Biomass with carbon capture and storage (BECCS/Bio-CCS)

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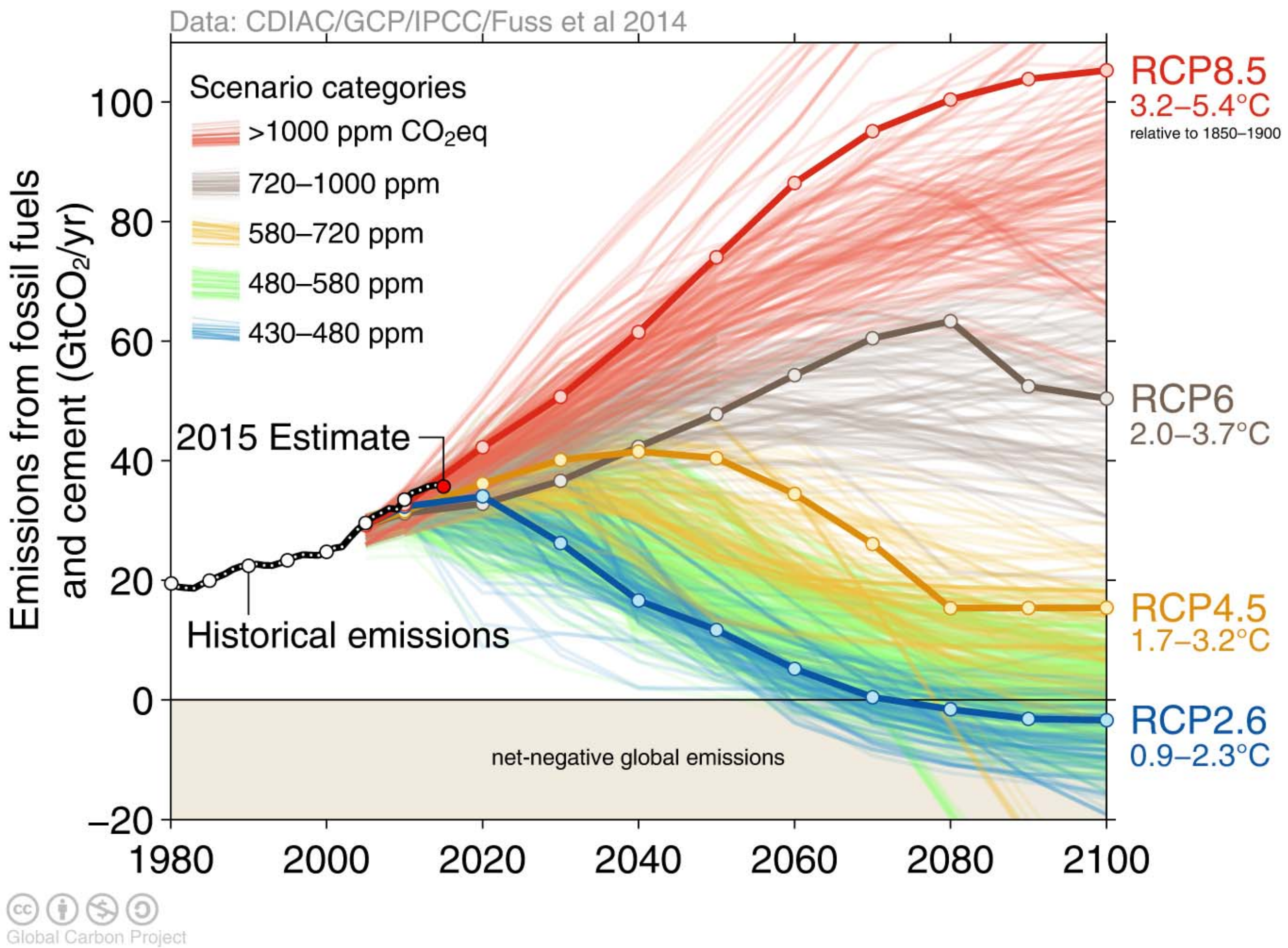
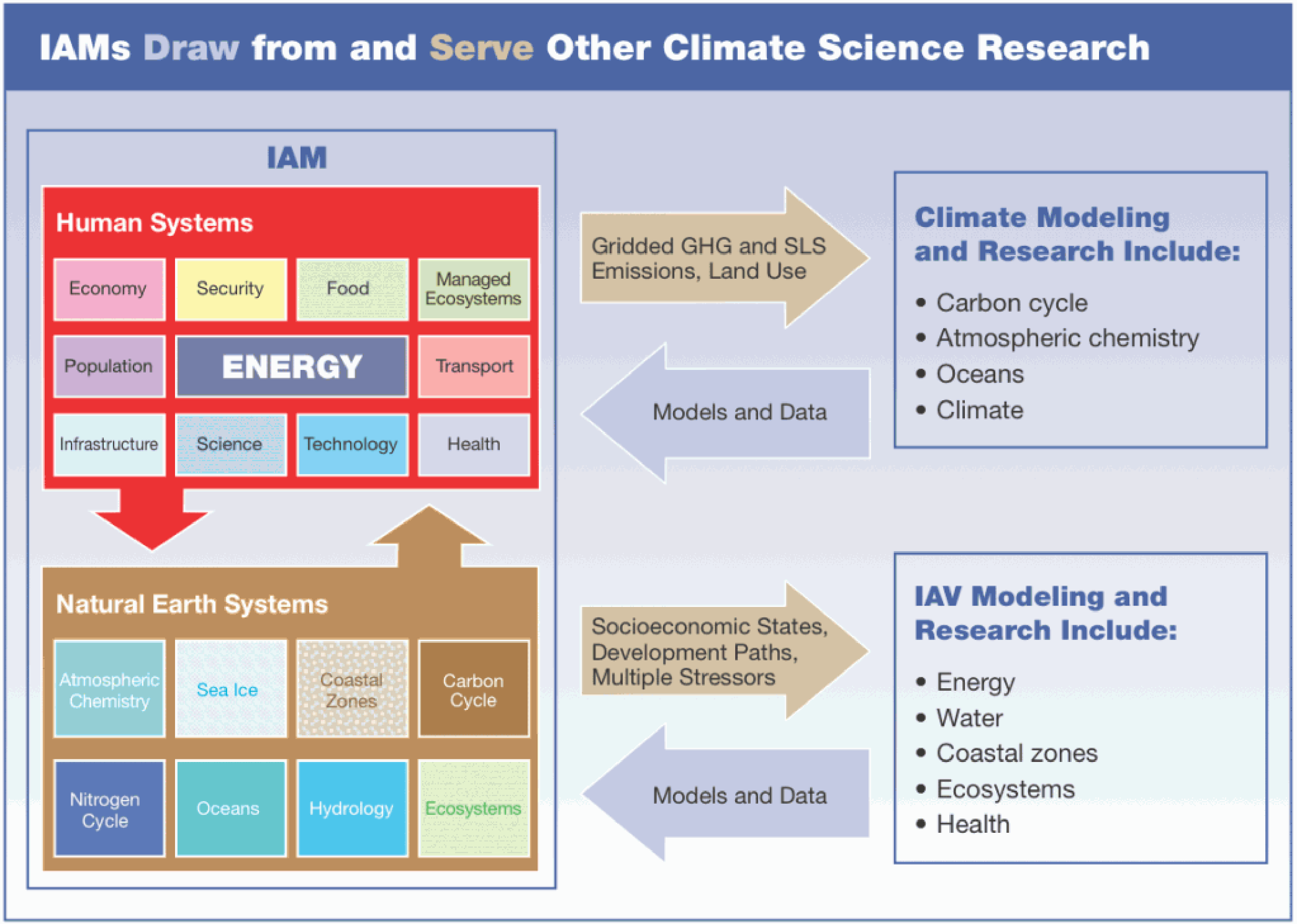
10 March 2017, London

Emission scenarios

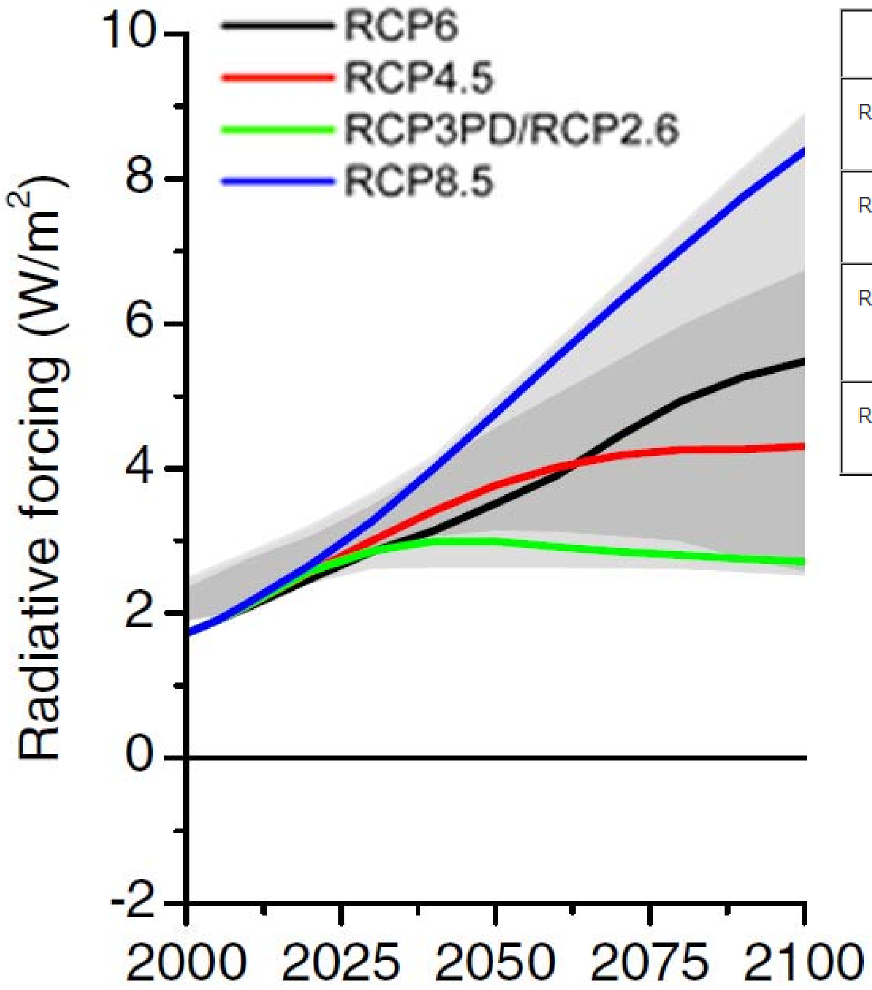


- **Net negative emissions are crucial for achieving a 1.5°C target**

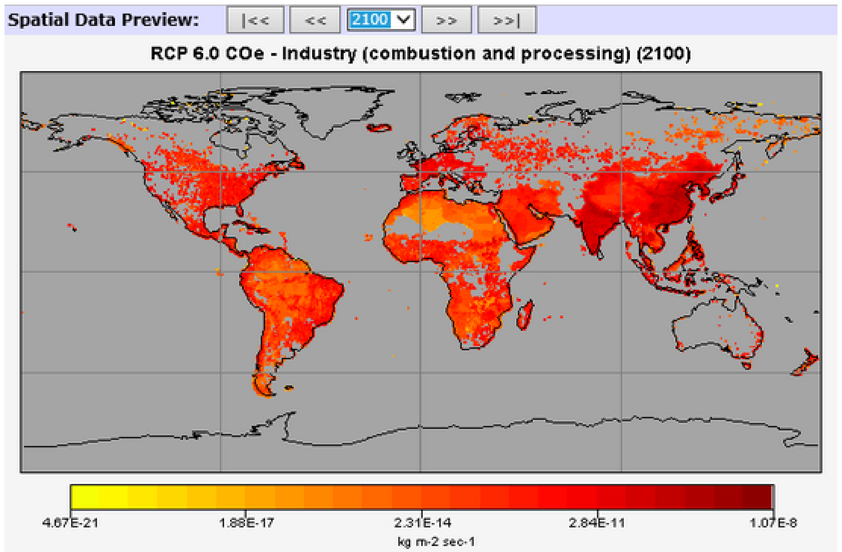
Integrated assessment models (IAMs)



Representative concentration pathways (RCP) scenarios

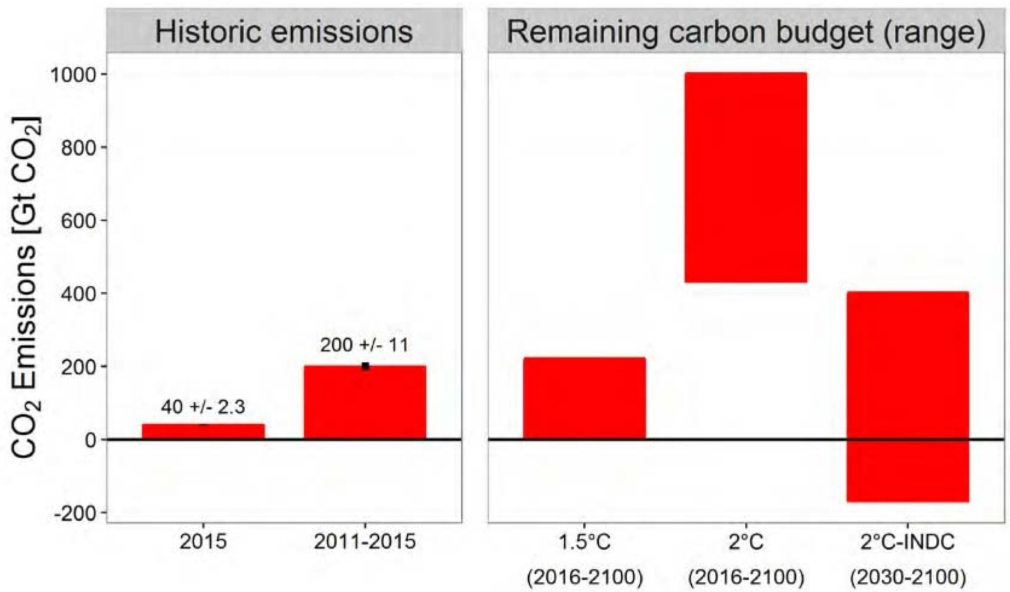


	Description	IA Model	Publication – IA Model
RCP8.5	Rising radiative forcing pathway leading to 8.5 W/m2 in 2100.	MESSAGE	Riahi et al. (2007) Rao & Riahi (2006)
RCP6	Stabilization without overshoot pathway to 6 W/m2 at stabilization after 2100	AIM	Fujino et al. (2006) Hijioka et al. (2008)
RCP4.5	Stabilization without overshoot pathway to 4.5 W/m2 at stabilization after 2100	GCAM (MiniCAM)	Smith and Wigley (2006) Clarke et al. (2007) Wise et al. (2009)
RCP2.6	Peak in radiative forcing at ~ 3 W/m2 before 2100 and decline	IMAGE	van Vuuren et al. (2006; 2007)



IPCC

Carbon budget



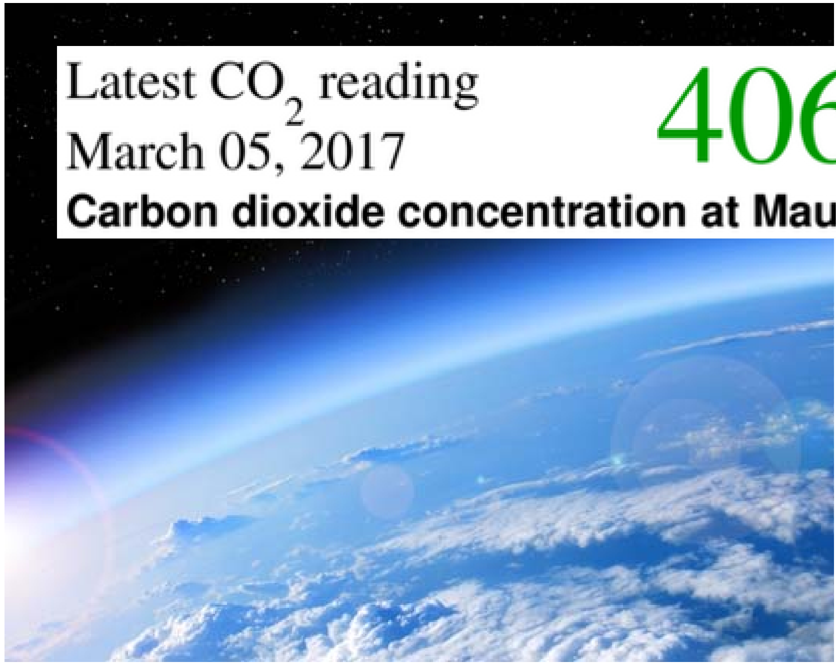
- Carbon budgets usually include fossil sources as well as land use change (LUC)
- Non-CO_2 greenhouse gases (GHGs) can contribute up to 33%
- Carbon budget 1750-2500 is ~3670 $GtCO_2$ → already used up half of this until 2009 → only 1800 $GtCO_2$ left (to have a 50% chance of meeting 2°C) (Allen et al. 2009)

