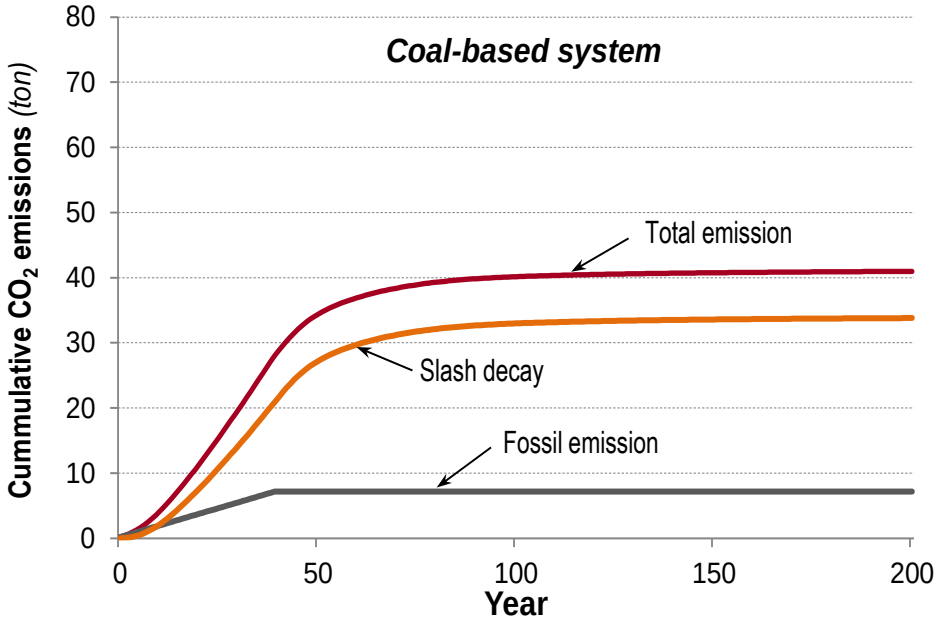

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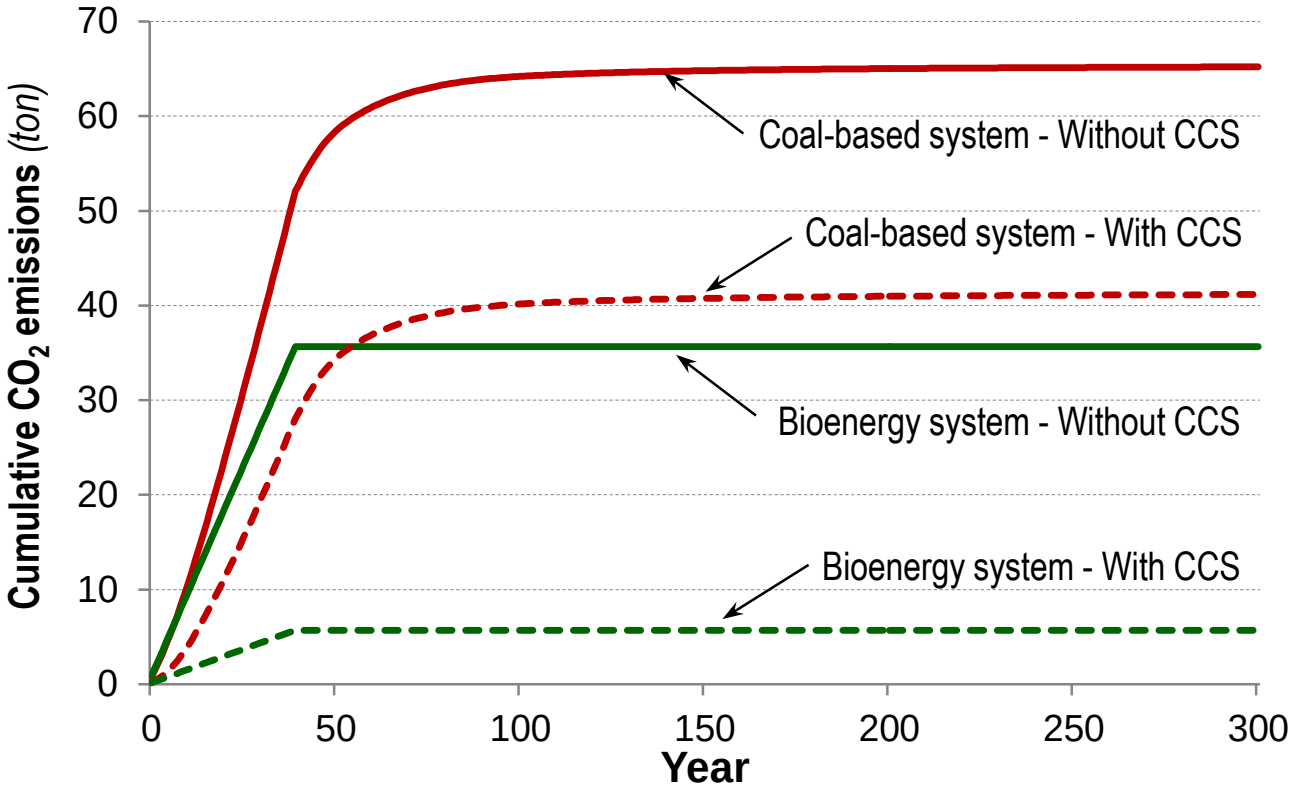
Cumulative fuel-cycle and combustion CO_2 emissions

