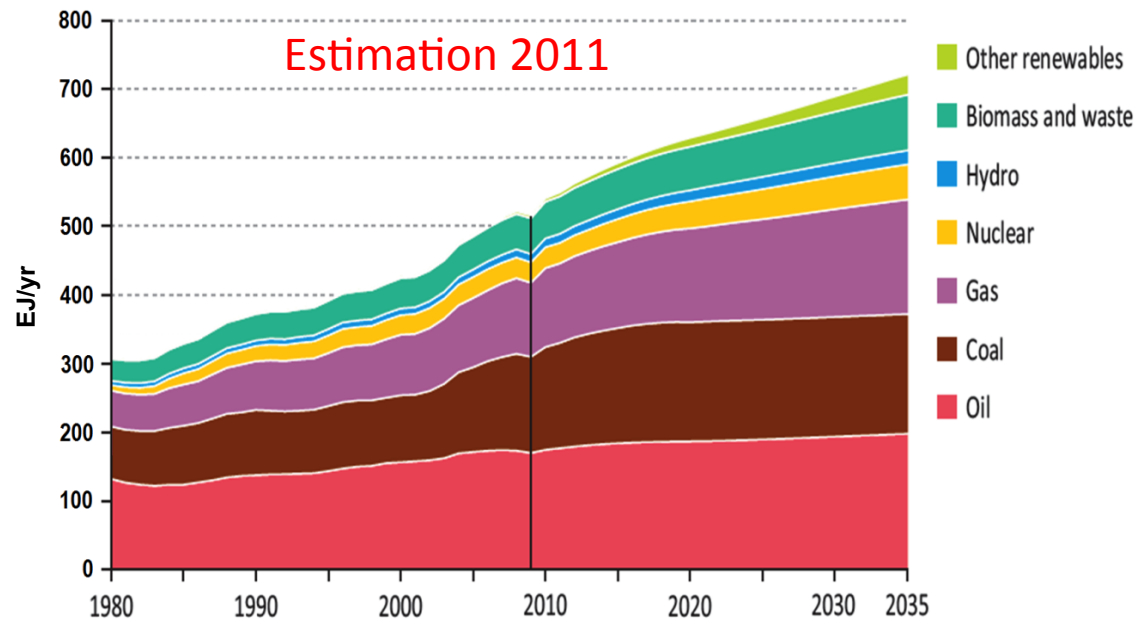


Climate effects of woody biomass and fossil fuel use in stand-alone and integrated energy systems

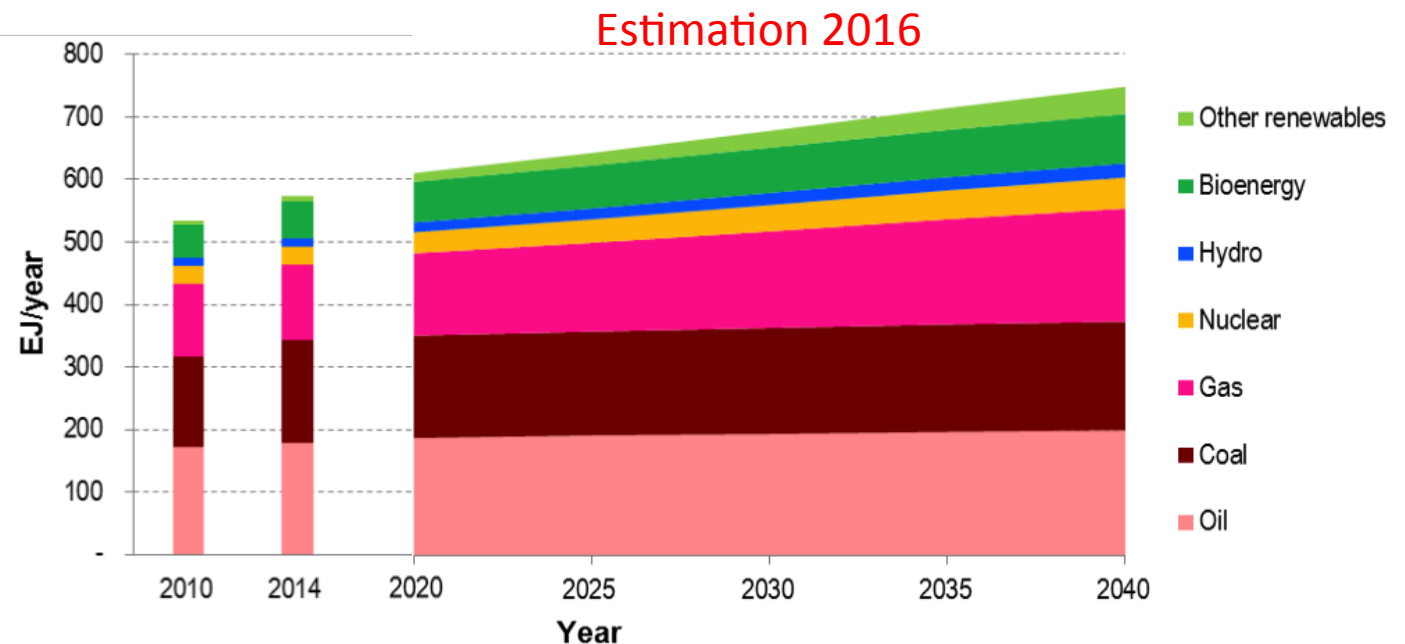
Leif Gustavsson and Nguyen Le Truong
Linnaeus University, Sweden



Annual global primary energy use and trends (IEA)

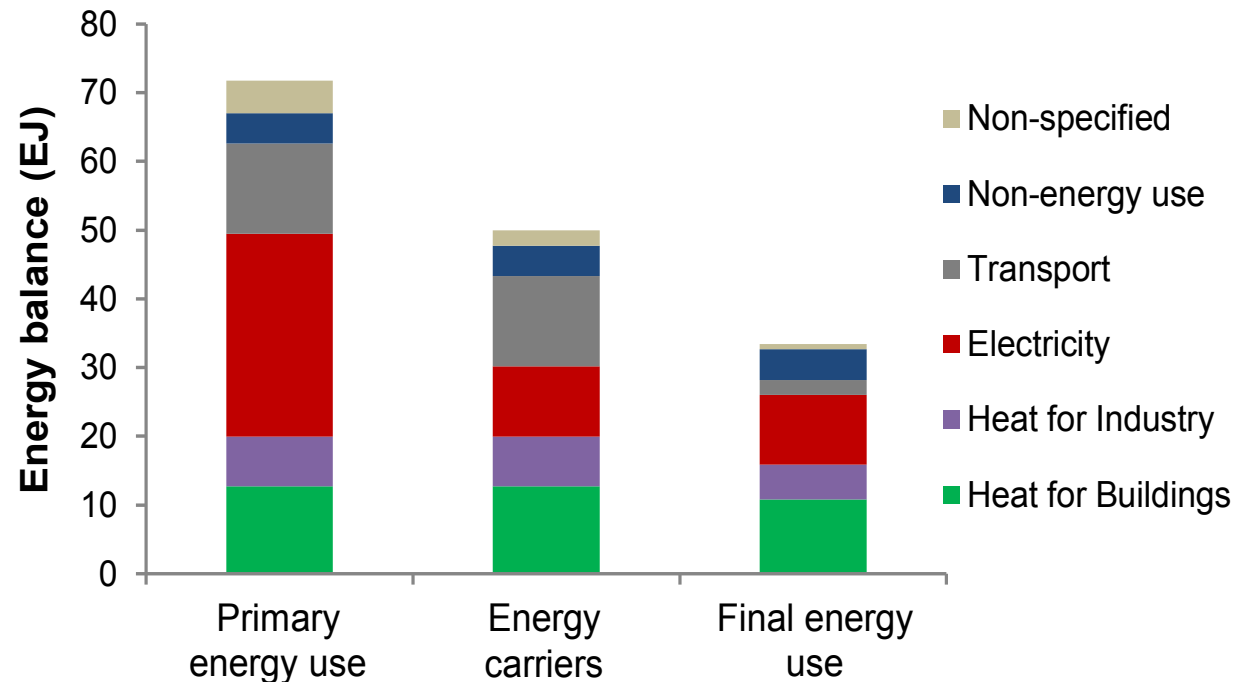


Year	2010	2014
Total (EJ)	533	573
Distribution (%)		
Oil	32.4	31.2
Coal	27.3	28.7
Gas	21.4	21.1
Total fossil	81.1	81.0
Bioenergy	10.0	10.4
Nuclear	5.7	4.8
Other	3.2	3.8