➢ Estimation of carbon budgets contains uncertainties

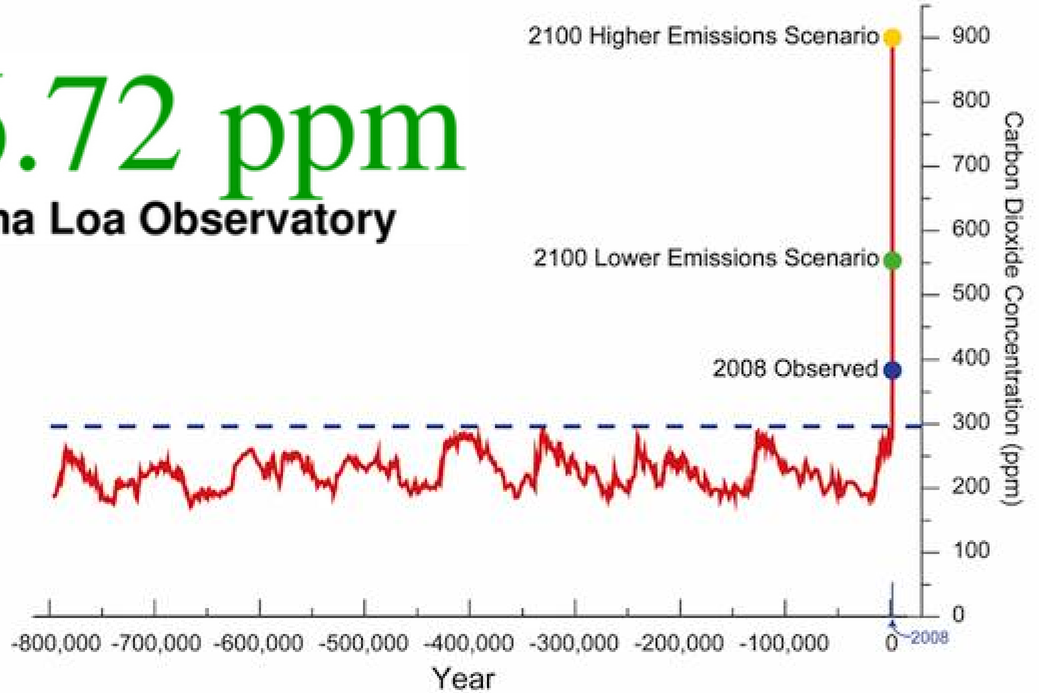
➢ But: current emissions rate 40 $GtCO_2$/yr → quick erosion of carbon budget

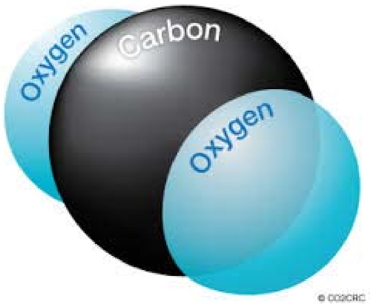
Fuss 2016 (Figure by Jan Minx 2016 with data from Le Quere et al. 2015, Rogelj et al. 2013/2015, Luderer et al. 2013)

Atmospheric CO_2 reduction requirements



Latest CO_2 reading
March 05, 2017 **406.72 ppm**
Carbon dioxide concentration at Mauna Loa Observatory



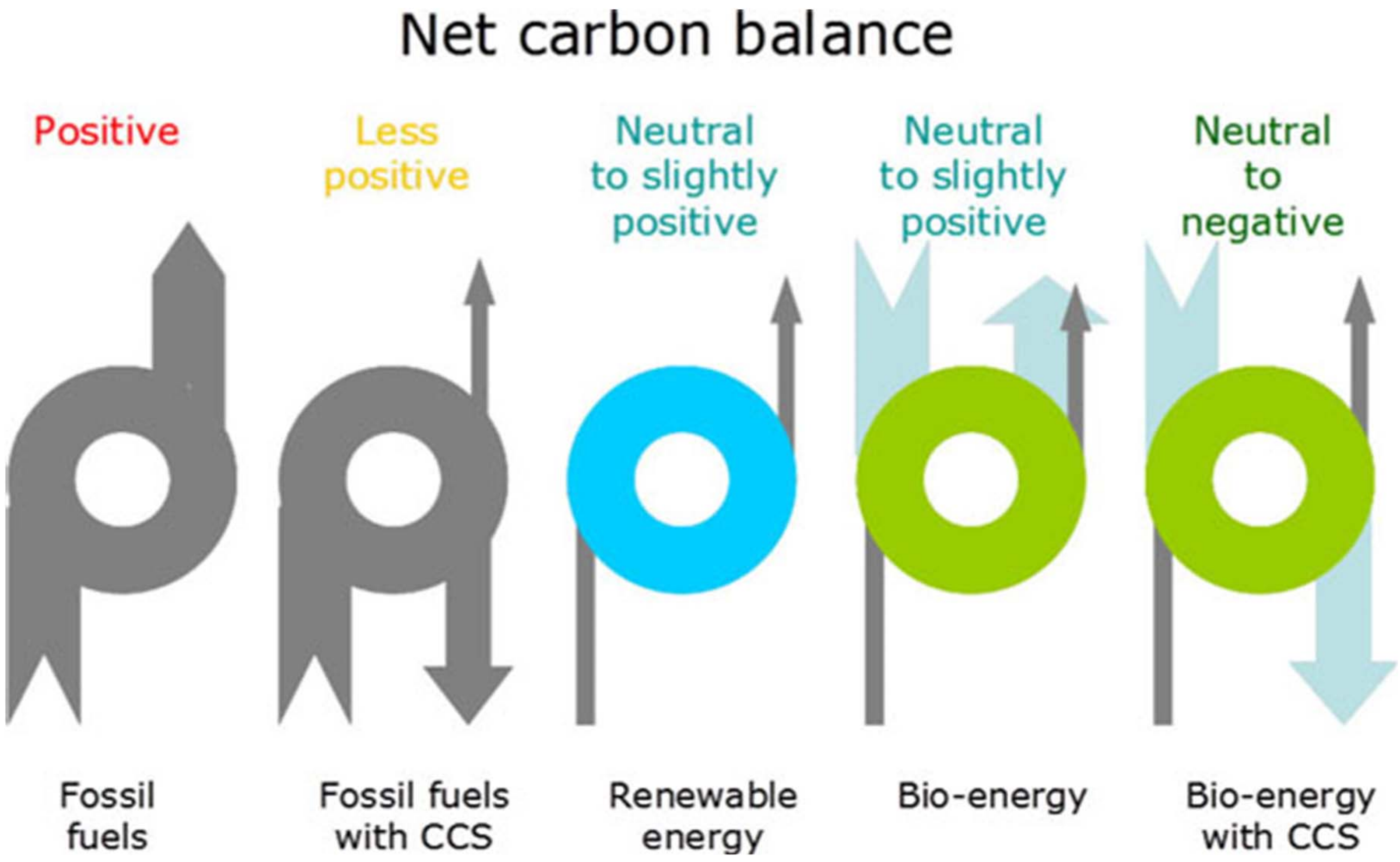


Reducing atmospheric CO_2 concentration by ½ to 1 ppm in one year

→ Need to take out 8-16 $GtCO_2$

MIT, NOAA, MLO, Azar 2010

C balance of energy systems

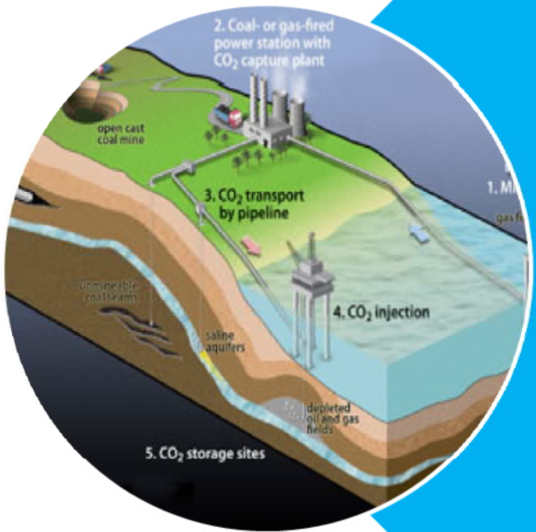


IEAGHG/Ecofys 2011, adapted from ecofriendlymag.com; grey denotes carbon of fossil origin, blue denotes carbon of biogenic origin)

C balance of energy systems

- Past/current energy systems based on the far left (fossil fuels)
- Now efforts underway transitioning to the mid three technologies (Fossil-CCS, RE, bioenergy)
- Should we stop at Fossil-CCS/RE/bioenergy?
- ➢ Need help from the far right (NETs) to make up for "damage done" in the past

Carbon capture and storage (CCS)



NERC

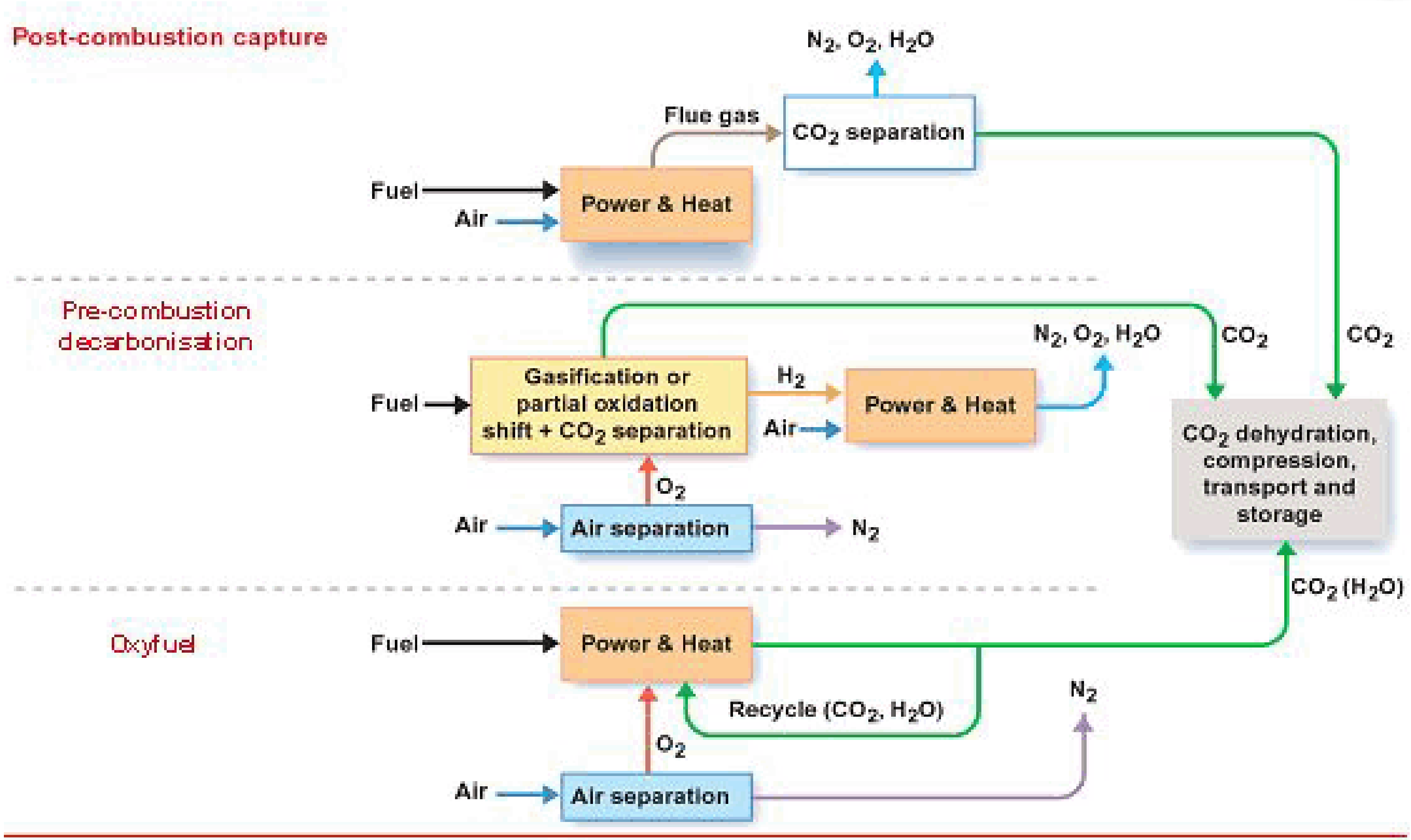
CCS (carbon capture and storage)

- **Process of capturing, transporting and permanently storing CO_2 emission from anthropogenic large-point sources**
- **Capture**
  - Pre-combustion, post-combustion, oxyfuel-combustion
- **Transport**
  - Pipeline, ship
- **Storage**
  - Enhanced oil recovery (EOR), depleted oil/gas fields, deep saline aquifers

➢ **All parts of CCS chain technically feasible, issues remain with costs and public perception**

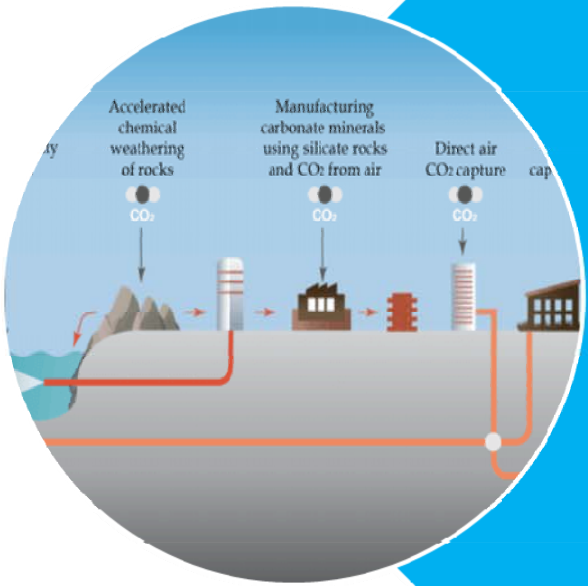
➢ **15 large-scale projects with 29 $MtCO_2$/yr in operation, 7 with additional 11 $MtCO_2$/yr under construction (GCCSI 2016)**

Carbon capture and storage (CCS)



CO_2 capture processes (Linde AG Linde Engineering Division)

Negative emissions technologies (NETs)