1 MWh of electricity is produced annual during 40 years (slash)



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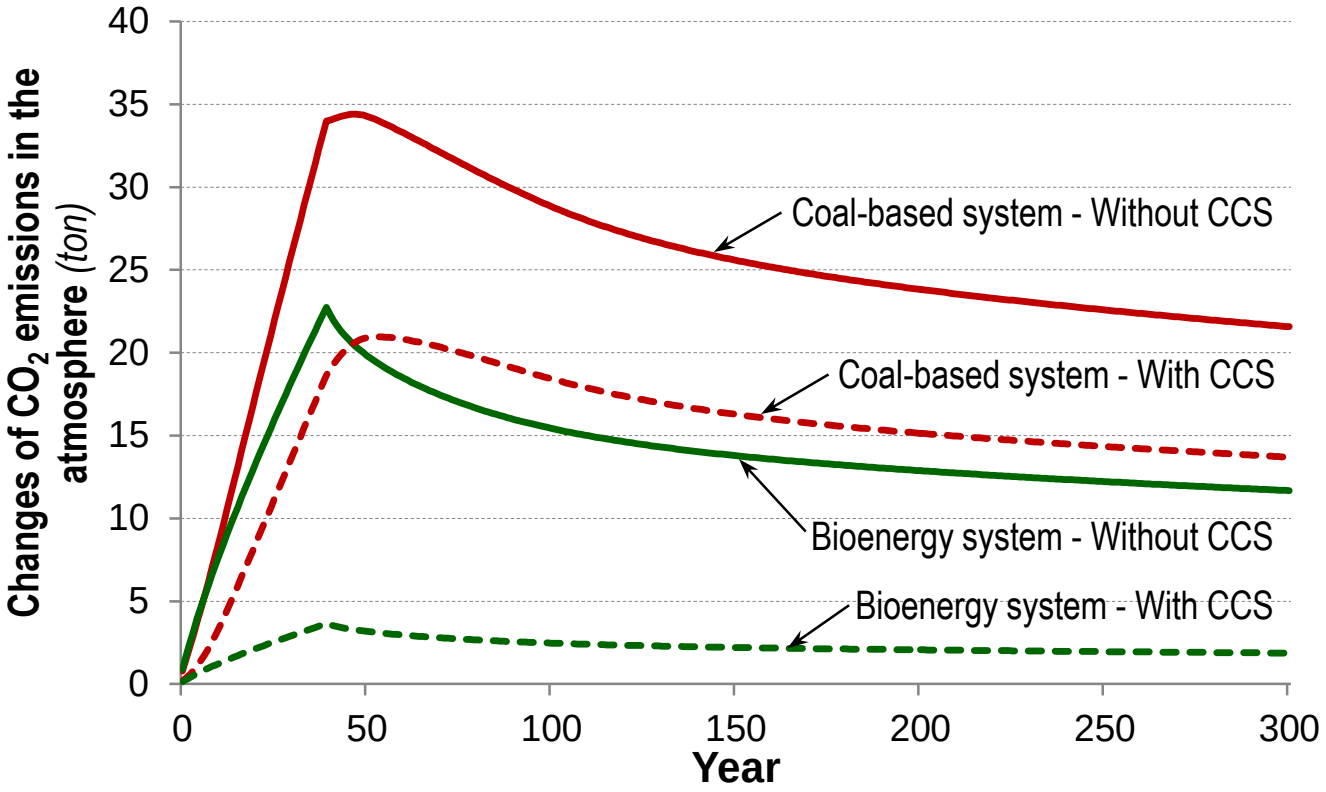
Changes of CO_2 in the atmosphere