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

From primary to final energy use for the EU27 in 2010



- Electricity, heat, and motor fuels are the major energy carriers to supply different energy services

@ Connolly et al., 2013. Heat Roadmap Europe 2050



Aims

We evaluate the climate effects of using forest slash (branches and tops) or fossil fuels to produce

- heat
- electricity
- transport distance

We quantify the

- primary energy use
- annual CO₂ emissions
- cumulative CO₂ emissions and
- cumulative radiative forcing (CRF)

of the bioenergy and corresponding fossil energy systems



Technologies for different final energy services

Heat

- Coal boiler
- Fossil gas boiler
- Wood chip boiler

Stand-alone power, combined heat and power (CHP)

- Biomass steam turbine (BST)
- Coal-based steam turbine CST)
- Fossil gas combined cycle (FGCC)
- Biomass integrated gasification combined cycle (BIGCC)

Transport distance

- Electric vehicle (EV)
- Fuel based vehicle (FV): Diesel, Gasoline, DME, MeOH



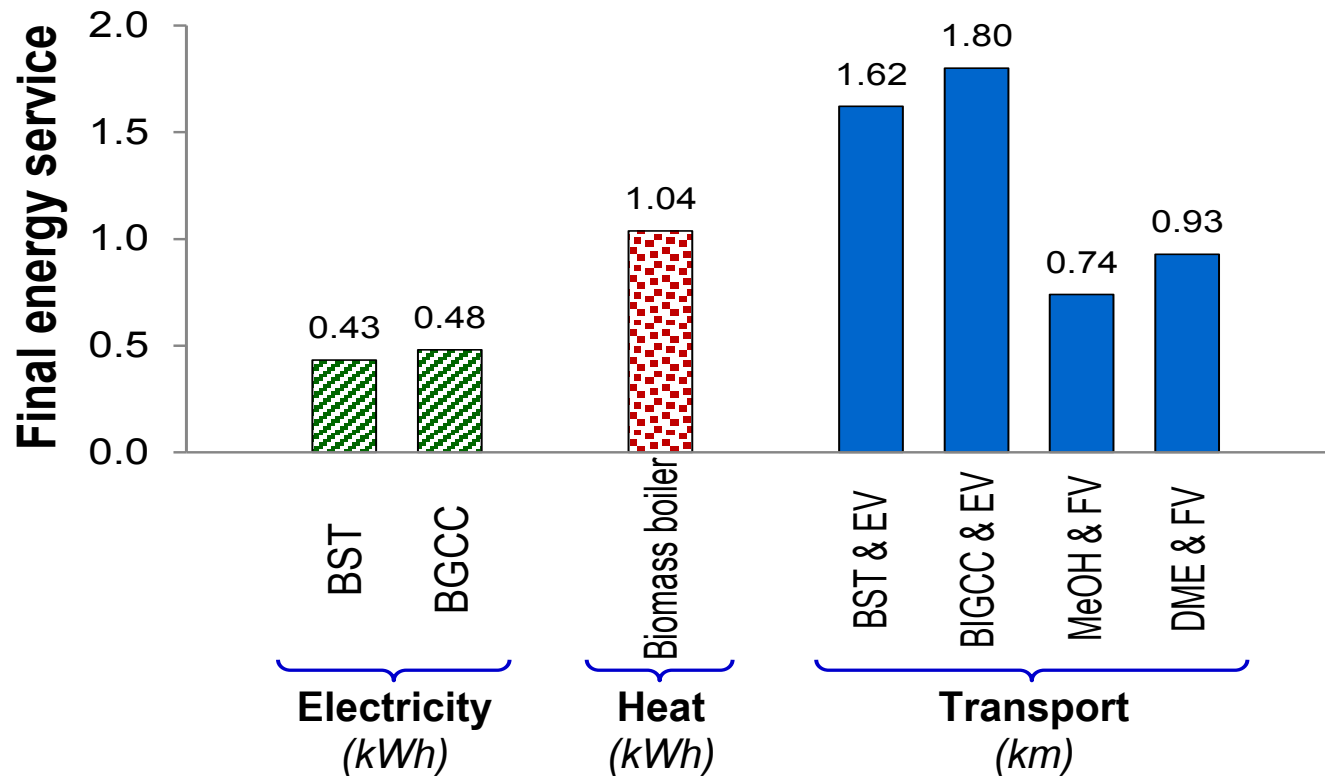
Technologies for transport distance: light-duty vehicle model B-class from Mercedes-Benz

Fuel and energy use, including wall-to-vehicle charging losses:

Vehicle type	Fuel type	Consumption (kWh/km)		
		Electricity	Gasoline	Diesel
EV	Electricity	0.249	-	-
FV	Gasoline	-	0.597	-
FV	Diesel	-	-	0.510



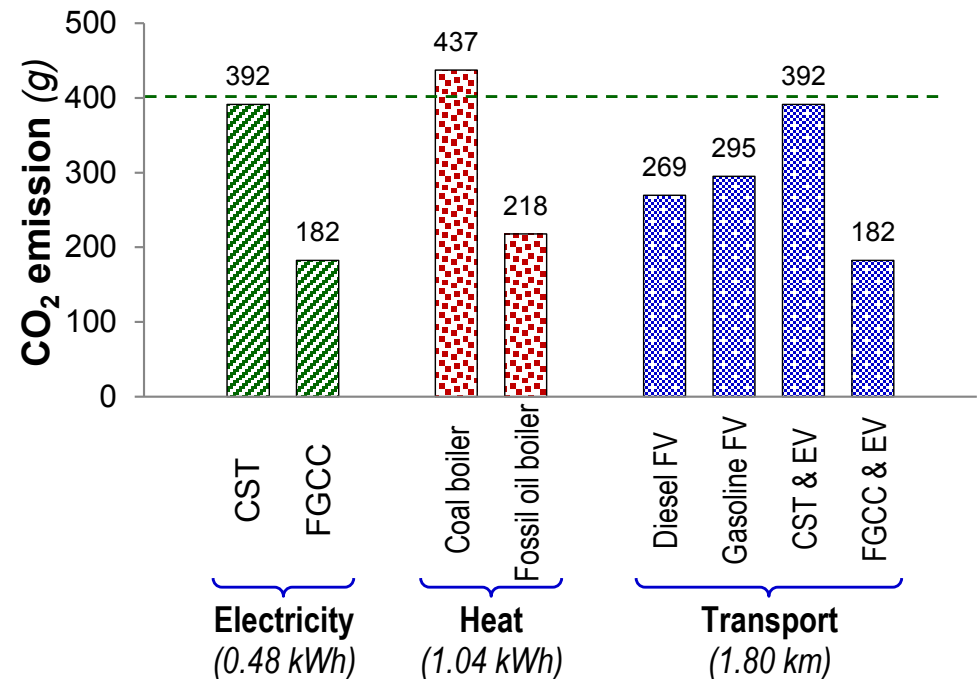
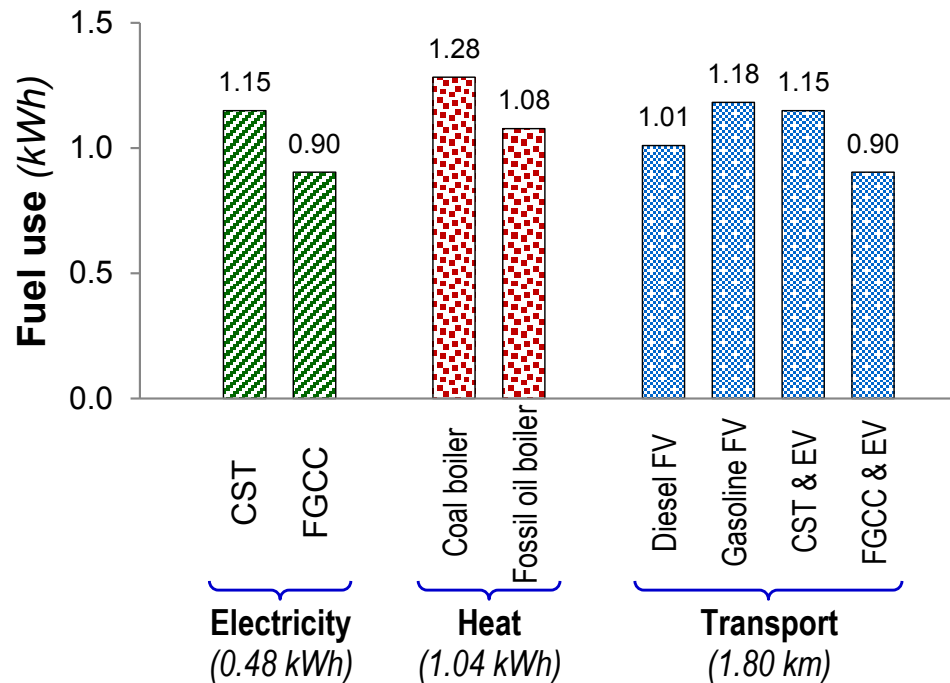
Energy services produced by a kWh of forest slash