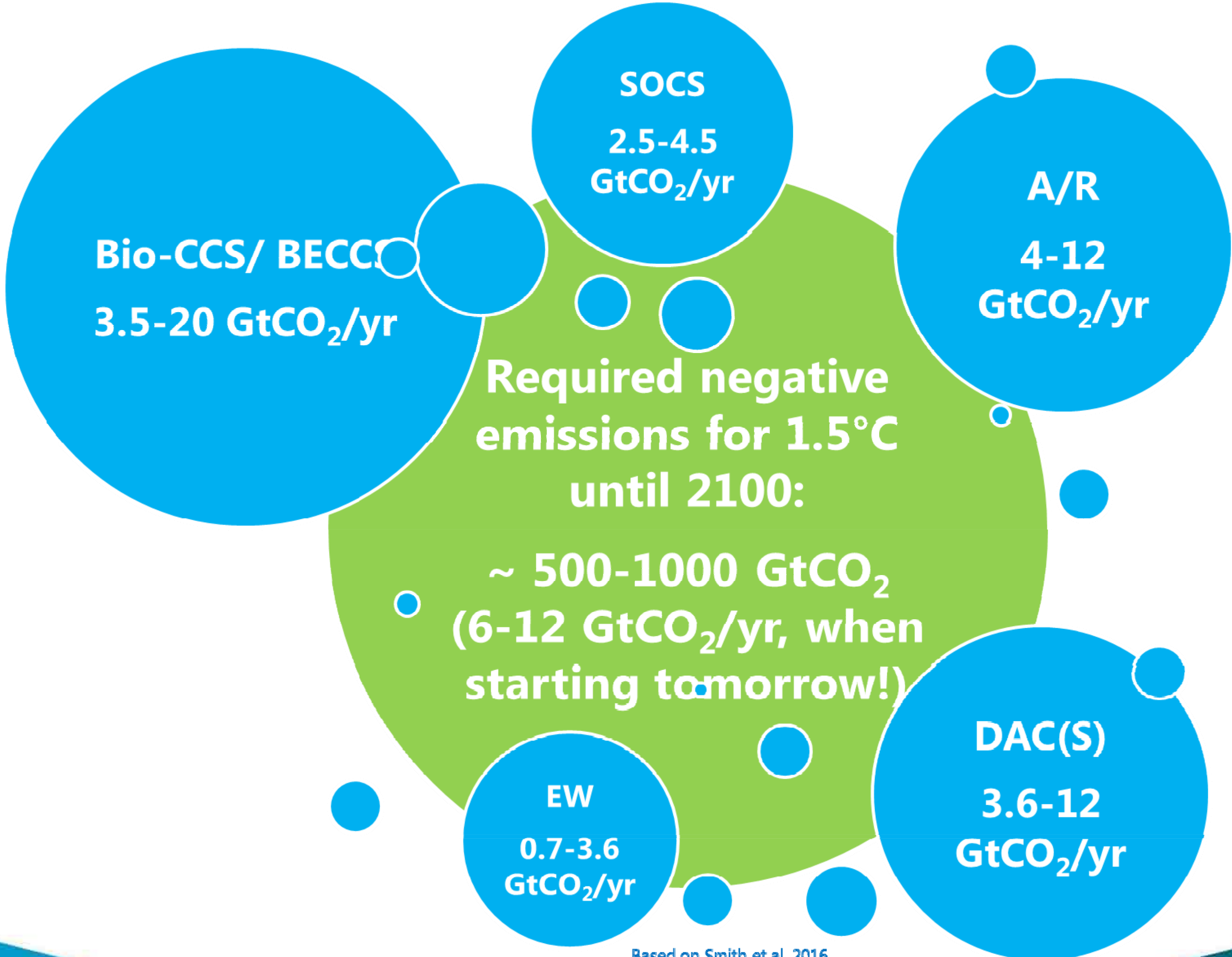


Virgin Earth Challenge

NETs (negative emission technologies)

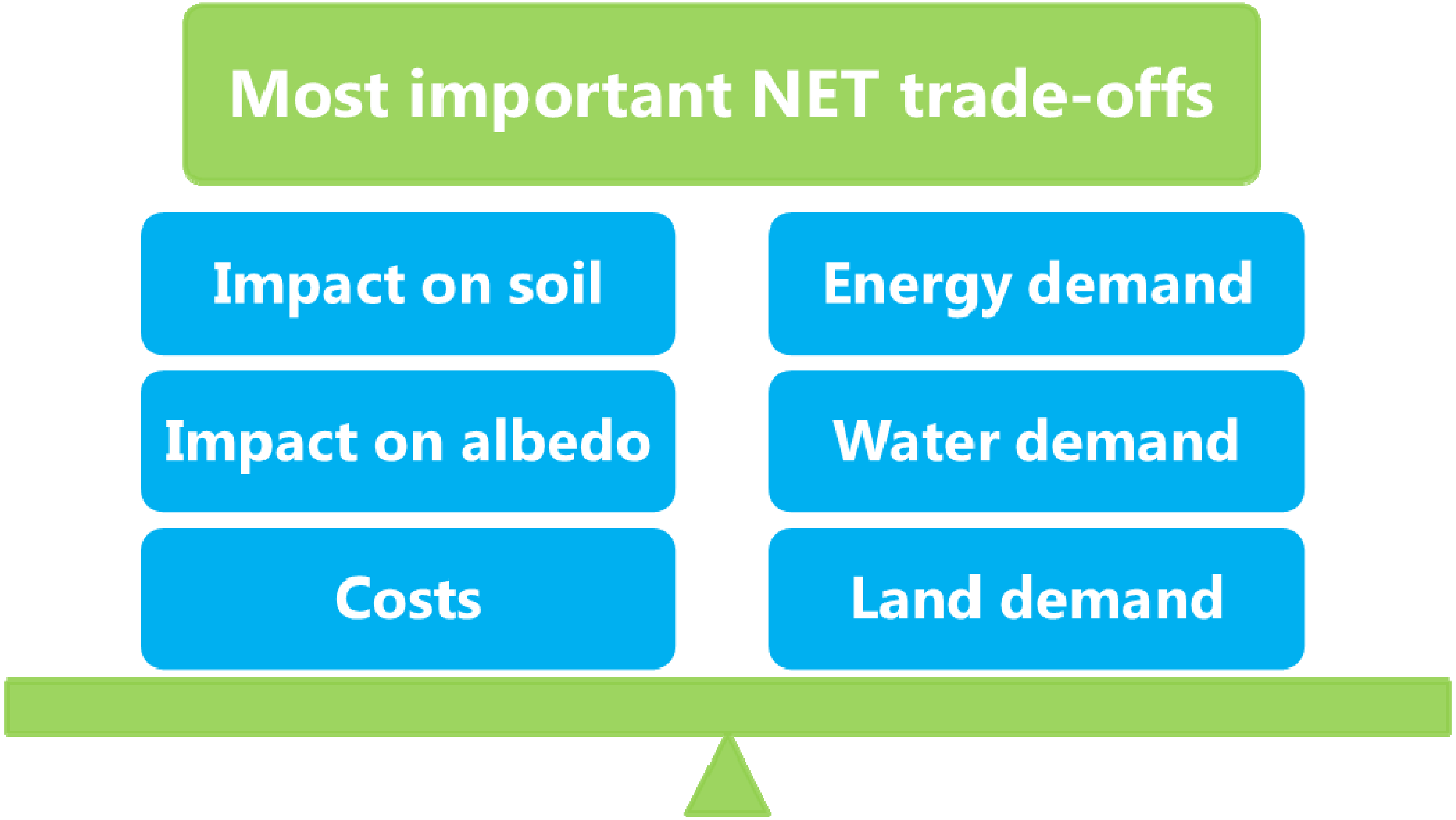
- **Bio-CCS/BECCS (bioenergy with CCS)** – using biomass that has previously taken up CO_2 during growth to produce power/heat/fuels, then capturing and storing the emitted CO_2
- **A/R (afforestation/reforestation)** – planting trees where previously (a) there were none or (b) they have been cut down
- **DAC(S) (direct air CCS)** – capturing CO_2 directly from air
- **EW/MC (enhanced weathering/mineral carbonation)** – spreading pulverised rock on land/water to take up CO_2 and form bicarbonate
- **SOCS (soil organic carbon sequestration)** – storing CO_2 in soil through advanced farming methods, restoration and land creation
- **Biochar** – adding burnt/torrefied biomass to soil for long term storage
- **Ocean fertilisation** – adding Fe or N to accelerate CO_2 uptake by microorganisms for photosynthesis
- **Cloud/ocean treatment** – (a) using alkalis to wash CO_2 out of the atmosphere, (b) using lime to absorb CO_2 from the oceans

CO_2 reduction potential of negative emissions technologies (NETs)

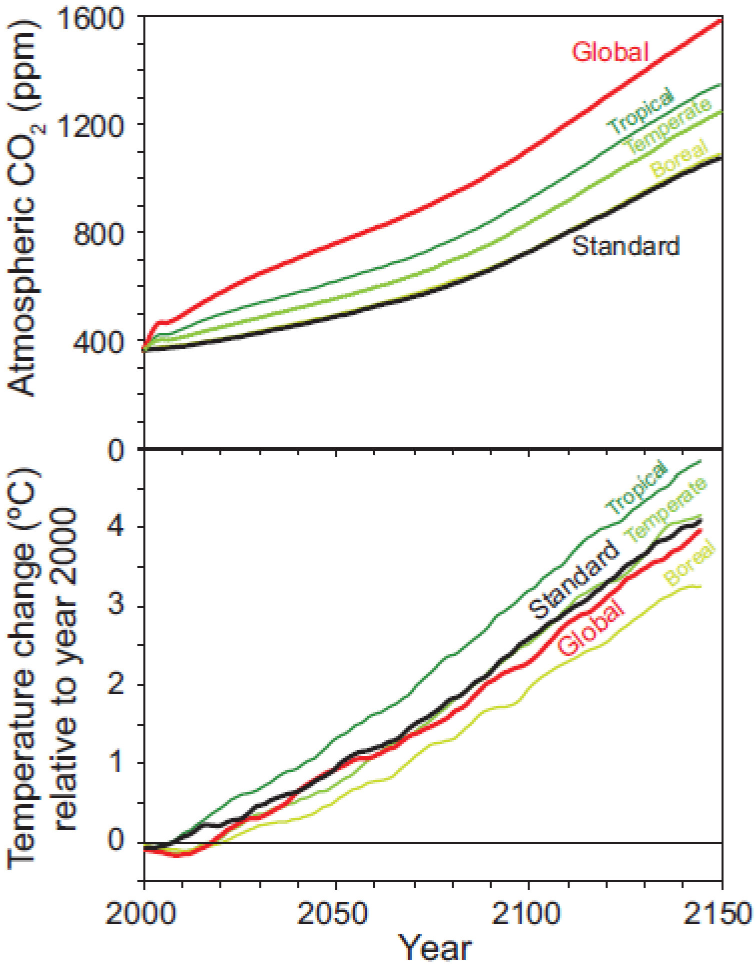


Based on Smith et al. 2016

NET trade-offs



NET trade-offs: albedo



"Latitude-specific deforestation experiments indicate that afforestation projects in the tropics would be clearly beneficial in mitigating global-scale warming, but would be counterproductive if implemented at high latitudes and would offer only marginal benefits in temperate regions. Although these results question the efficacy of mid- and high-latitude afforestation projects for climate mitigation, forests remain environmentally valuable resources for many reasons unrelated to climate."

Bala 2007

NET trade-offs: albedo

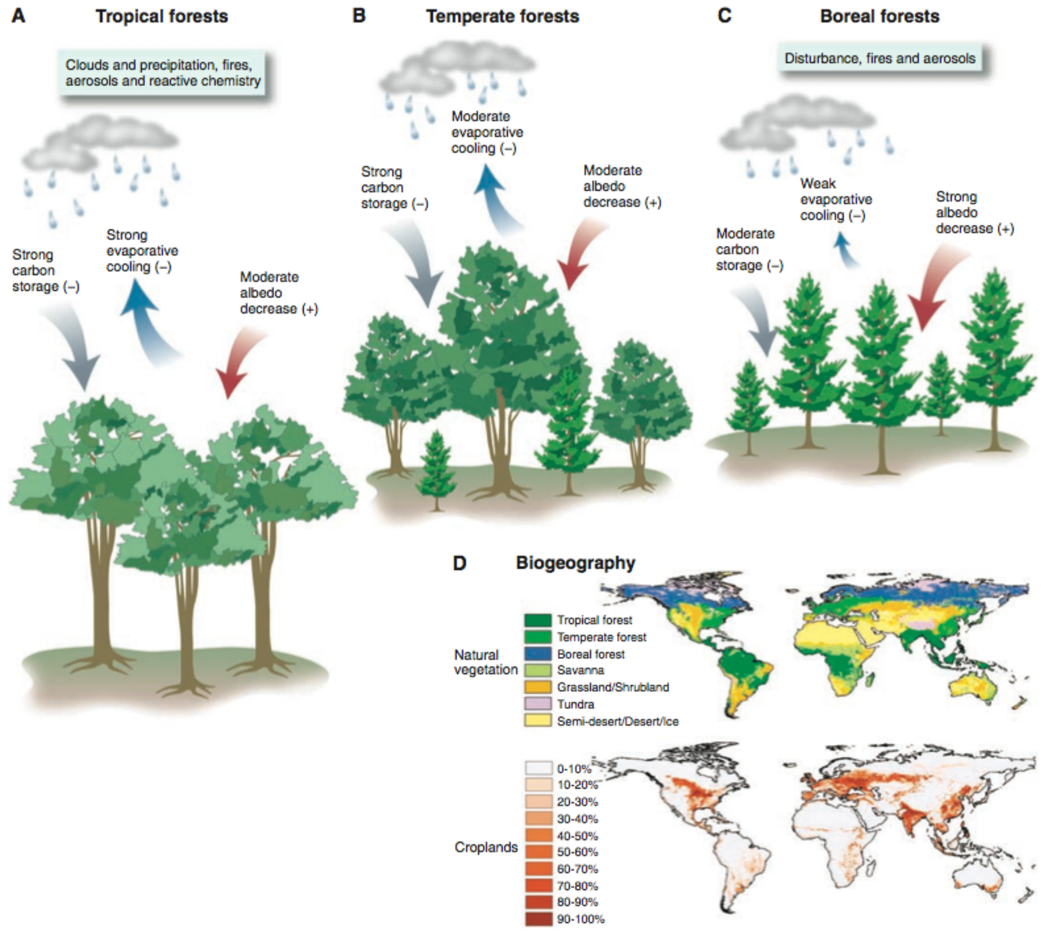
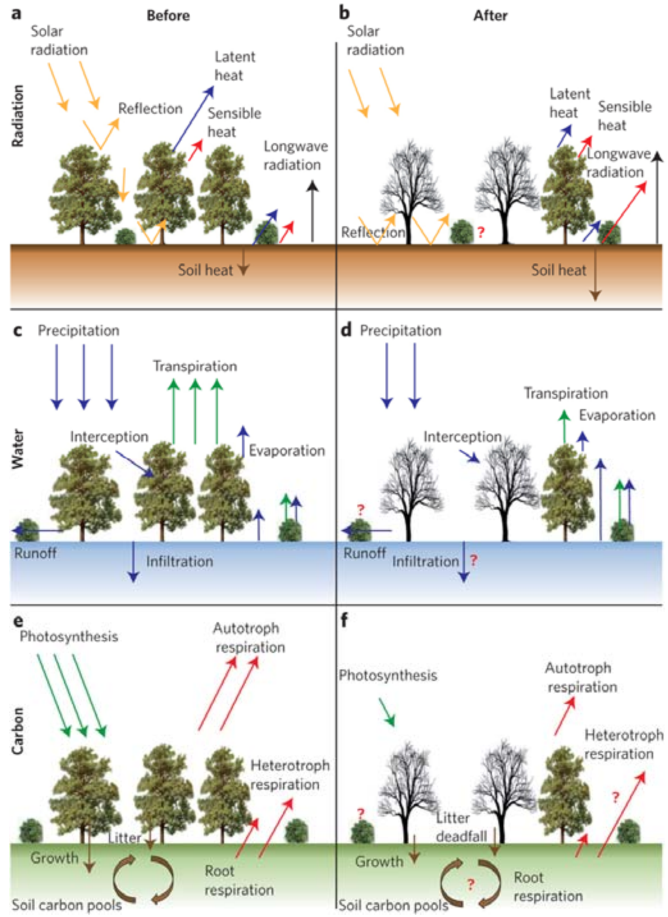