1 MWh of electricity is produced annual during 40 years



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Cumulative radiative forcing (CRF)

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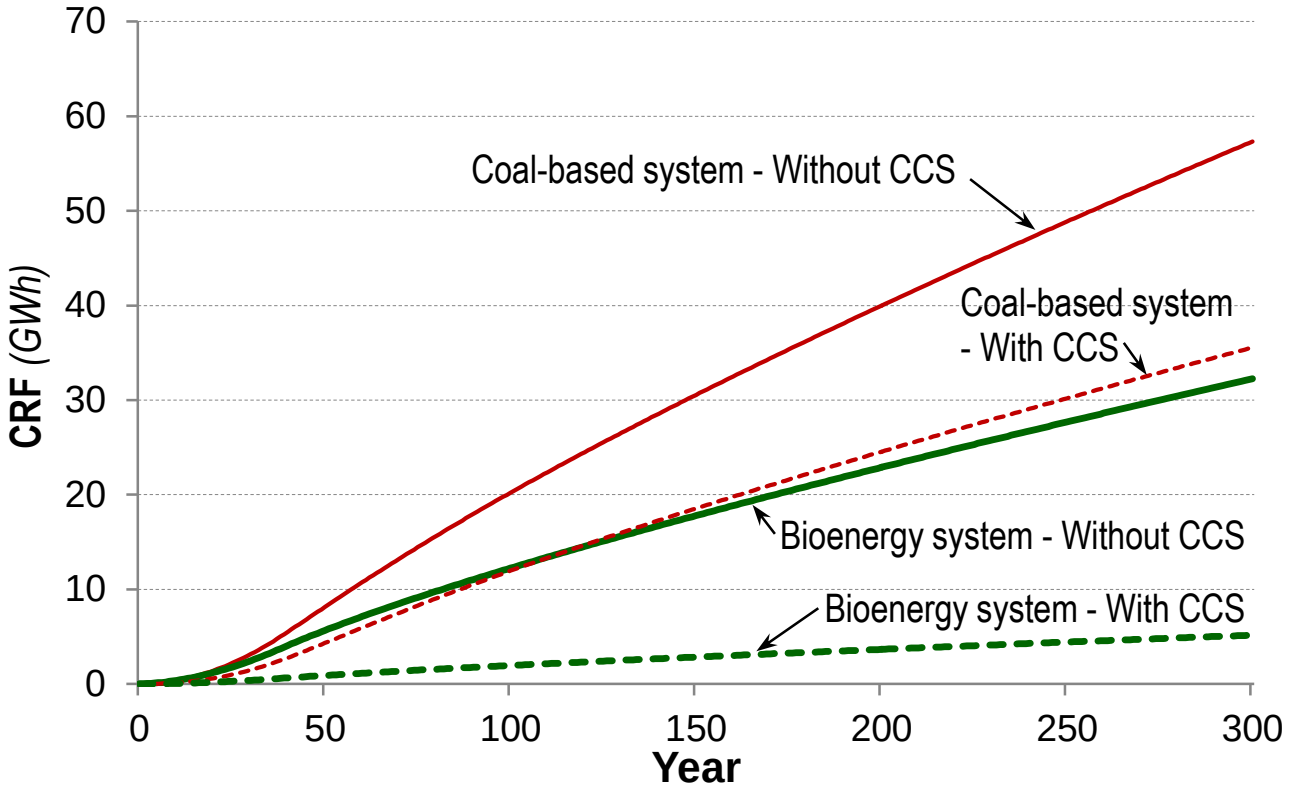