👉 A package of energy services providing **0.48 kWh** of electricity, **1.04 kWh** of heat or **1.80 km** of transport distance is considered for integrated systems



Fuel use and CO₂ emission of standalone systems based on fossil fuels for the corresponding energy services



Forest slash

Bioenergy system

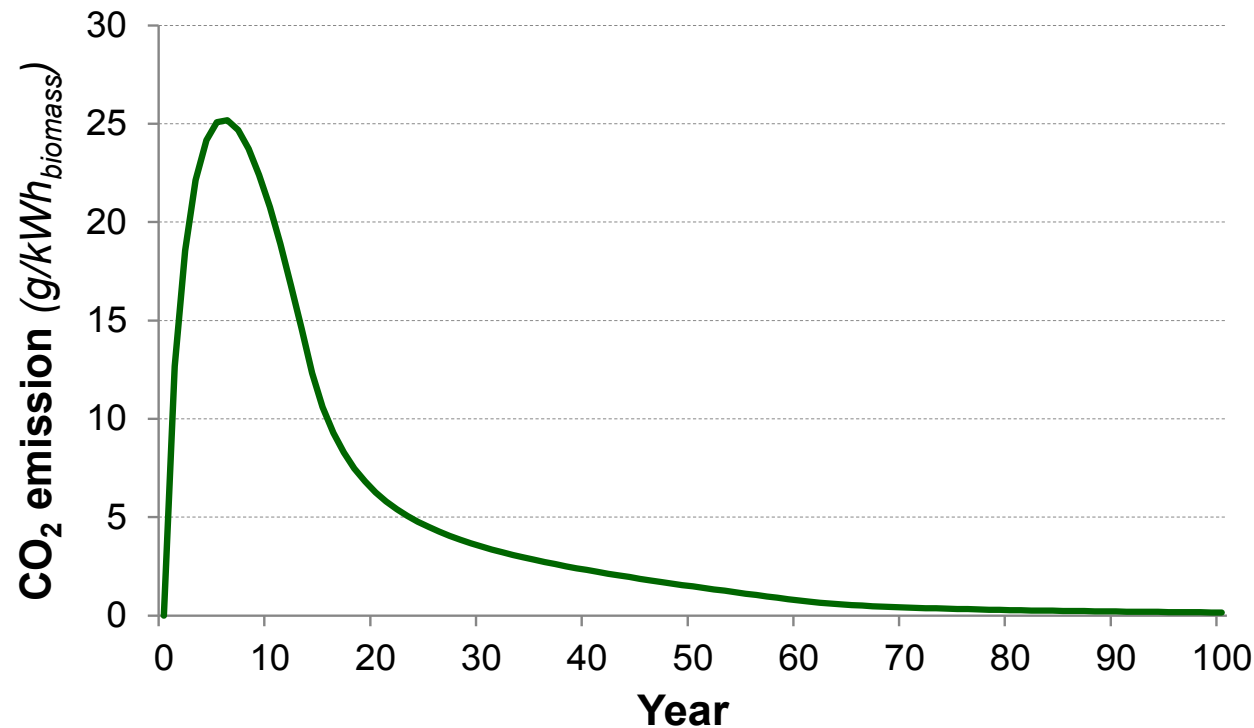
- Forest slash is harvested in central Sweden. Transported 100 km (truck) + 250 km (train) + 1100 km (ship) to harbour in Europe as chips

Fossil energy system

- Forest slash is not recovered and decays naturally



CO₂ emission from the decay of 1kWh of forest slash left on the forest floor in year 0



👉 The decaying biomass releases **383g** out of **403g** CO₂ emission during a 100-year time period