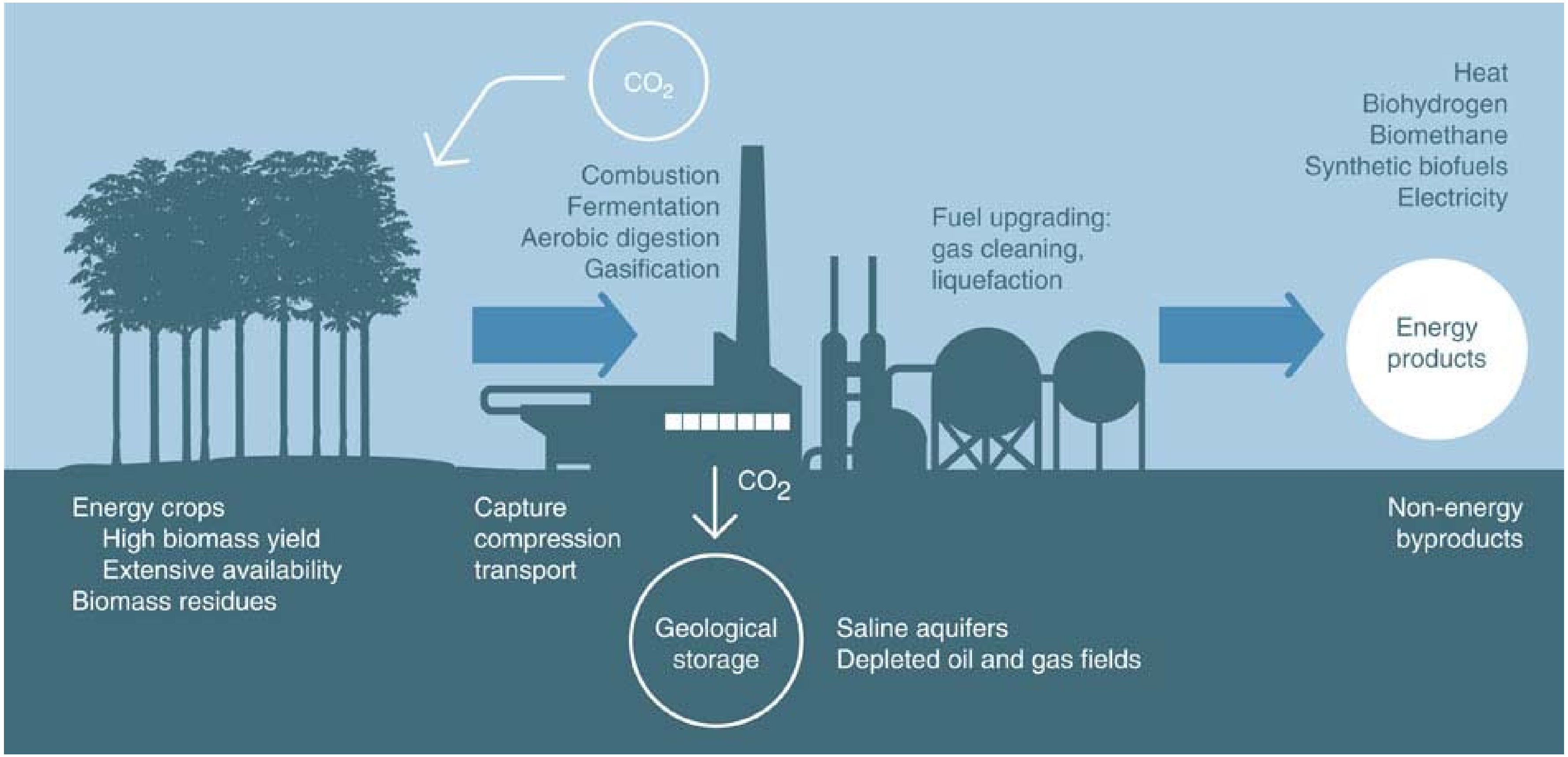
Fig. 3. Climate services in (A) tropical, (B) temperate, and (C) boreal forests. Text boxes indicate key processes with uncertain climate services. (D) Natural vegetation biogeography in the absence of human uses of land and cropland (percent cover) during the 1990s. Vegetation maps are from (51).

Bonan 2010



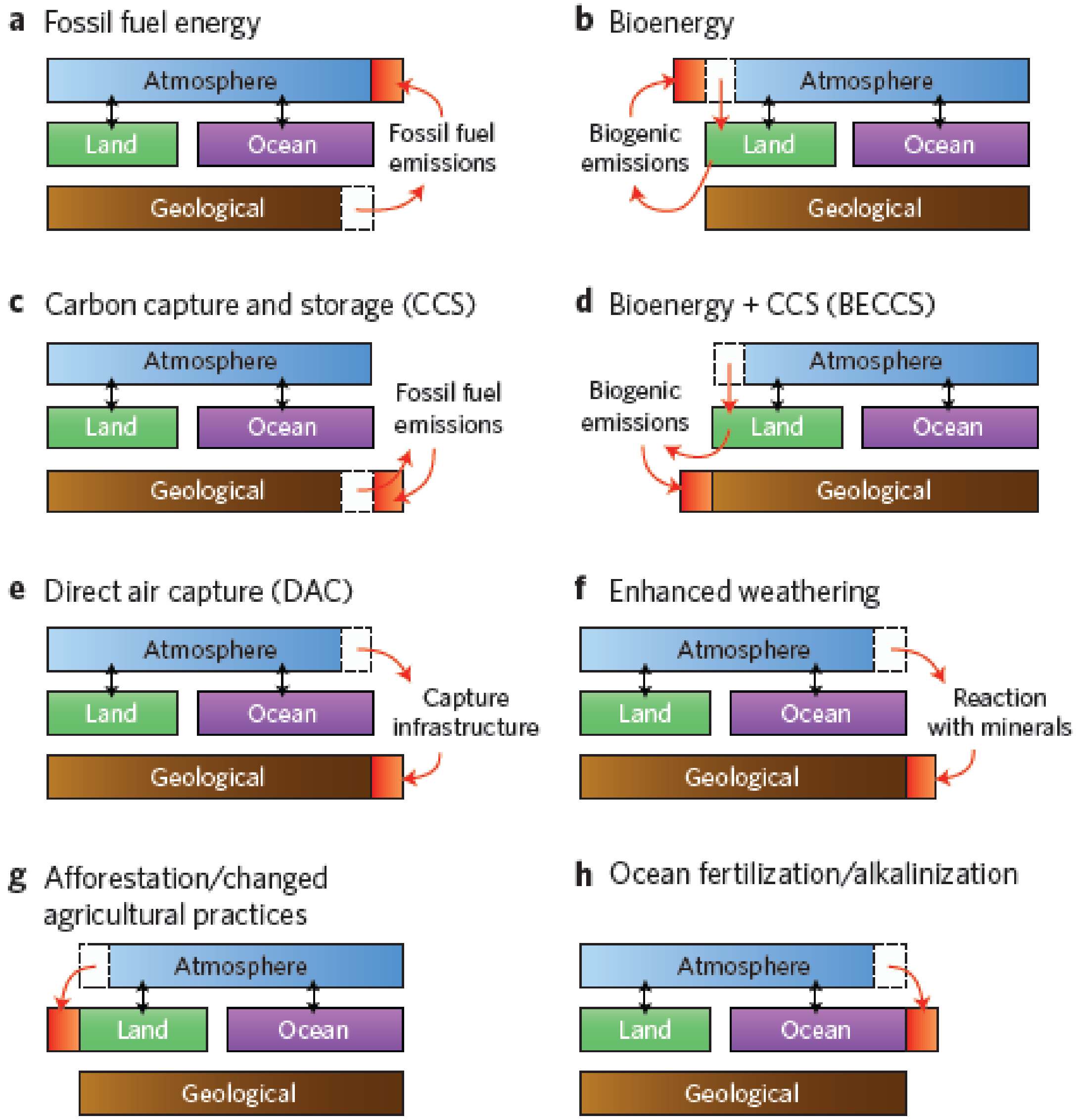
Anderegg 2013

Concept of BECCS



Canadell and Schulze. 2014, courtesy of Nature

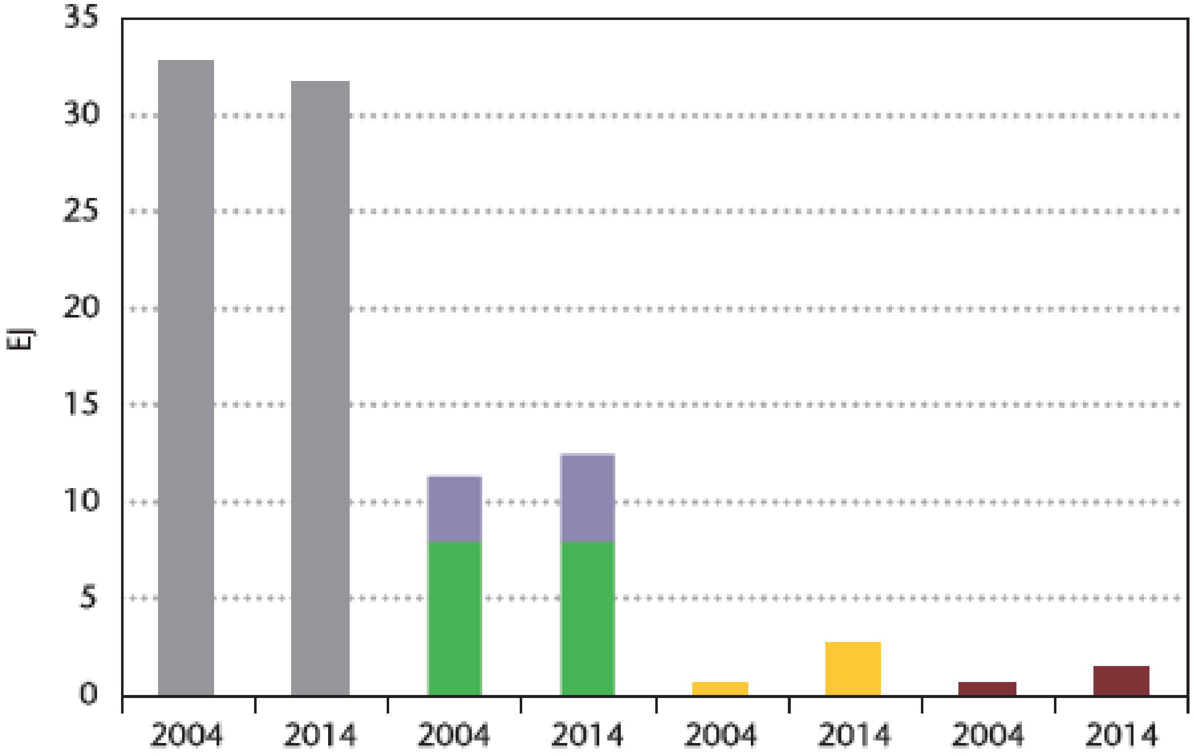
Concept of different NETs



Smith 2015

Global bioenergy use

Biomass produced in a sustainable way, the so-called “**modern biomass”**, excludes traditional uses of biomass as fuelwood and includes electricity generation and heat production, as well as transportation fuels, from agricultural and forest residues and solid waste. On the other hand, **“traditional biomass”** is produced in an unsustainable way and it is used as a non-commercial source, usually with very low efficiencies for cooking in many countries.



Notes: this figure differentiates total final consumption of heat from traditional use of biomass and from modern bioenergy; the latter is broken down into buildings and industry; EJ = exajoule.

Source: IEA analysis based on 2014 data (IEA [2016e], *World Energy Outlook 2016*).

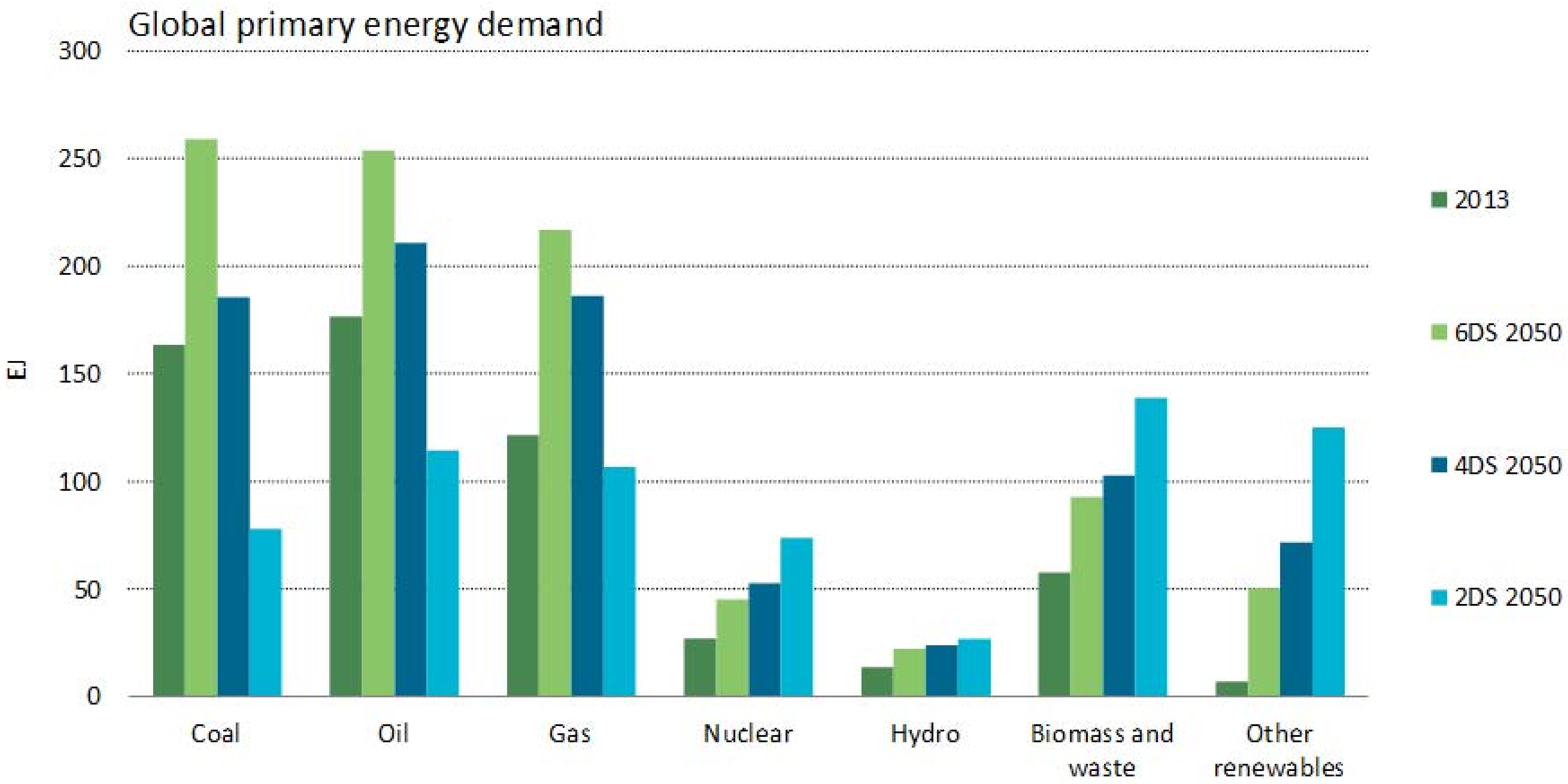
IEA scenarios

The **2°C Scenario (2DS)** is the main focus of Energy Technology Perspectives (ETP). The 2DS lays out an energy system deployment pathway and an emissions trajectory consistent with at least a 50% chance of limiting the average global temperature increase to 2°C. The 2DS limits the total remaining cumulative energy-related CO_2 emissions between 2015 and 2100 to 1,000 $GtCO_2$. The 2DS reduces CO_2 emissions (including emissions from fuel combustion and process and feedstock emissions in industry) by almost 60% by 2050 (compared with 2013), with carbon emissions being projected to decline after 2050 until carbon neutrality is reached.

The **4°C Scenario (4DS)** takes into account recent pledges by countries to limit emissions and improve energy efficiency, which help limit the long-term temperature increase to 4°C. In many respects the 4DS is already an ambitious scenario, requiring significant changes in policy and technologies. Moreover, capping the long-term temperature increase at 4°C requires significant additional cuts in emissions in the period after 2050.