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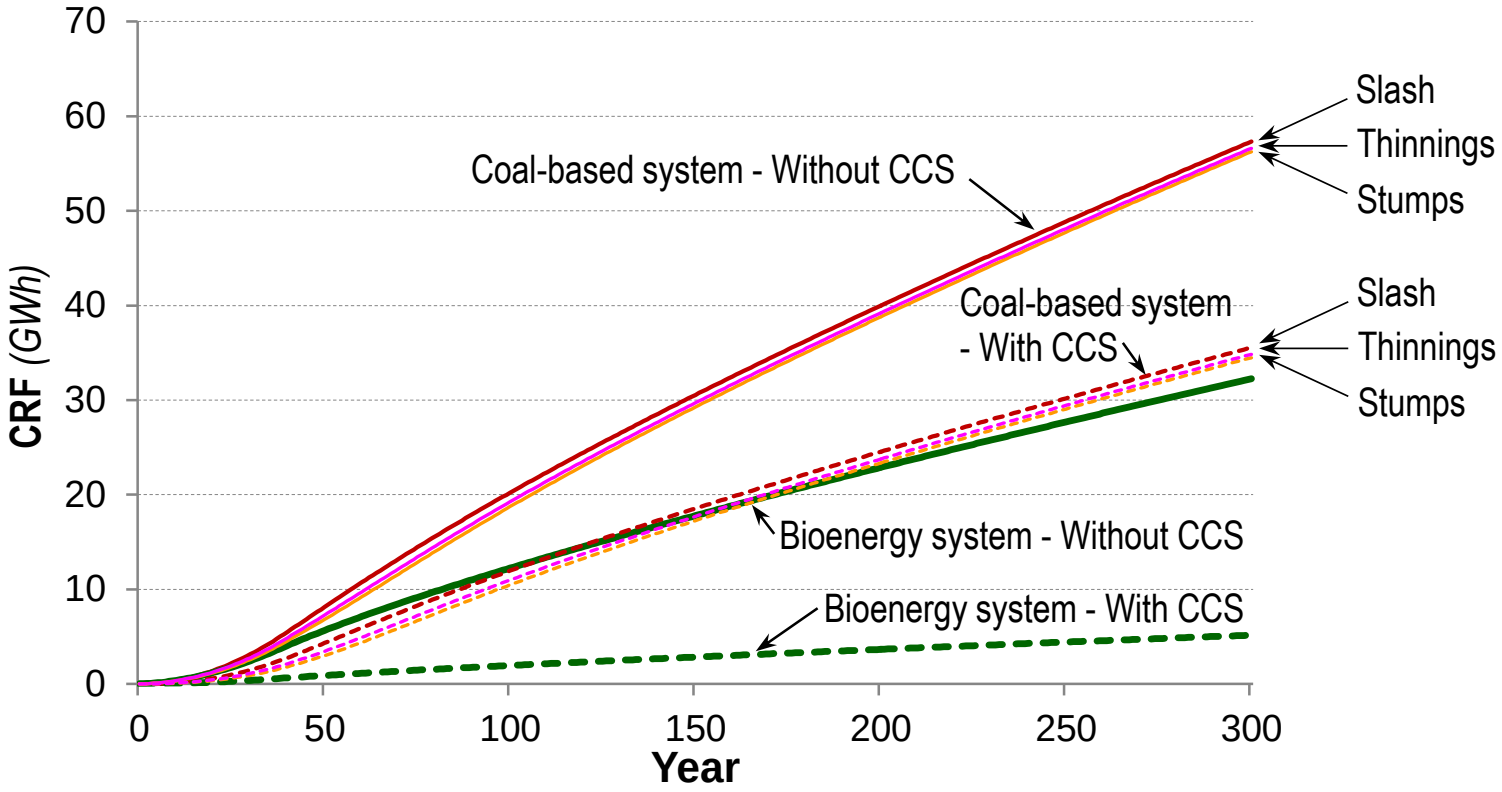