Human activities

- GHG emissions
- Albedo change
- Aerosols
- Ozone

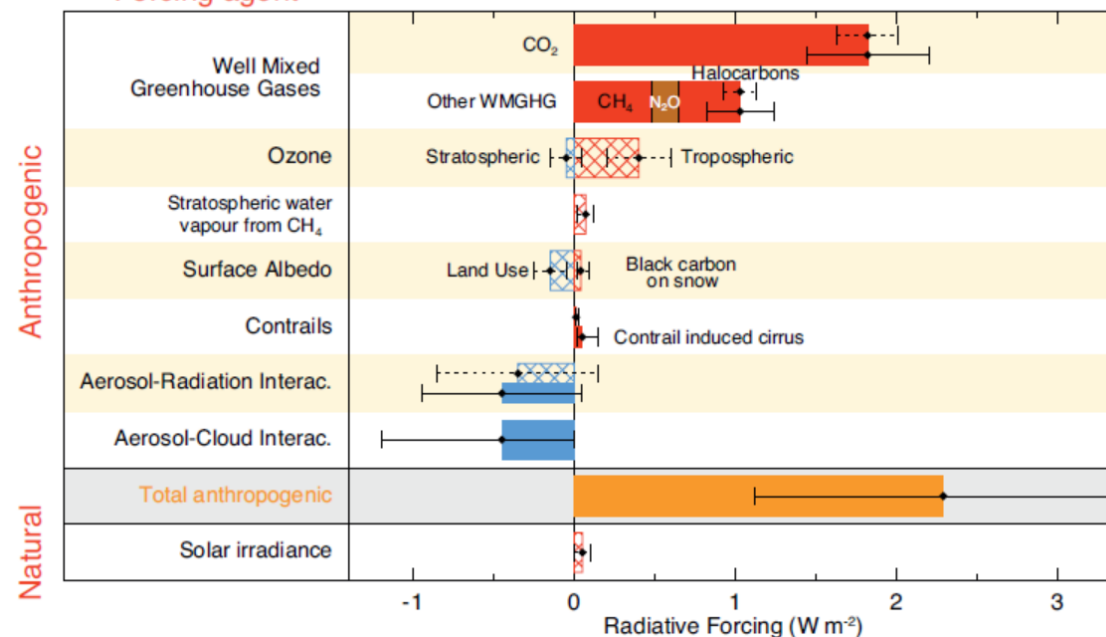
Radiative forcing

Mean temperature change

Physical, ecological, and social disturbances

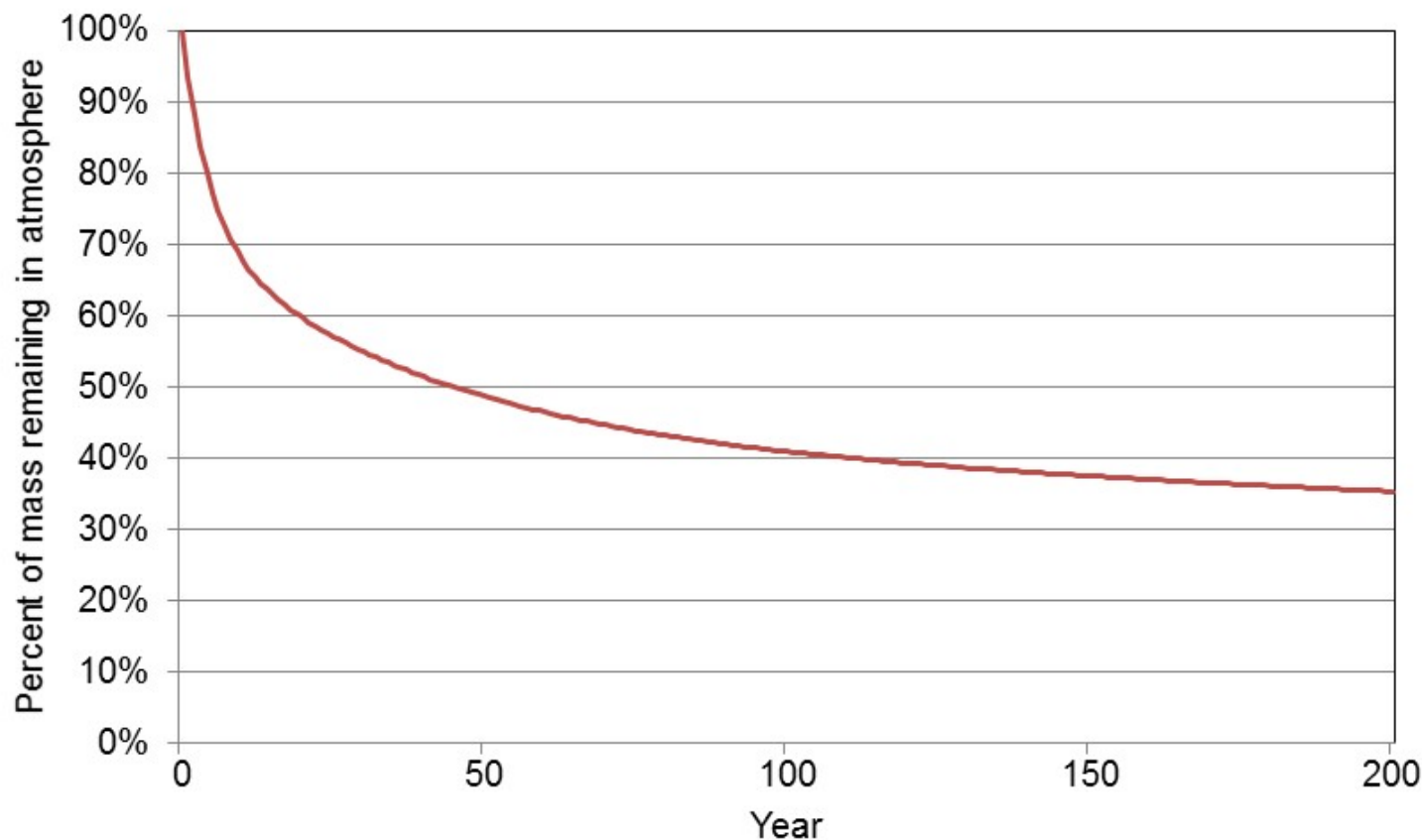
Anthropogenic climate change: Chain of events

Radiative forcing of climate between 1750 and 2011
Forcing agent



(IPCC 2013)