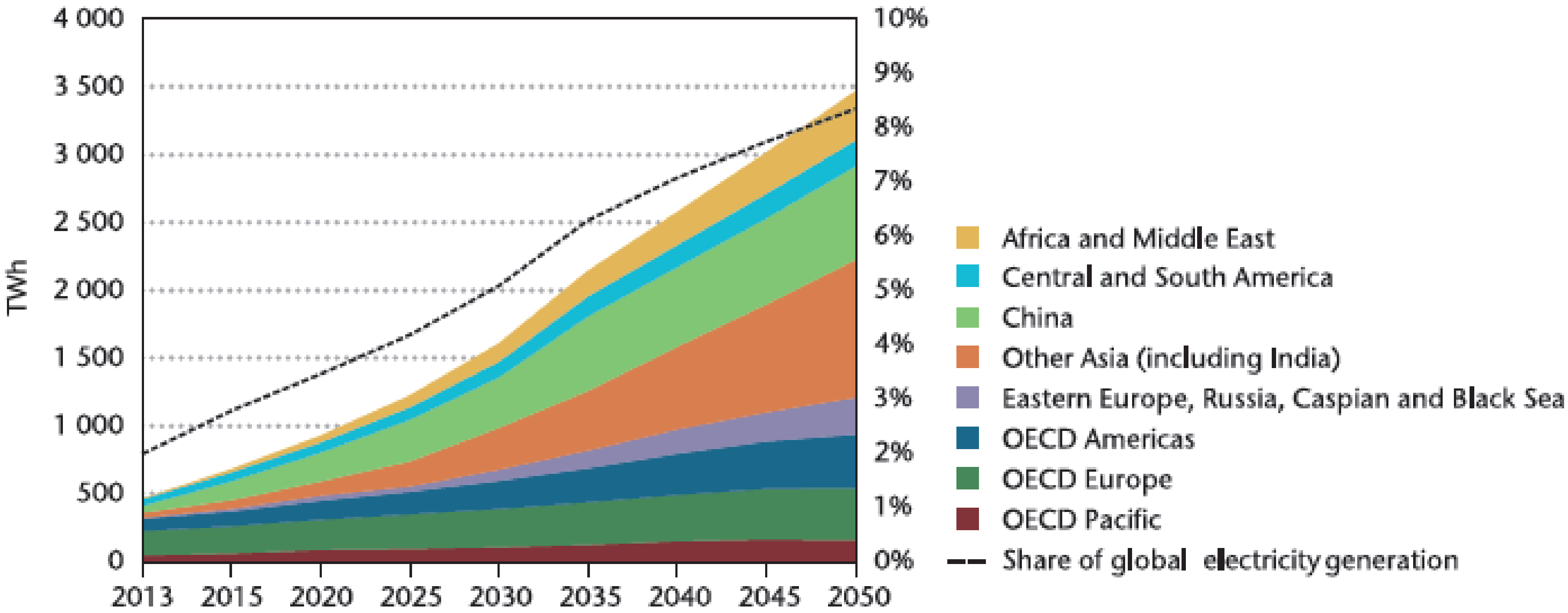
The **6°C Scenario (6DS)** is largely an extension of current trends. Primary energy demand and CO_2 emissions would grow by about 60% from 2013 to 2050, with about 1,700 $GtCO_2$ of cumulative emissions. In the absence of efforts to stabilise the atmospheric concentration of GHGs, the average global temperature rise above pre-industrial levels is projected to reach almost 5.5°C in the long term and almost 4°C by the end of this century.

Projected energy demand



Share of fossil fuels in primary energy is in the 2DS with 45% almost halved by 2050 compared to today (81%), biomass becomes the largest energy source in 2050 in the 2DS.

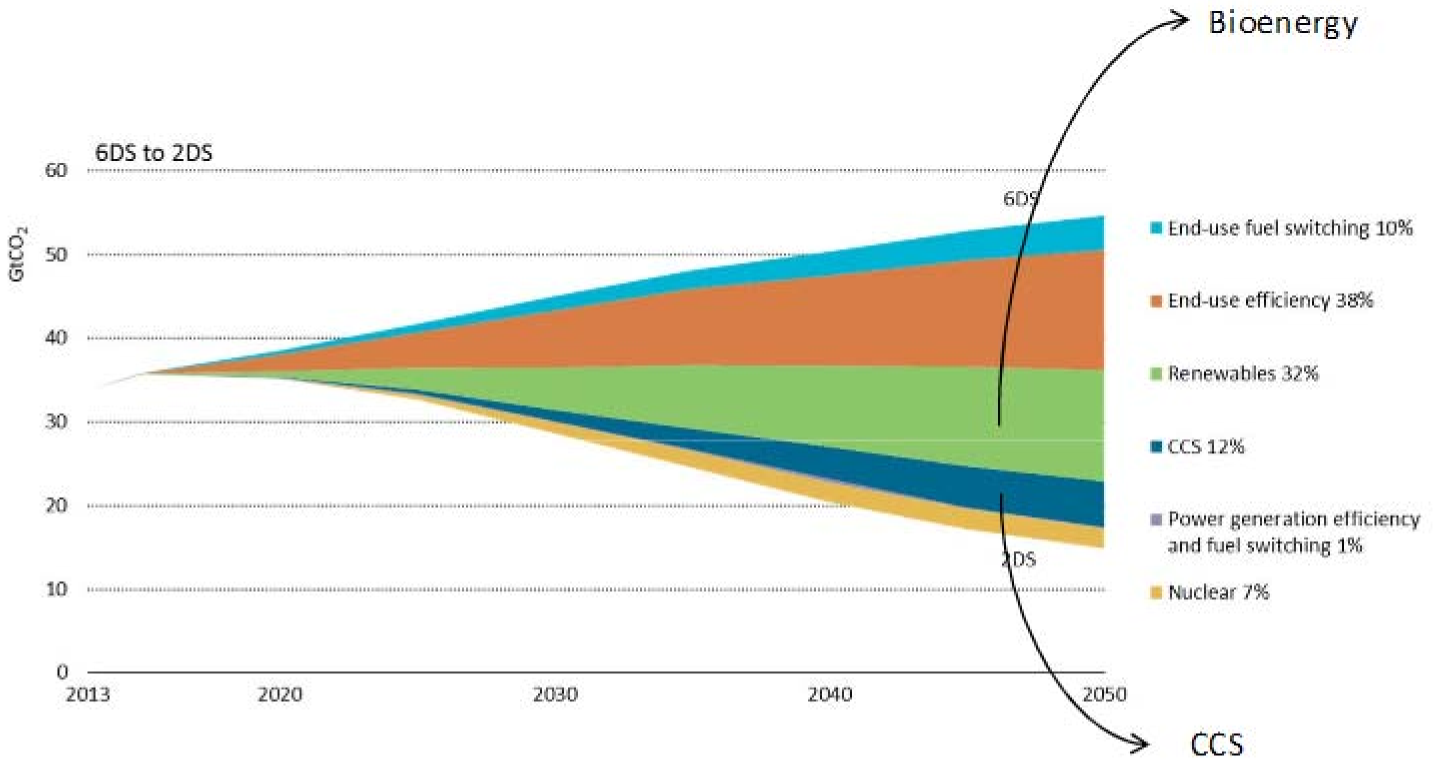
Projected bioelectricity



Source: IEA analysis based on data from the *Energy Technology Perspectives* (ETP) 2°C Scenario (2DS) (IEA, 2016c).

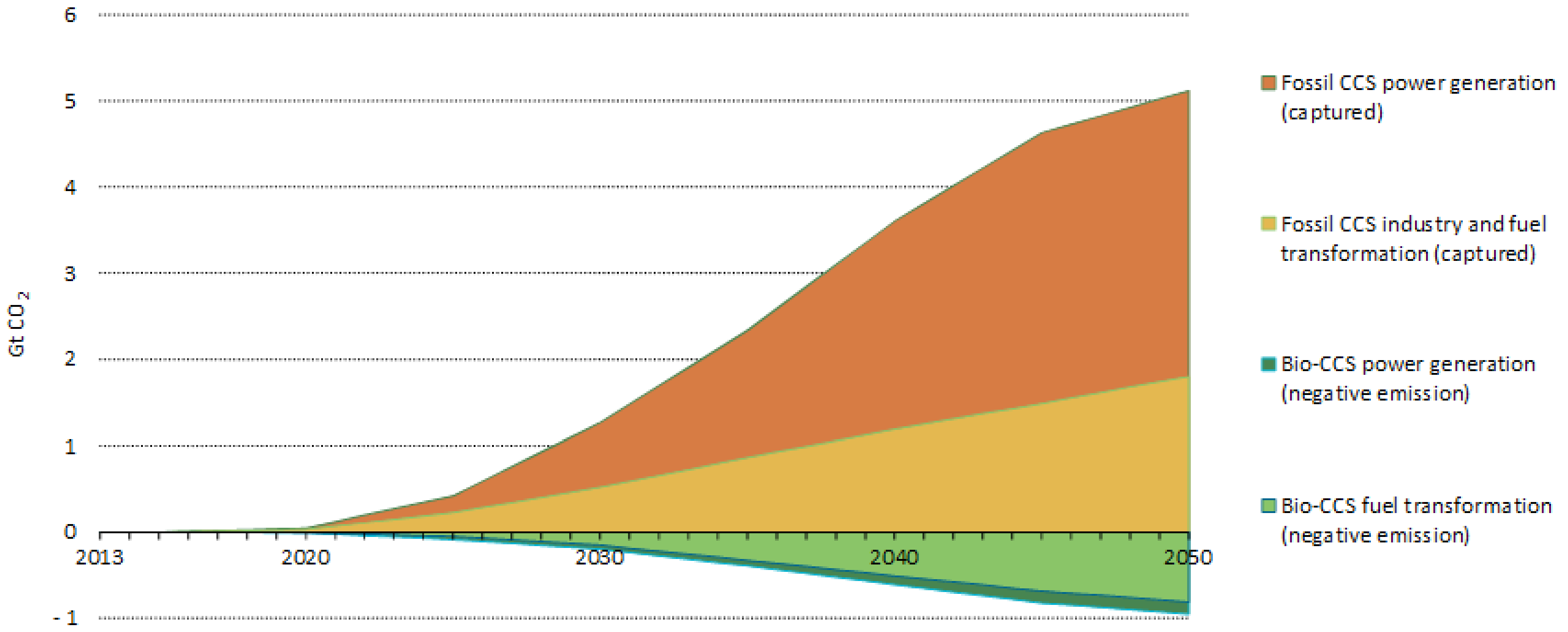
Note: this example is particularly interesting in that it sets a global target over 8% of electricity generation from bioenergy by 2050 and it provides a breakdown for key world regions, in line with IEA models that integrate the technical and economic characteristics of existing technologies and aspects specific to each market. The underlying approach can be used at national or regional level to determine the cost-effective mix of biomass resource and technologies in the bioenergy roadmap.

BECCS and the IEA 2DS



- Bioenergy provides around 10% and CCS 12% of the cumulative reductions
- Bio-CCS accounts for 2% of the cumulative reductions.

BECCS and the IEA 2DS



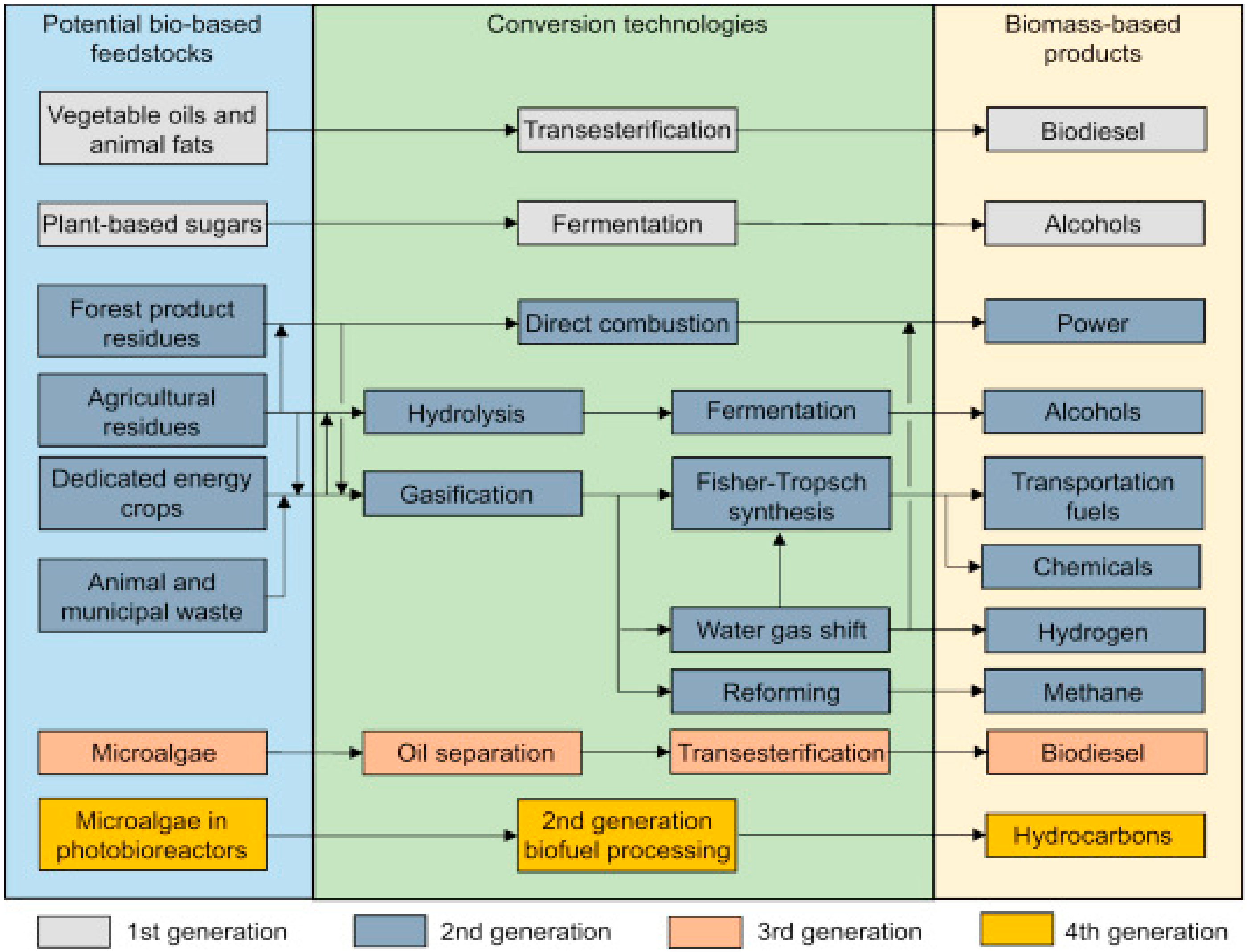
- Almost **1 Gt of CO_2** captured in 2050 is linked to biomass with CCS, corresponding to 16% of total CO_2 captured globally

Biomass feedstocks

1. Dedicated energy crops
    a. Conventional annual crops
        i. Oil crops *(palm, canola, sunflower, etc.)*
        ii. Sugar/starch crops *(sugar cane, sugar beet, corn, all types of cereals, etc.)*
    b. Perennial crops and energy grasses *(Miscanthus, switchgrass, etc.)*
2. Forestry and forestry residues
    a. Short rotation forestry (SRF) *(alder, ash, Southern Beech, birch, eucalyptus, paper mulberry, Australian Blackwood, sycamore etc.)*
    b. Short rotation coppice (SRC) *(willow, poplar, etc.)*
    c. Forestry residues
        i. Primary *(wood chips from branches/tips/poor quality stemwood etc.)*
        ii. Secondary *(saw mill by-products: chips sawdust, bark etc.)*
        iii. Tertiary *(material from municipal tree management, waste wood etc.)*
3. Other residues and wastes
    a. Agricultural crop residues *(straw from cereals/oil seeds, bagasse etc.)*
    b. Municipal organic waste *(paper/cardboard, food, garden, textiles etc.)*
    c. Sewage sludge
    d. Animal manure
    e. Land fill gas
4. Marine biomass *(microalgae/phytoplankton and macroalgae/seaweed)*

IEA & FAO 2017, Slade 2011

Biomass tree



Sukumara 2014

BECCS – 10 years ago

IPCC‘s SRCCS 2005

- Merely described BECCS as „CCS in which feedstock is biomass“
- Acknowledged negative emissions potential if sustainable harvesting
- Cost estimate 22-110 $/tCO_2$
- Conclusion: BECCS at small scale and high costs

IPCC‘s 4th Assessment Report (AR4) 2007

- Information spread out and not very coherent
- Global bioenergy potential 100-300 EJ/yr (total range 50-1000)
- No numbers for BECCS potential and costs

BECCS – 10 years ago

IEA Bioenergy

IEA Bioenergy (set up in 1978)