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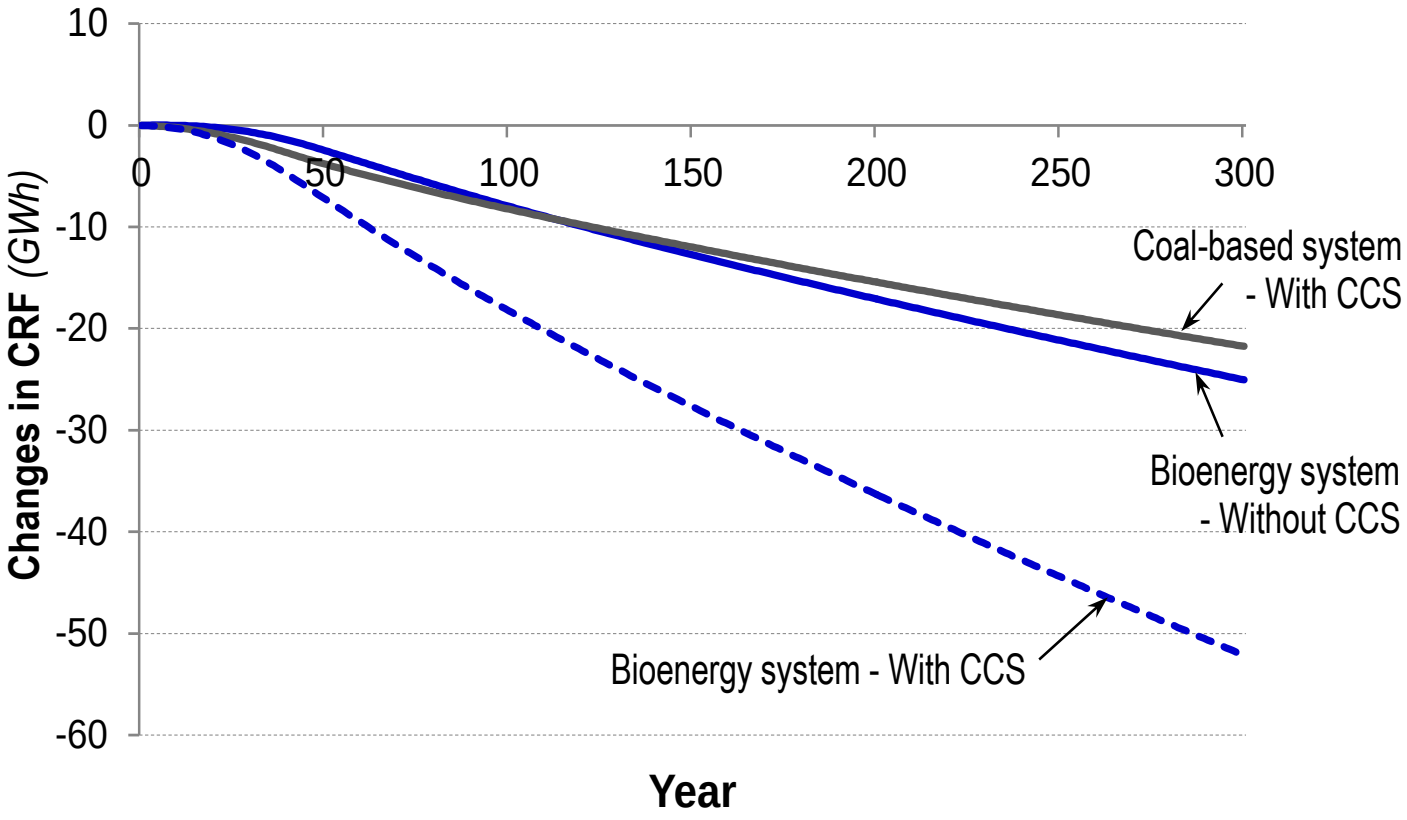
Changes of cumulative radiative forcing (CRF)

Slash with and without CCS and *Coal with CCS* is used instead of ***Coal without CCS*** to produce 1 MWh of electricity annually during 40 years



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Conclusions

- Forest biomass increase the primary energy use and CO_2 emission at conversion plant compared to coal
- Considering the natural decay of forest biomass, biomass gives much lower net CO_2 emission than fossil coal
- CCS requires additional fuel but strongly reduces CO_2 emission at conversion plant
- Using forest biomass with CCS strongly reduces CO_2 emission compared to fossil coal and gives global cooling