Atmospheric decay of a unit pulse of CO₂



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



Radiative forcing (W/m²) due to CO₂ concentration change

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

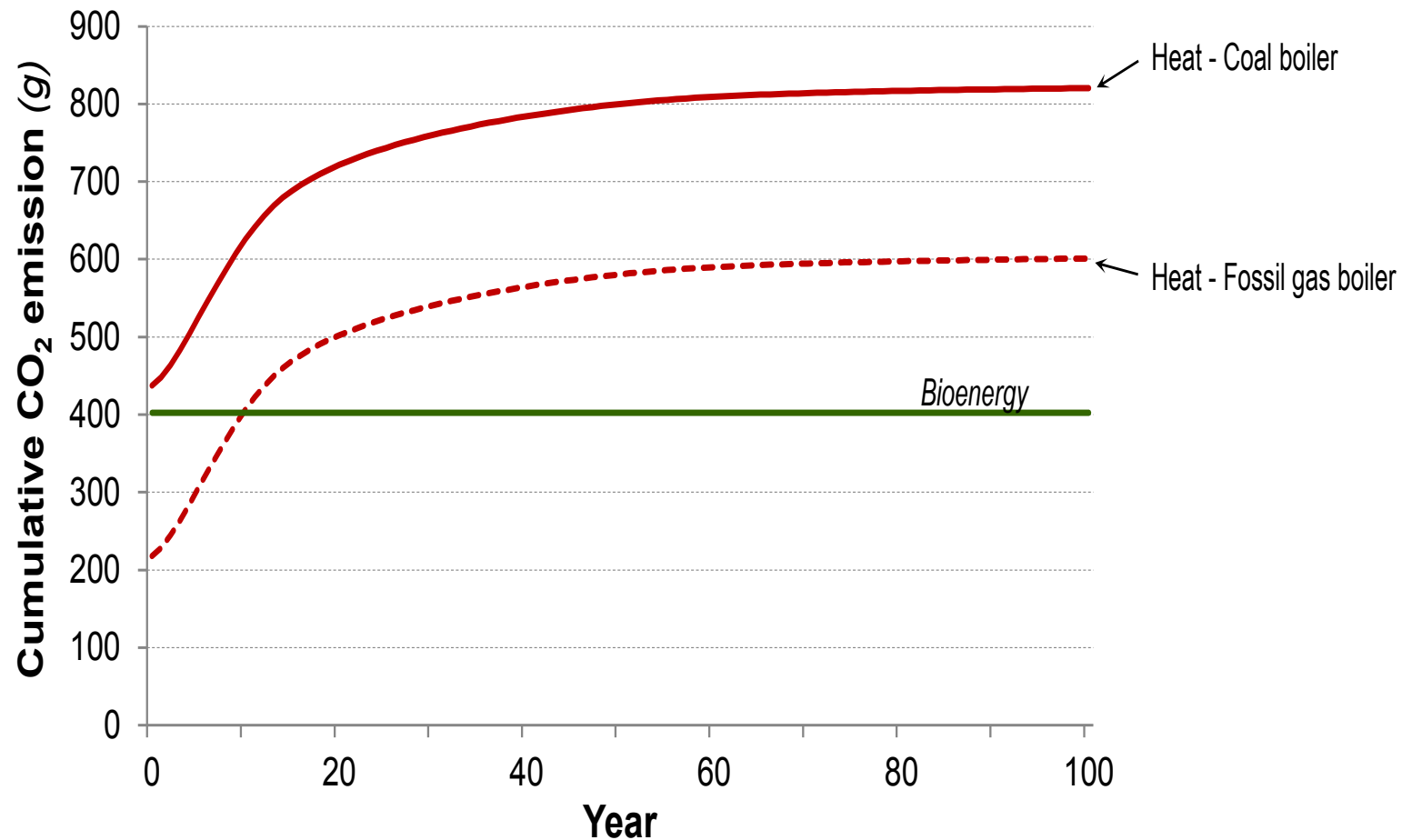
where $CO_{2ref} = 400$ ppmv

Assumes relatively minor marginal changes in CO₂ concentrations



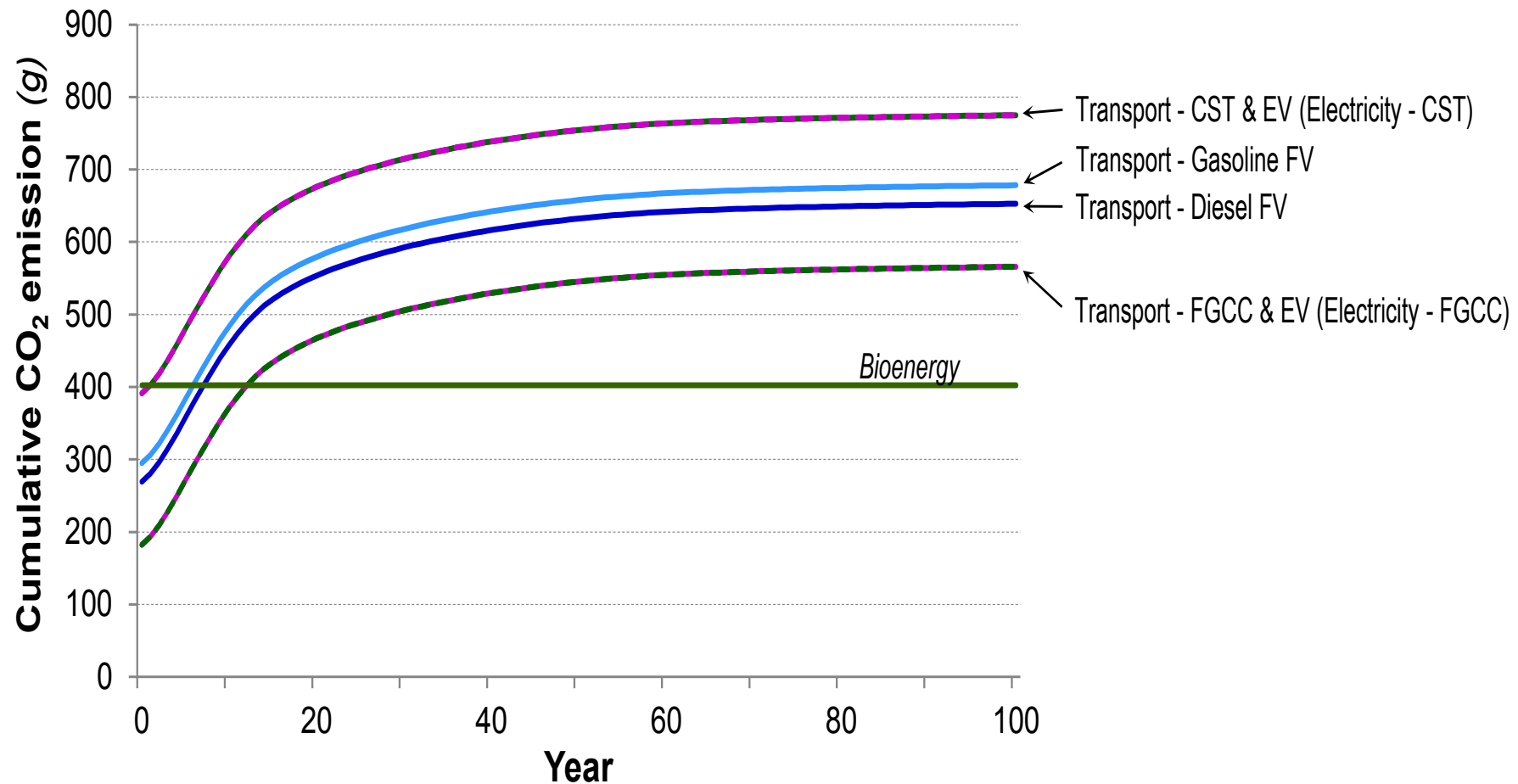
Cumulative CO₂ emission from stand-alone energy systems