- Biomass gasification
- Liquid biofuels
- Biomass co-firing
- Biogas production and utilisation
- Availability and sustainability of biomass feedstocks

Only small number of small-scale BECCS projects starting to come online:

- Russel EOR project: first negative emissions delivery at small scale (7.7 ktCO_2) [completed 2005]
- Arkalon: CO_2 from ethanol plant for EOR, 0.1-0.3 MtCO_2/yr [operating since 2009]

BECCS – now

EBTP/ZEP BECCS Joint Task Force 2011

IPCC's Special Report on Renewable Energy (SRREN) 2011

- First time bioenergy got dedicated chapter

Lots of organisations working on bioenergy (e.g. in UK: SUPERGEN, ETI, E4Tech)

IEAGHG reports on BECCS potential and accounting

IPCC's 5th Assessment Report (AR5) 2014

- Relies on SRREN for biomass related discussion
- Highlights BECCS as one of the few technologies to remove historic CO_2 emissions from the atmosphere
- Considers competing land use and impacts of sourcing biomass (dedicated appendix)
- Update: „agreement" on 100 EJ/yr bioenergy potential
- Global BECCS potential: 10 $GtCO_2$/yr (total range 0-20)
- No info on levelised cost of electricity (LCOEL of BECCS, citing other reviews' ballpark range of 60-250 \$/tCO_2
- In general: downward revision of potentials and upward revision of costs
- Overall impact of LUC remains unclear
- Biomass options with low life-cycle emissions already exist (e.g. miscanthus, SRCs, SRF, sugarcane, residues)

BECCS – brief status summary

Many studies conclude: BECCS, incl. its CCS components, technically feasible as of today (TRL 3-7) [except microalgal biomass]

Perceived „double benefit“: heat/power + negative emissions

5 operating BECCS projects 0.1-1 $MtCO_2$/yr (all EtOH, 3 for EOR, 4 in US, 1 rather BECCU), several more underway

GHG accounting: only 2006 IPCC GLs, CDM/JI, Ca LCFS and EU RED/FQD cover BECCS

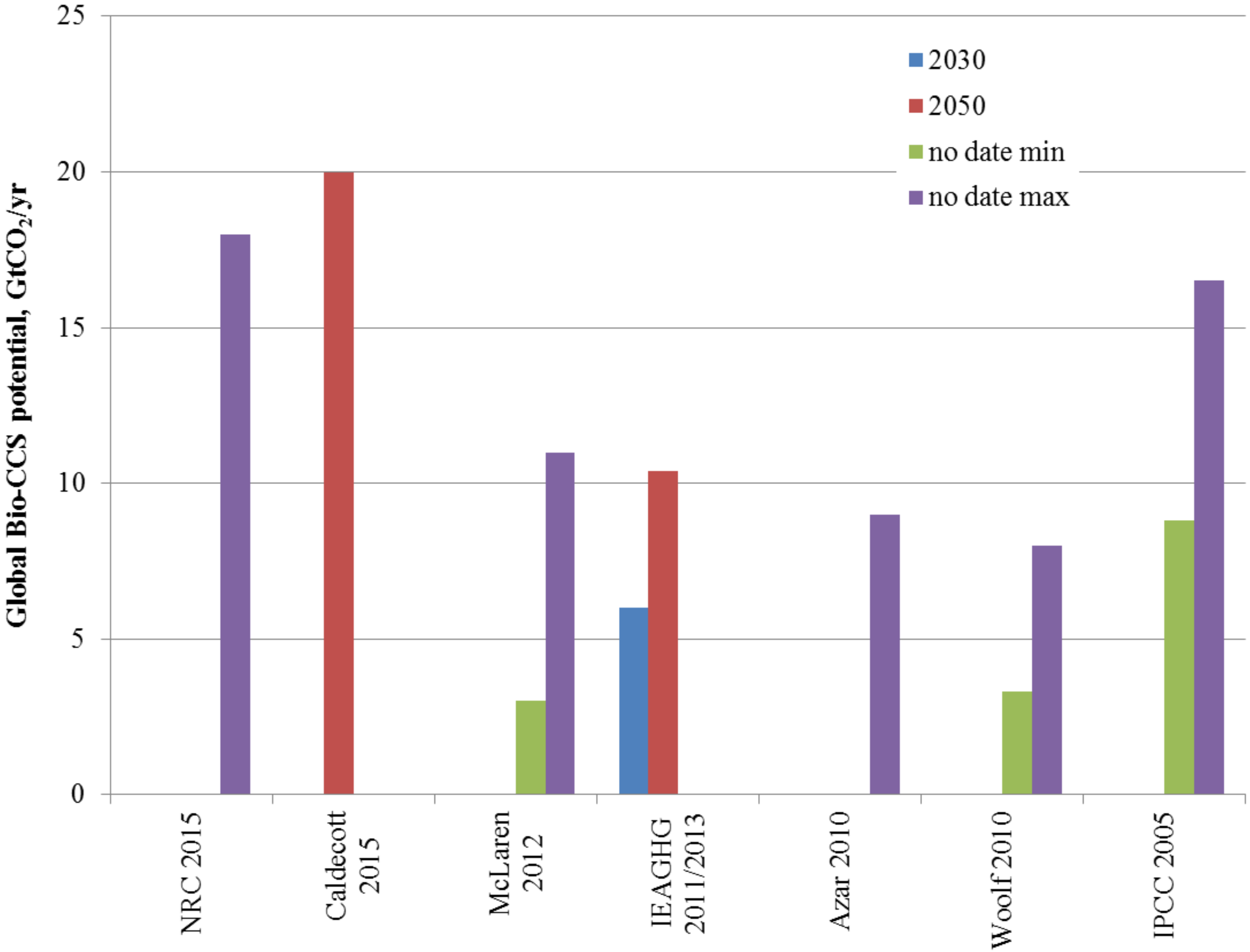
Plenty of research on public perception of CCS but very limited and contradictory on BECCS

- BECCS generally has lower profile than Fossil-CCS

Main drivers/barriers for BECCS:

- CO_2/NG price, infrastructure/clusters, sustainable feedstocks, public perception

Global BECCS potential



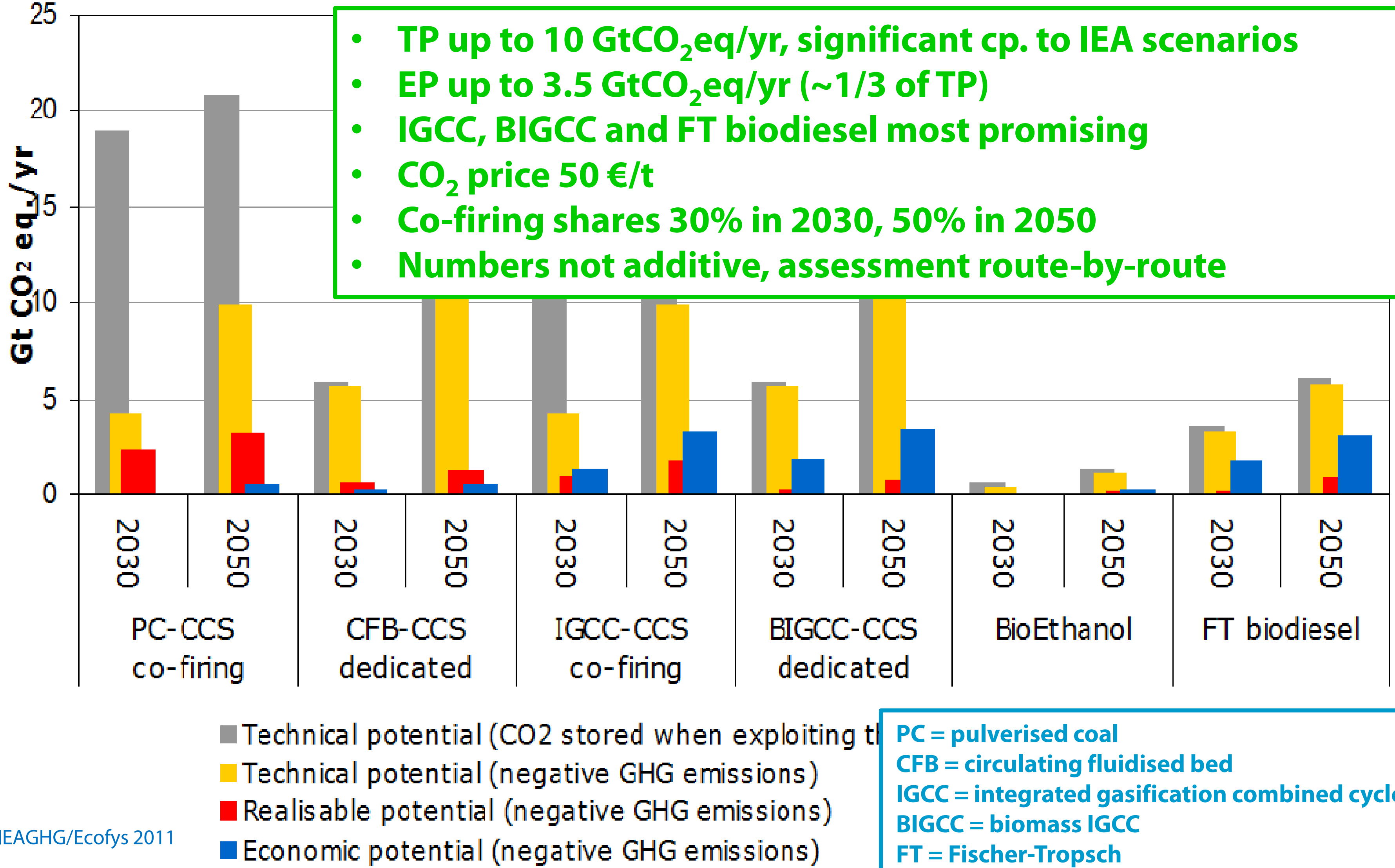
Kemper 2015

Technical, economic and realisable potential

- The technical potential (TP) was determined by the net energy conversion efficiency (including the energy penalty) and the carbon removal efficiency of the BECCS route.
- The realisable potential (RP) adds limitations to the technical potential by including energy demand, capital stock turnover and possible deployment rate.
- The economic potential (EP) further considers the costs of biomass resources, biomass conversion and CCS for selected BECCS routes.

Negative emissions potential for BECCS

- TP up to 10 $GtCO_2eq/yr$, significant cp. to IEA scenarios
- EP up to 3.5 $GtCO_2eq/yr$ (~1/3 of TP)
- IGCC, BIGCC and FT biodiesel most promising
- CO_2 price 50 €/t
- Co-firing shares 30% in 2030, 50% in 2050
- Numbers not additive, assessment route-by-route

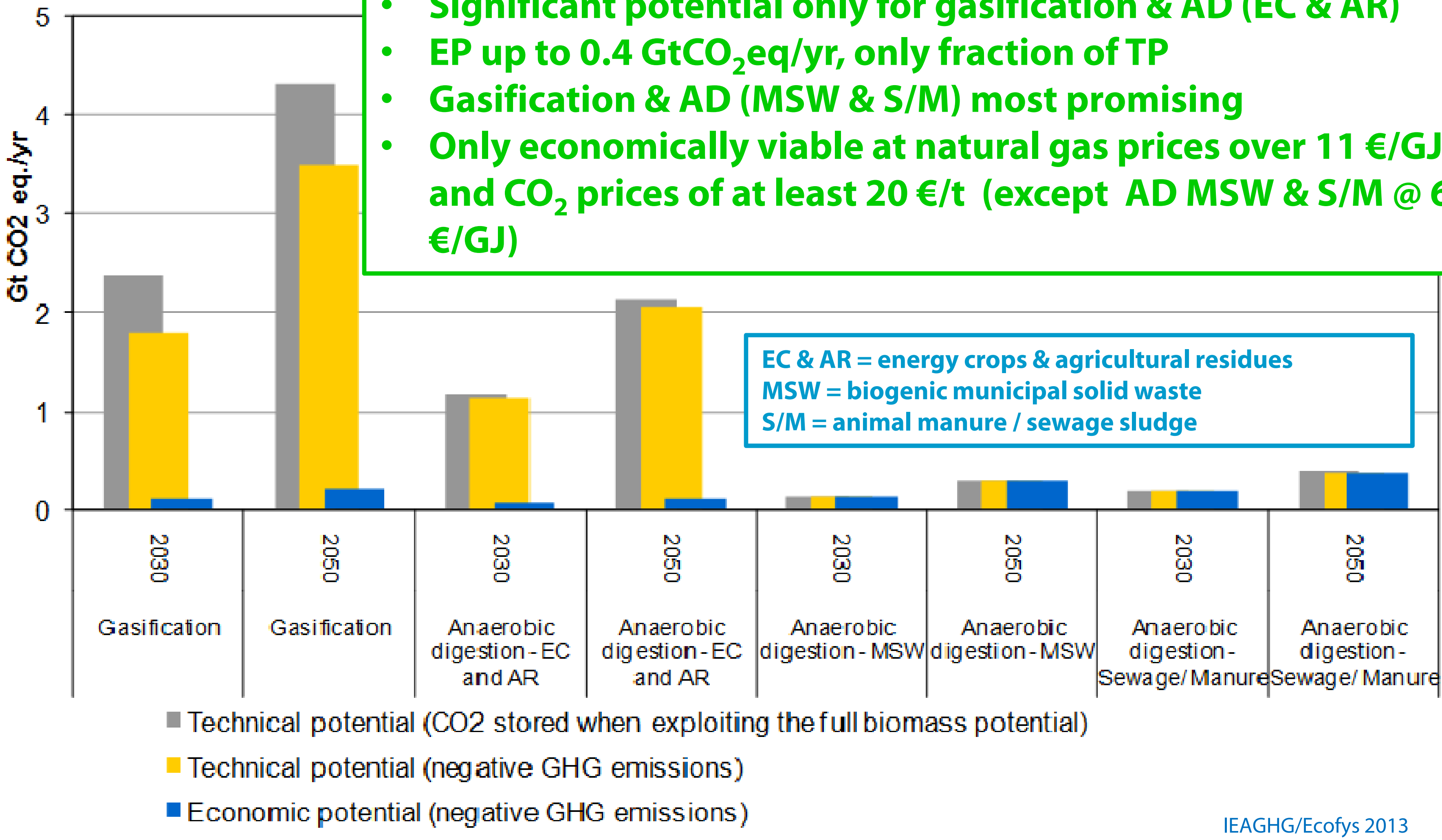


PC = pulverised coal
CFB = circulating fluidised bed
IGCC = integrated gasification combined cycle
BIGCC = biomass IGCC
FT = Fischer-Tropsch