The CO₂ emission from the decay of biomass is added to fossil systems

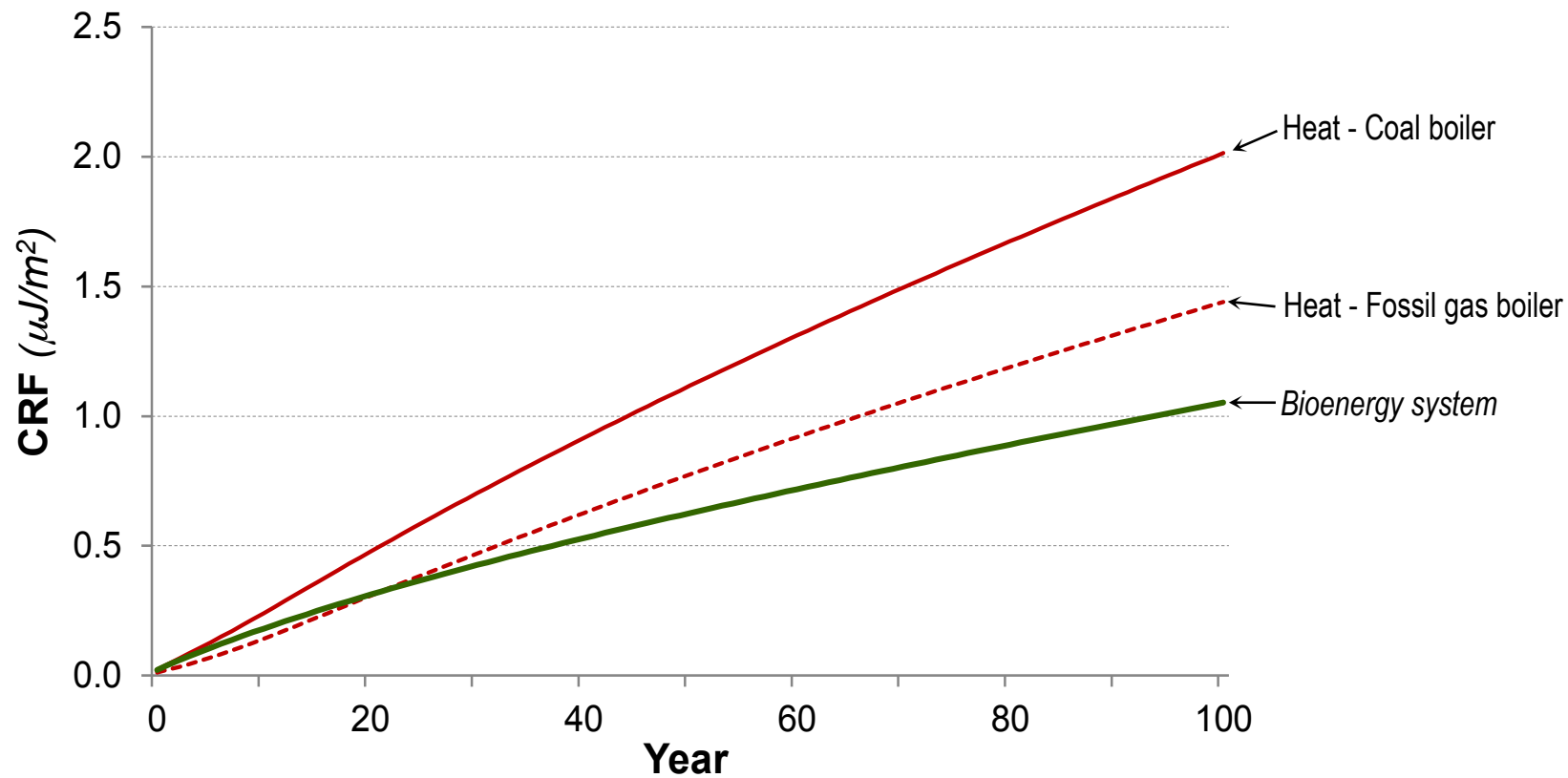


Cumulative CO₂ emission from stand-alone energy systems

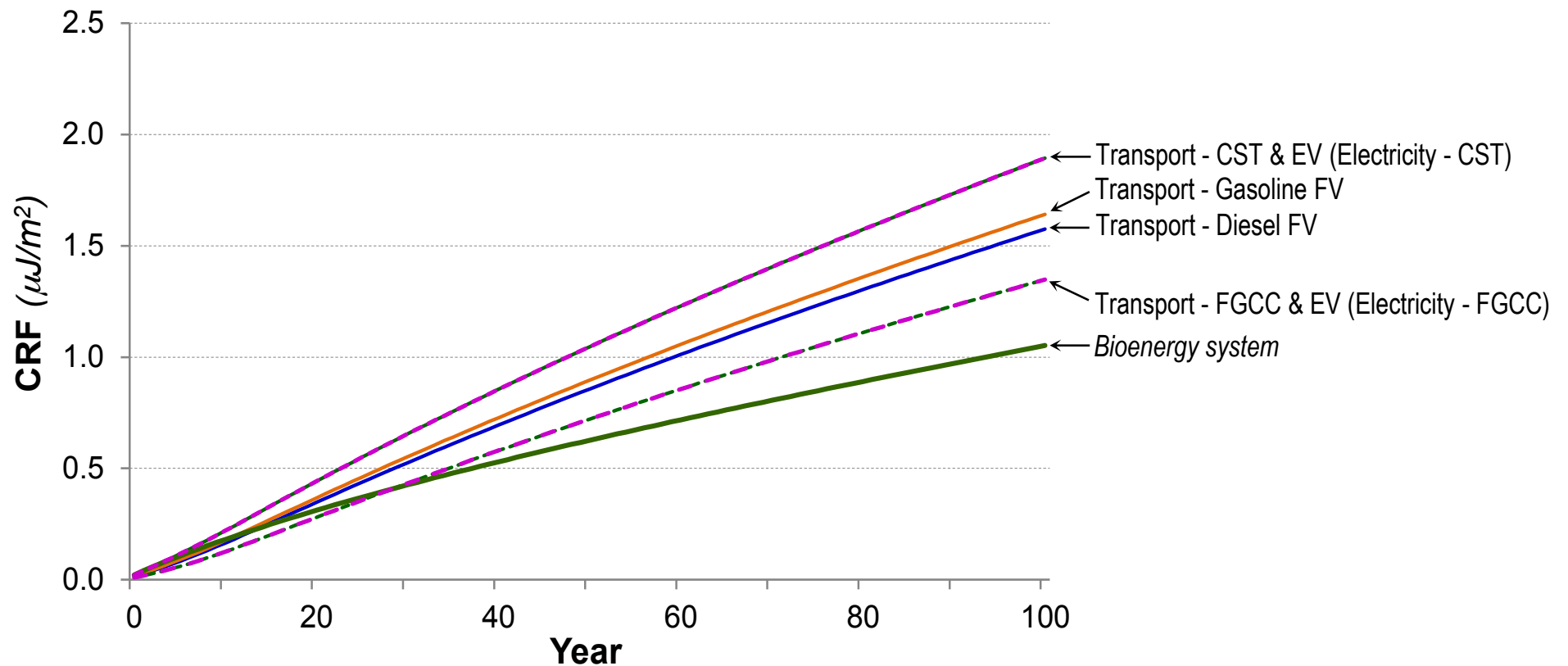
The CO₂ emission from the decay of biomass is added to fossil systems



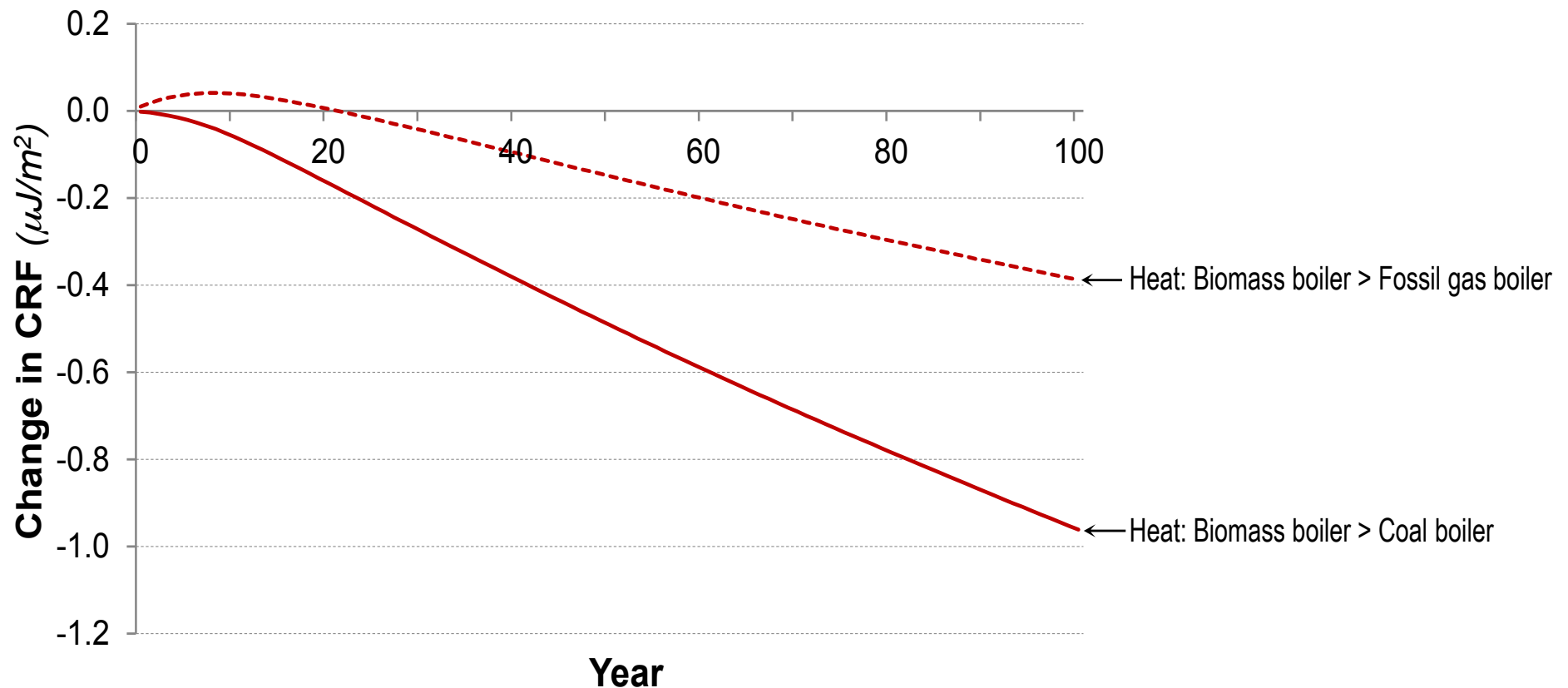
Cumulative radiative forcing of standalone energy systems



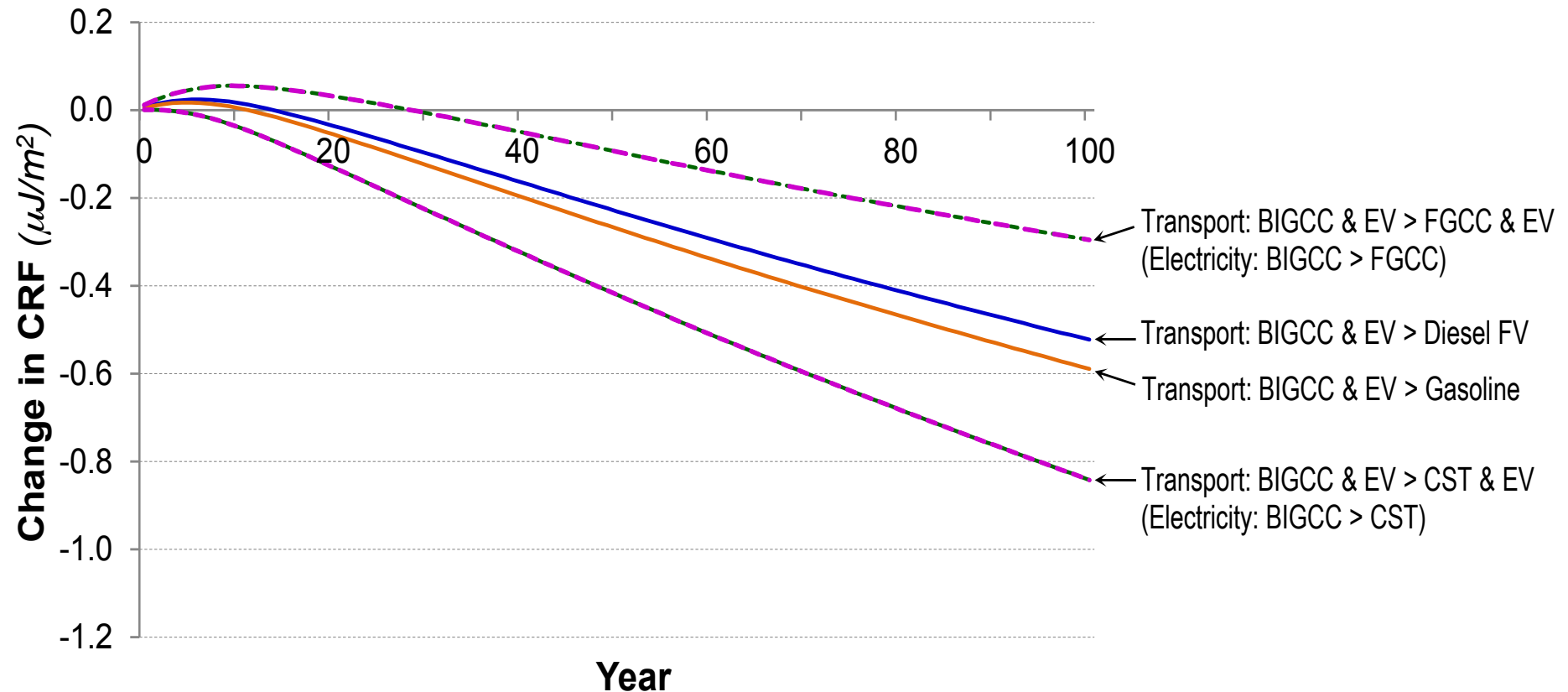
Cumulative radiative forcing of standalone energy systems