IEAGHG/Ecofys 2011

Negative emissions potential for biomethane BECCS routes

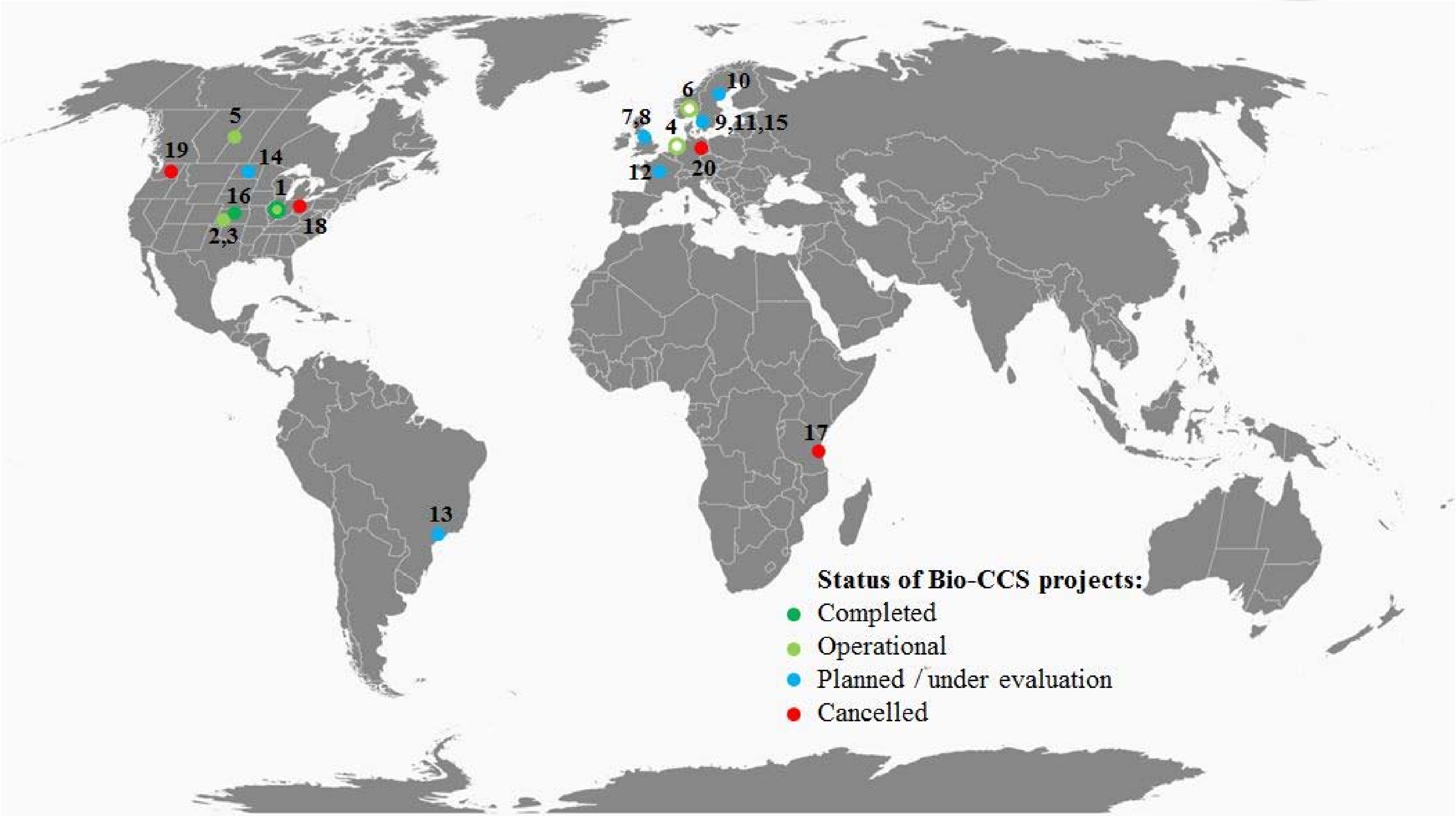
- TP up to 3.5 $GtCO_2eq/yr$, smaller than previous routes
- Significant potential only for gasification & AD (EC & AR)
- EP up to 0.4 $GtCO_2eq/yr$, only fraction of TP
- Gasification & AD (MSW & S/M) most promising
- Only economically viable at natural gas prices over 11 €/GJ and CO_2 prices of at least 20 €/t (except AD MSW & S/M @ 6.7 €/GJ)



EC & AR = energy crops & agricultural residues
MSW = biogenic municipal solid waste
S/M = animal manure / sewage sludge

IEAGHG/Ecofys 2013

Overview BECCS projects



Kemper 2015, with data from Karlsson and Byström 2011, DiPietro et al. 2012, GCCSI 2015a, 2015b; map by FreeVectorMaps.com

Overview BECCS projects

Project name	Location	Status	CO_2 capacity $MtCO_2/yr$	CO_2 source	CO_2 sink
Operational projects					
IL-ICCS project (expected to continue operation in Q2 2017)	Decatur, IL, USA	Second phase to continue operation in early 2017, awaiting permits	1.0	Archer Daniels Midland ethanol plant, other	Mount Simon sandstone
Arkalon	Liberal, KS, USA	Operating since 2009	0.18-0.29	Conestoga's Arkalon ethanol plant	EOR, Booker and Farnsworth oil fields, TX
Bonanza	Garden City, KS, USA	Operating since 2011	0.10-0.15	Conestoga's Bonanza BioEnergy ethanol plant	EOR, Stuart oil field, KS
RCI/OCAP/ROAD	Rotterdam, NL	Operating since 2011	0.1 (Abengoa) 0.3 (Shell)	Shell's Pernis refinery, Abengoa's ethanol plant, Maasvlakte power plant, various other	Nearby greenhouses, TAQA's P18-4 gas reservoir after 2015
Husky Energy	Lloydminster, SK, CA	Operating since 2012	0.09-0.1	Ethanol plant	EOR, Lashburn and Tangleflags oil fields
Saga City	Saga City, Saga, JP	Operating since 2016	0.004	Waste-to-energy plant	Crop and algae cultivation
Planned projects / projects under evaluation					
Klemetsrud	Oslo, NO	Planned start in	0.3	Waste-to-energy plant, 50-60% biomass	Smeaheia, North Sea
Norcem	Brevik, NO	Planned start in	0.4	Cement plant, >30% biomass	Smeaheia, North Sea
AVR Duiven	Duiven, NL	Planned start in 2018	0.05	Waste-to-energy plant, 54% biomass	Nearby greenhouses
Mikawa power plant	Omuta, Fukuoka, JP	Planned start in 2020, pilot-scale CO_2 capture since 2009	0.18	Mikawa power plant (coal and/or biomass)	?
C.GEN North Killingholme Power Project	North Killingholme, UK	Evaluating, planned start in 2019, now likely cancelled	2.5	Biomass co-fired IGCC power plant	Southern North Sea
Södra	Värö, SE	Identifying and evaluating	0.8	Pulp and paper mill	Skagerrak, North Sea

Overview BECCS projects (ctd.)

Project name	Location	Status	CO_2 capacity $MtCO_2$/yr	CO_2 source	CO_2 sink
Domsjö Fabriker	Domsjö, SE	Identifying and evaluating	0.26	Black liquor gasification pulp mill	Saline aquifer, North or Baltic Sea
Lantmännen Agroetanol	Norrköping, SE	Identifying and evaluating	0.17	Ethanol plant	Saline aquifer, North Sea
CPER Artenay project	Artenay and Toury, FR	Identifying and evaluating	0.045-0.2	Tereos ethanol plant	Dogger and Keuper saline aquifers, Paris Basin,
Sao Paulo	Sao Paulo state, BR	Identifying and evaluating	0.02	Ethanol plant	Saline aquifer
Biorecro/EERC	ND, USA	Identifying and evaluating	0.001-0.005	Gasification plant	Saline aquifer
Skåne	Skåne, SE	Identifying and evaluating	0.0005-0.005	Biogas plant	Saline aquifer
Completed projects					
Russel EOR research project	Russel, KS, USA	Completed 2005	0.004 (0.007 in total)	Ethanol plant	EOR, Hall-Gurny-Field
Norcem	Brevik, NO	Testing 2014-2016, CO_2 capture only	Small-scale	Cement plant, >30% biomass-fuelled	N/A
IBDP	Decatur, IL, USA	First phase completed in 2014, now monitoring	0.3 (1.0 in total)	Archer Daniels Midland ethanol plant	Mount Simon sandstone
Cancelled projects					
White Rose CCS Project	Selby, UK	Planned start in 2019	2.0	Drax power station, biomass (co)-firing	Bunter sandstone
Rufiji cluster	TZ	Cancelled	5.0-7.0	Sekab's ethanol plants	Saline aquifer
Greenville	Greenville, OH, USA	Cancelled in 2009	1.0	Ethanol plant	Saline aquifer, Mount Simon sandstone
Wallula	Wallula, WA, USA	Cancelled	0.75	Boise Inc's pulp mill	Saline aquifer
CO_2 Sink	Ketzin, DE	Cancelled	0.08		Saline aquifer

Kemper 2015, Karlsson and Byström 2011, DiPietro et al. 2012, GCCSI 2017

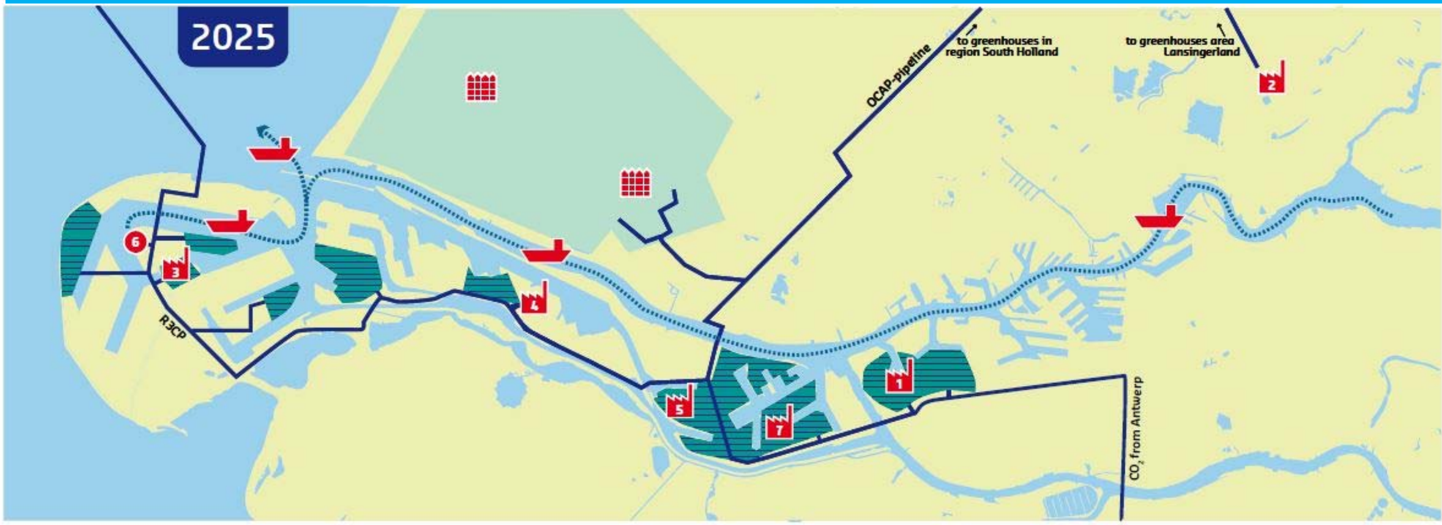
Illinois Industrial CCS Project

- IBDP (Illinois Basin Decatur Project)
  - CO_2 source: ADM's corn EtOH plant (350 Mgal/yr)
  - Captured ~ 0.3 $MtCO_2$/yr over more than 3 years (total 1.0 $MtCO_2$ achieved in Nov 2014)
  - Stored in Mount Simon sandstone
  - 3-year post-injection monitoring
- IL-ICCS (Illinois Industrial CCS Project)
  - Will capture 1.0 $MtCO_2$/yr over 3 years
  - Expected to be operational later in 2017
  - Close the gap to Fossil-CCS demo scale
  - Biggest hurdle: permits and regulations
  - Credits off-set operational costs

McDonald 2016, Archer Daniels Midland, openclipart.org

OCAP

- Rotterdam, NL
- 0.1 $MtCO_2$/yr from Abengoa ethanol plant
- CO_2 utilisation in nearby greenhouses
- Operating since 2011
- Part of wider cluster development under RCI, which plans to store total of 2.5 $MtCO_2$/yr in the North Sea, including a “BECCS ready” power plant



Rotterdam Climate Initiative 2011

1 Shell Pernis
2 E.ON-ROCA
3 E.ON CO_2-Catcher (CATO-2 pilot project)
3 ROAD
4 Abengoa
5 Air Liquide

6 CO_2 Hub CINTRA
7 Air Products
Connecting industry to CCS network (not just large scale demo’s)

Pegasus: location not yet determined

Maasvlakte II, under construction
Transport by pipeline
Transport by ship
CO_2 capture
Green houses
Energy intensive industry
CO_2 Hub

BECC(U)S: Waste-to-energy

ARV Duiven

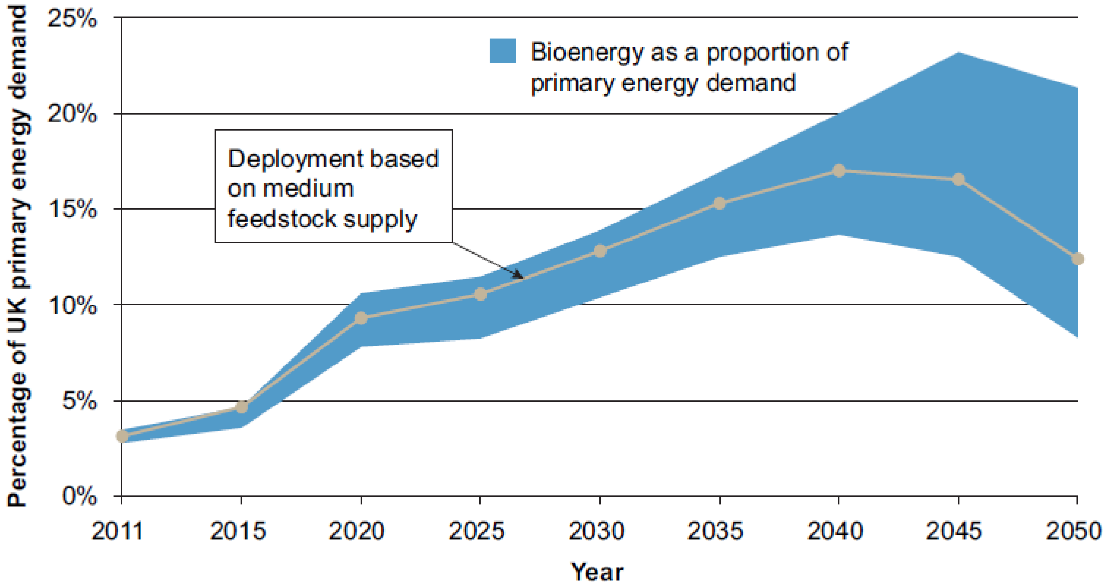
- Duiven, The Netherlands
- Aim: capture 50,000 tCO_2/yr
- 70 MW_{th}
- 126 GWh_e
- 54% biomass
- Flue gas: 10% CO_2 (dry)
- Capture rate 78%
- MEA solvent
- CO_2 used for horticulture

Klemetsrud Plant AS

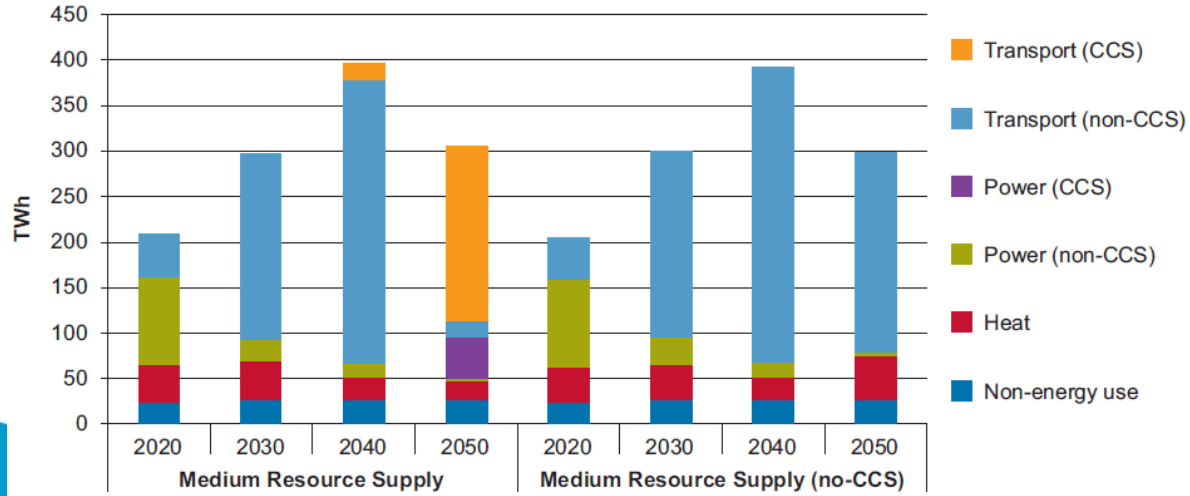
- Oslo, Norway
- Aim: capture 300,000 tCO_2/yr
- 55 MW_{th}
- 175 GWh_e / 10 MM_e
- 50-60% biomass
- Flue gas: 10% CO_2
- Capture rate: 90%
- Aker Solutions' amine process
- Pilot capturing 2,000 tCO_2/yr