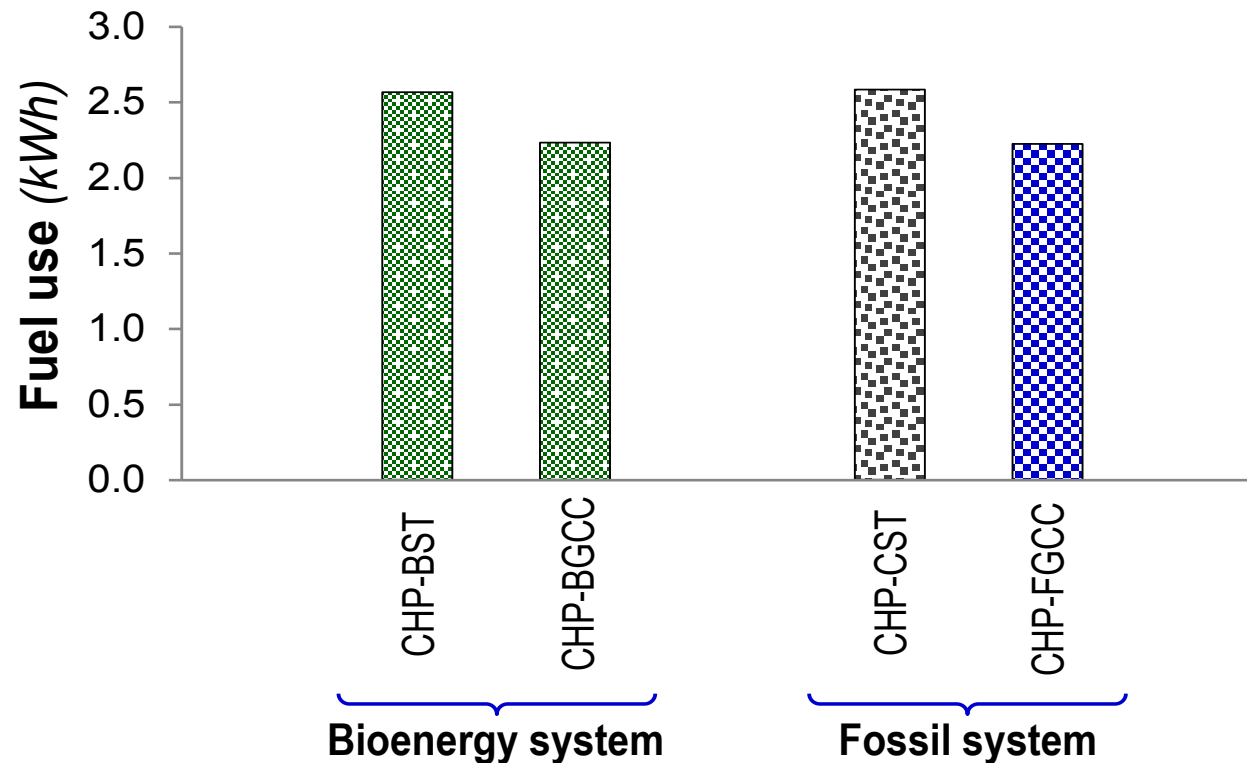
Change in CRF when bioenergy is used instead of fossil fuels



Change in CRF when bioenergy is used instead of fossil fuels

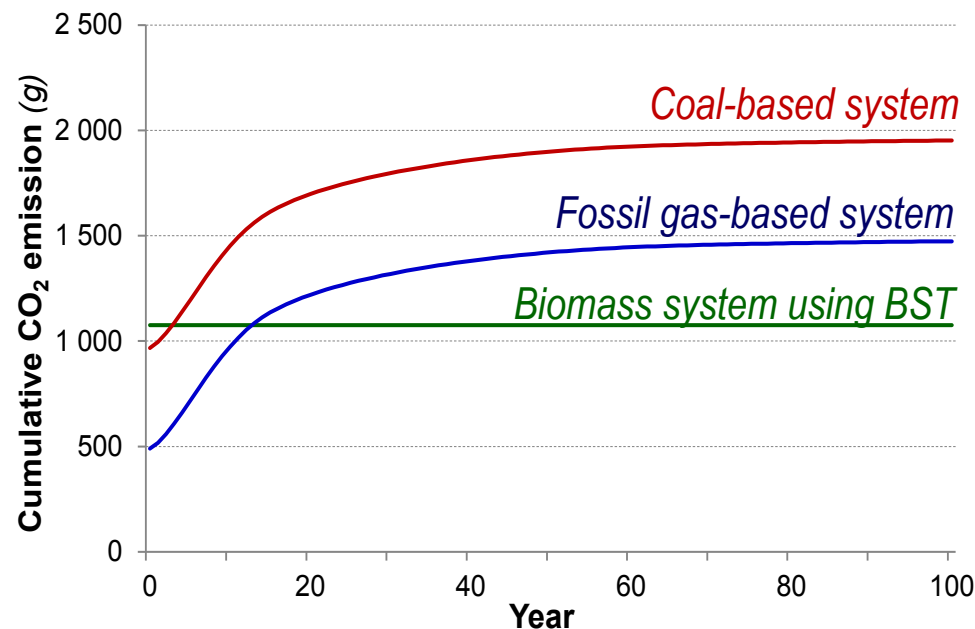


Fuel use of integrated energy systems providing 0.48 kWh electricity, 1.04 kWh heat and 1.80 km transport distance

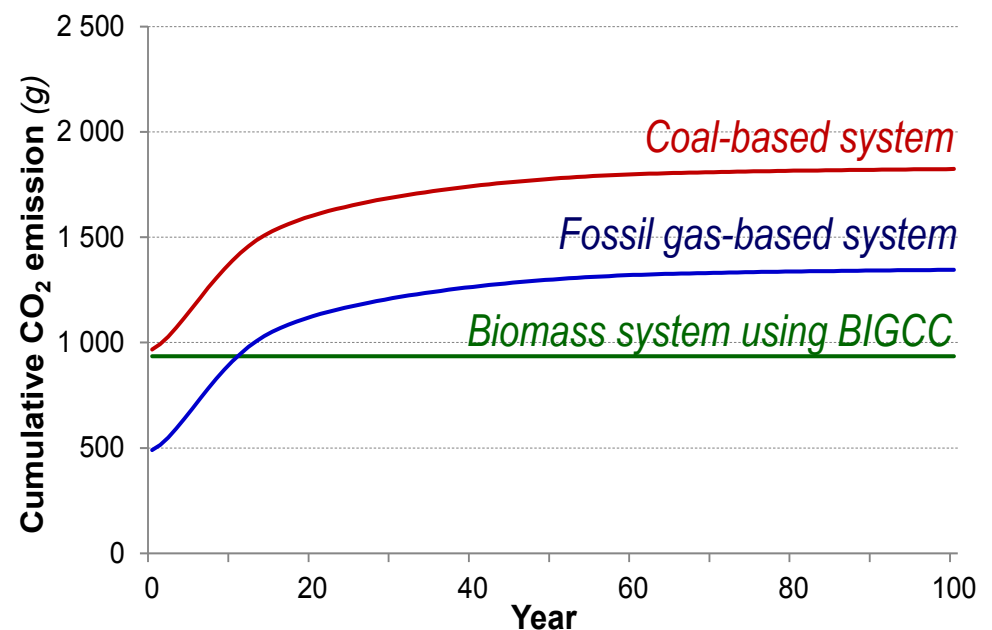


- 👉 Compared to standalone systems, integrated options reduce:
- 14-26% of forest slash use
 - 10-38% of fossil fuel use

Cumulative CO₂ emission of integrated energy systems providing 0.48 kWh electricity, 1.04 kWh heat and 1.80 km transport distance

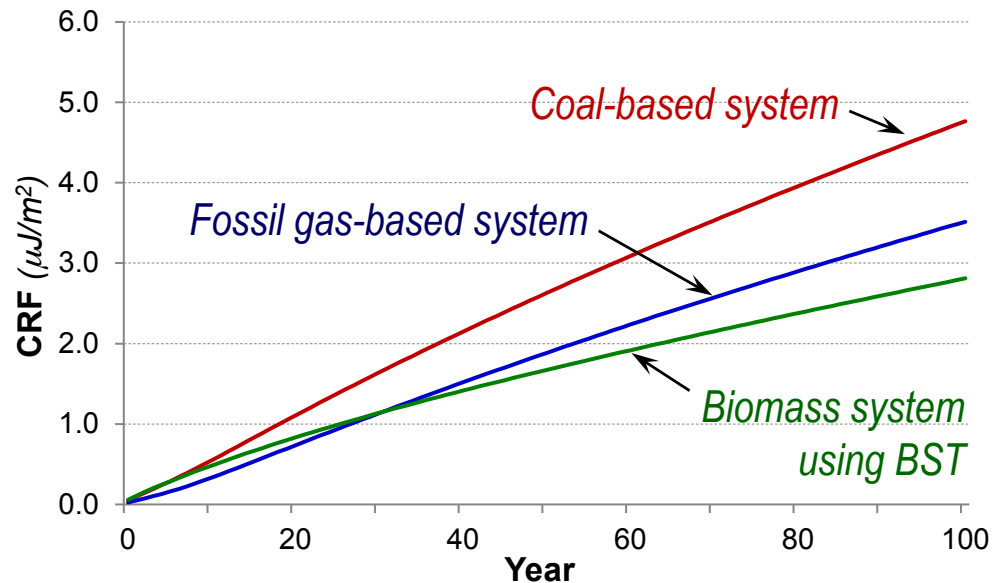


a) *BST as a reference*

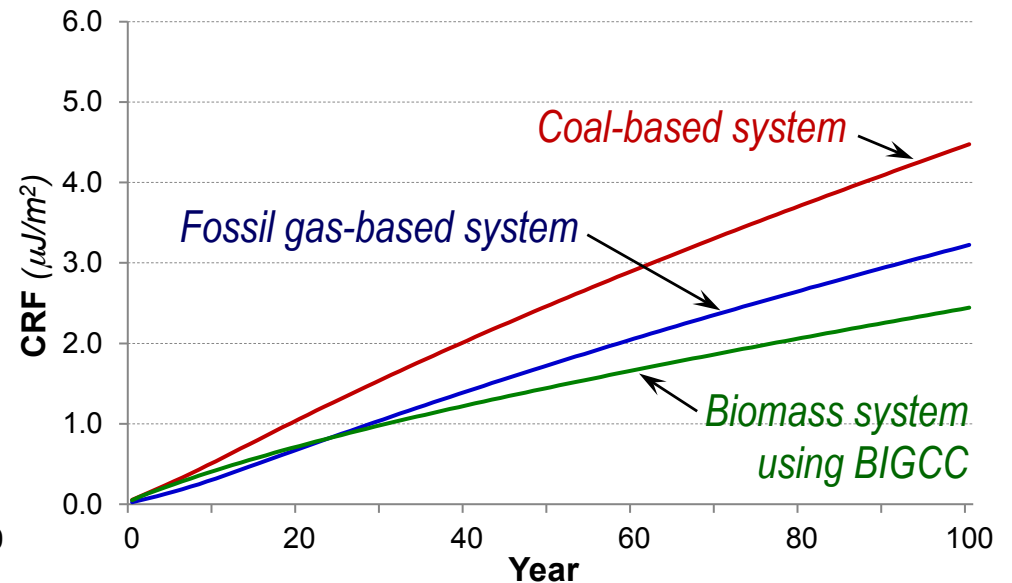


b) *BIGCC as a reference*

CRF of integrated energy systems providing 0.48 kWh electricity, 1.04 kWh heat and 1.80 km transport distance

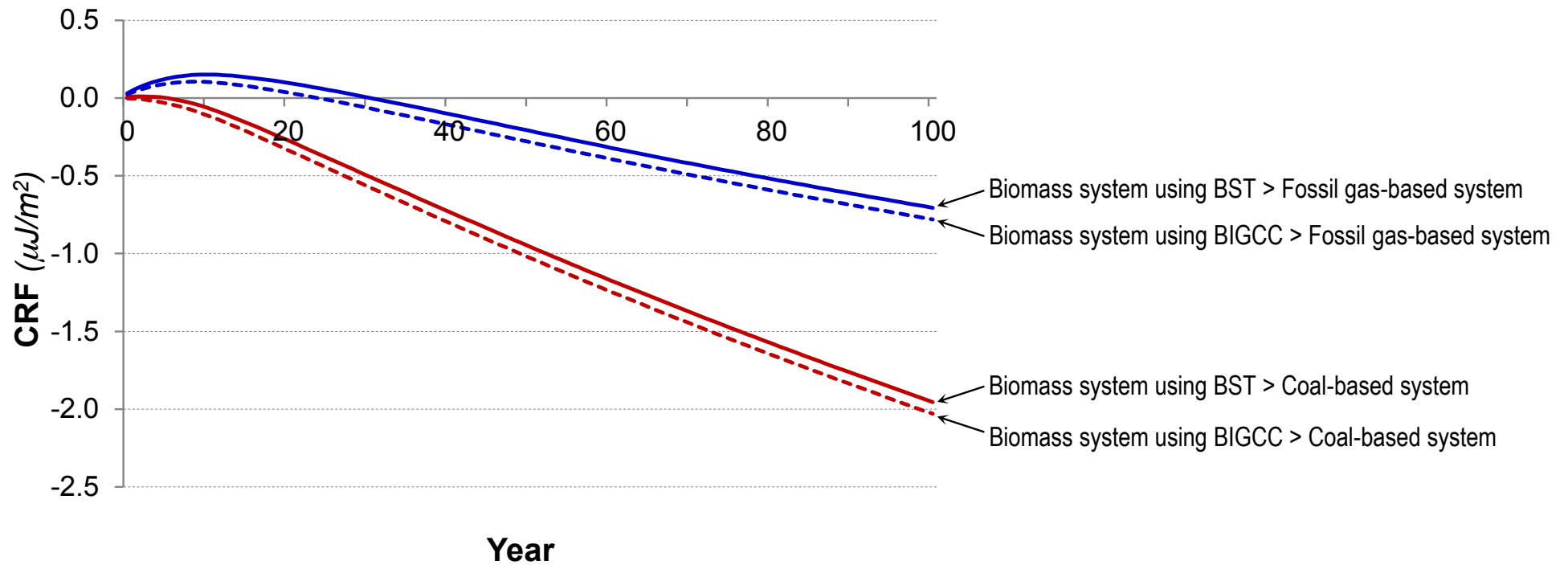


a) BST as a reference



b) BIGCC as a reference

Change in CRF when bioenergy is used instead of fossil fuels in integrated energy systems providing 0.48 kWh electricity, 1.04 kWh heat and 1.80 km transport distance



Conclusions

- Forest slash reduces cumulative CO₂ emission and global warming
- In-efficient use of forest slash could increase the radiative forcing during an initial period and the climate benefits could be rather small
- The use of bioelectricity and electric vehicles instead of biomotor vehicles gives about twice the transport distance per unit of consumed forest slash
- Integrated energy systems that supply electricity, heat and transport distance reduce the primary energy use and increase the climate benefits of woody biomass
- ☞ The use of woody biomass should be considered in the context of the overall energy system