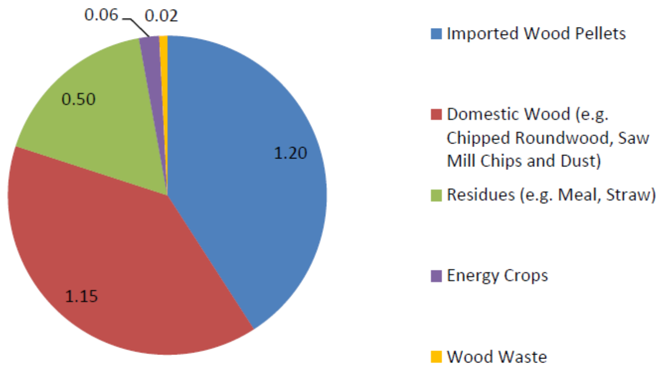
Koornneef et al. 2016, AVR, Aker Solutions

Case study: BECCS in UK



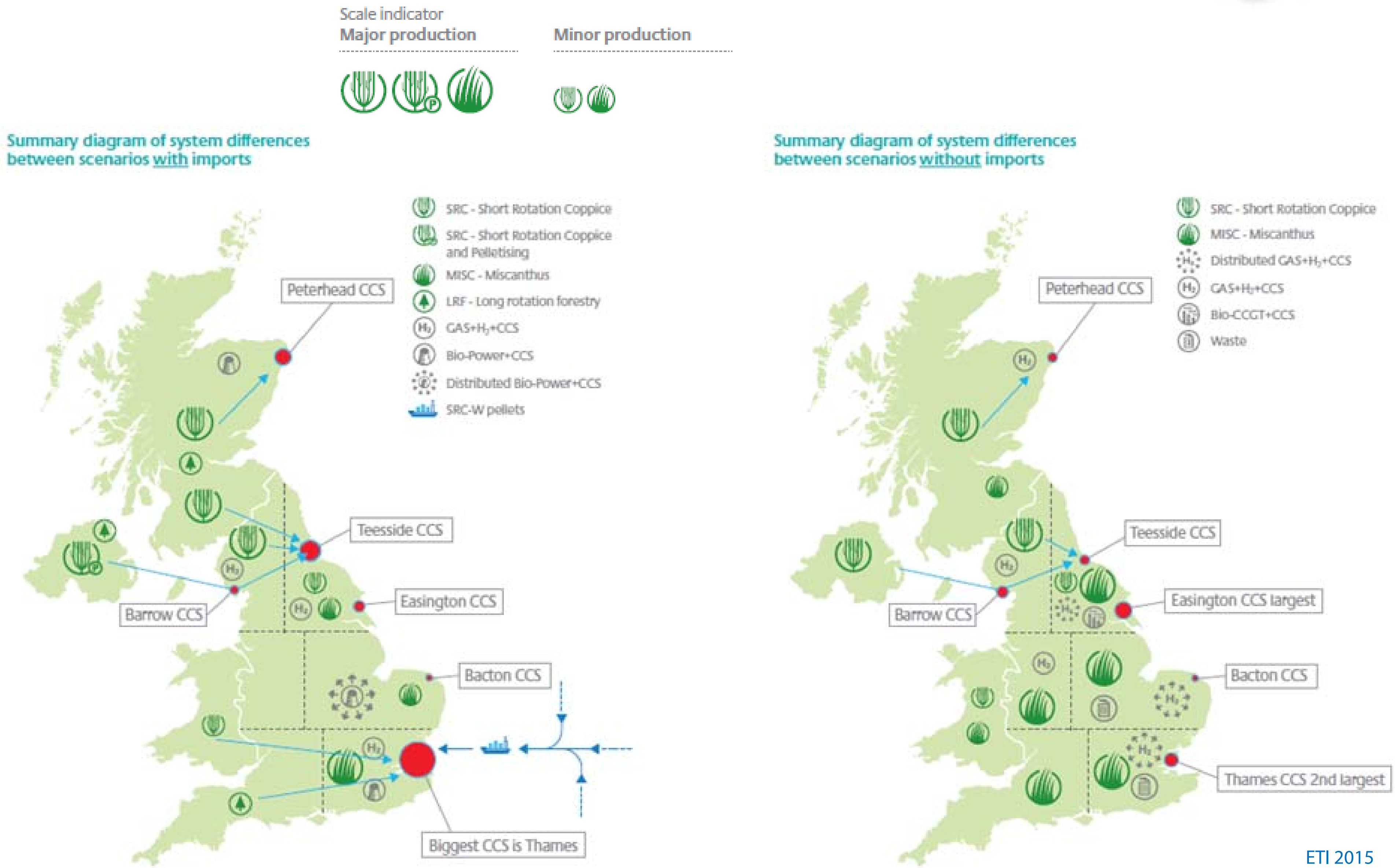
- BECCS essential for power sector
- Forest biomass from USA/CA will be key
- Uncertainty about Bio-CCS' role in transport
- Excl. biomass/BECCS, could cost the UK ~£44 billion (ETI 2015)





DfT, DECC and defra 2012, ETI 2015

Case study: BECCS in UK



ETI 2015

Technology readiness level (TRL)

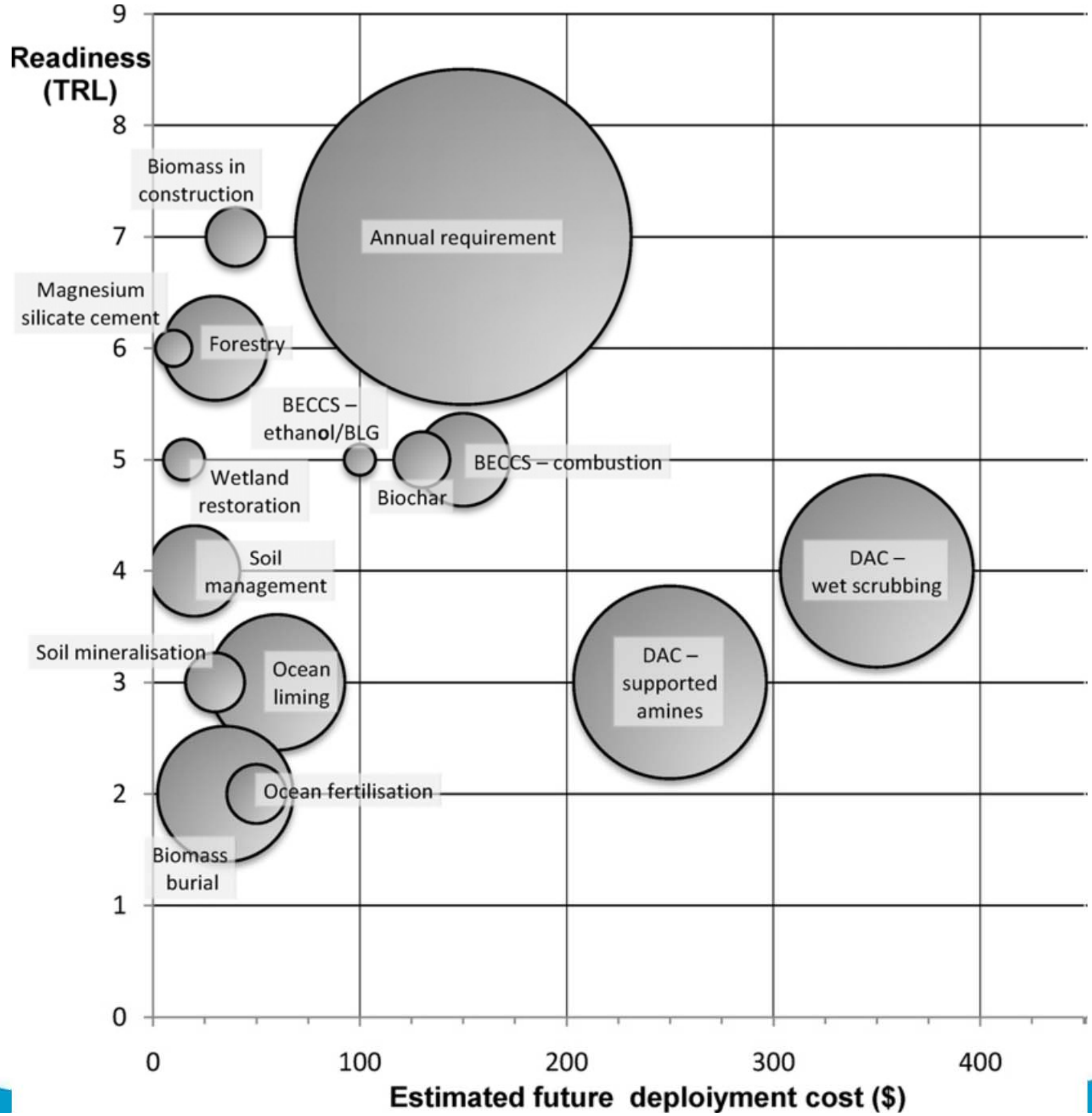
Demonstration	9	Normal commercial service
	8	Commercial demonstration, full scale deployment in final form
	7	Sub-scale demonstration, fully functional prototype
Development	6	Fully integrated pilot tested in a relevant environment
	5	Sub-system validation in a relevant environment
	4	System validation in a laboratory environment
Research	3	Proof-of-concept test, component level
	2	Formulation of the application
	1	Basic principles, observed initial concept

EPRI

Note:

- **TRL is not necessarily an indication of the amount of time and effort required to achieve commercialisation**
- **TRL 9 does not necessarily represent the be-all and end-all**

Cost and TRL of BECCS



McLaren 2012

Accounting frameworks

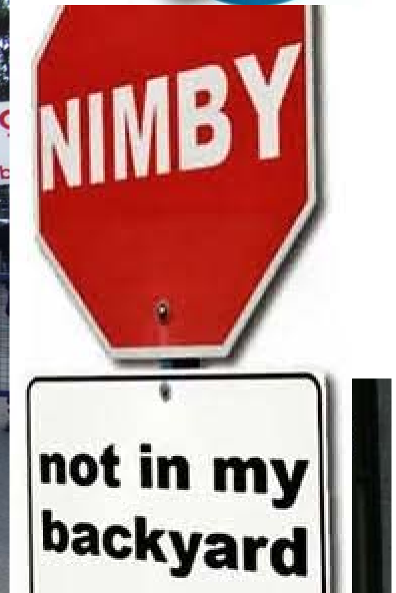
Scheme	CCS	Biomass growth/ harvesting/ combustion/ processing	dLUC/iLUC	Life cycle emissions	Negative emissions
2006 IPCC GLs	✓	✓	✓	✓	✓
EU ETS	(✓)	✓	✗	✗	✗
EU RED/FQD	✓	✓	✓	✓	✓
US GHGRP	✓	✓	✗	✗	(✓)
California ETS	✗	✓	✗	✗	(✓)
California LCFS	✓	✓	✓	✓	✓
Australia CPM#	✓	✗	✗	✗	✗
UNFCCC KP's CDM/JI	✓	(✓)	✓	✓	(✓)

Note that the Australian Senate repealed the CPM on 17th July 2014, taking effect from 1st July 2014. The repeal has no effect on entities' reporting obligations under the NGER.

Accounting frameworks

- 2006 IPCC Guidelines for National Greenhouse Gas Inventories (2006 GLs)
- United Nations Framework Convention on Climate Change (UNFCCC) Kyoto Protocol's (KP) Clean Development Mechanism (CDM) and Joint Implementation (JI)
- EU Emission Trading System (EU ETS)
- EU Renewable Energy Directive (RED)
- EU Fuel Quality Directive (FQD)
- US Greenhouse Gas Reporting Program (GHGRP)
- Australia National Greenhouse and Energy Reporting Determination (NGER) and Carbon Pricing Mechanism (CPM)
- California Emissions Trading System (California ETS)
- California Low Carbon Fuel Standard (California LCFS)

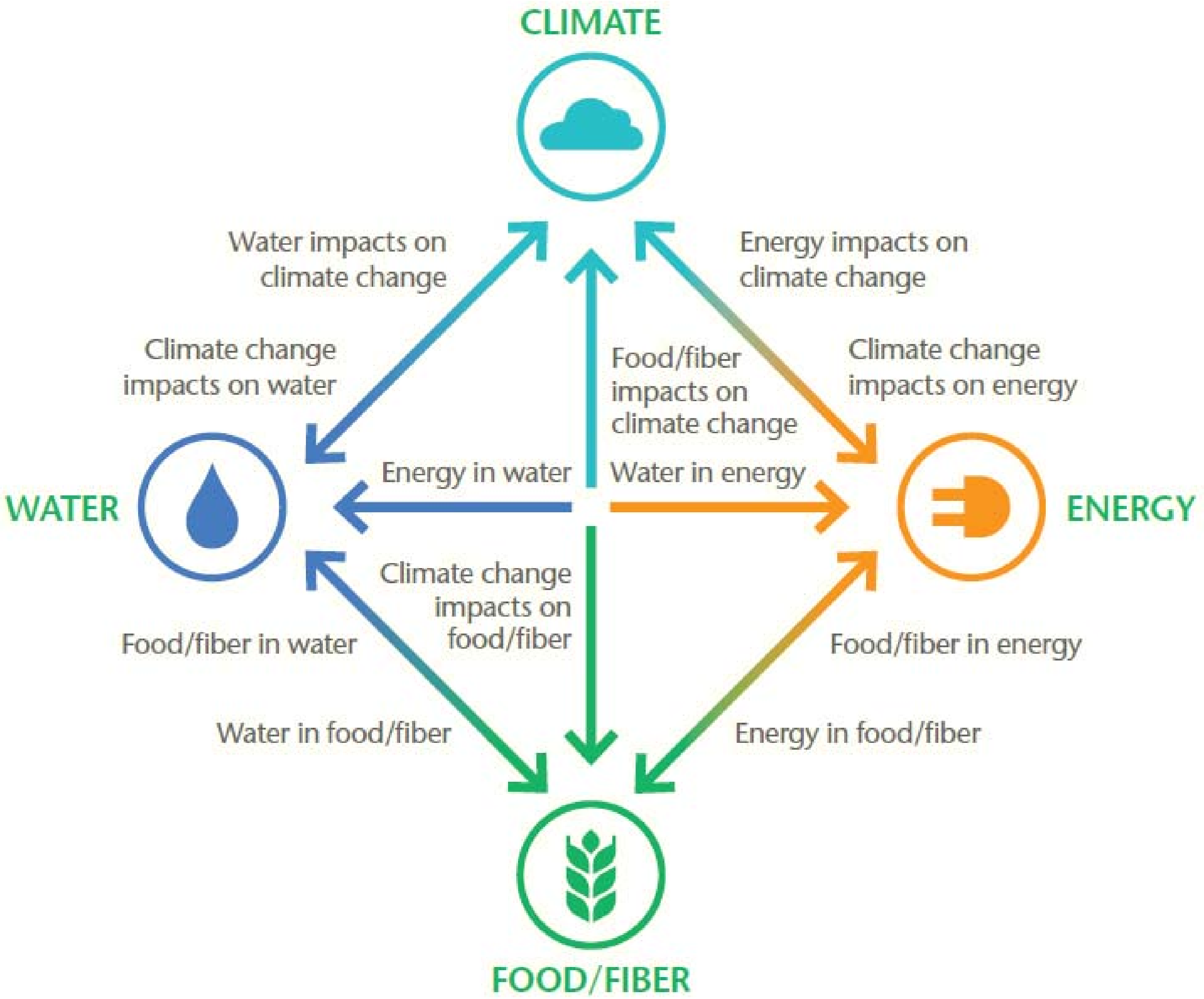
BECCS public perception



- Research on BECCS public perception limited
- Contradicting results
- Socio-cultural context of stakeholders important

dpa, biofuelwatch.org.uk, aero-news.net

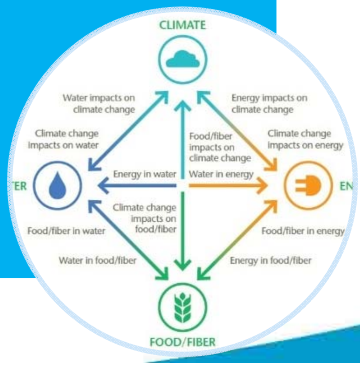
BECCS in nexus context



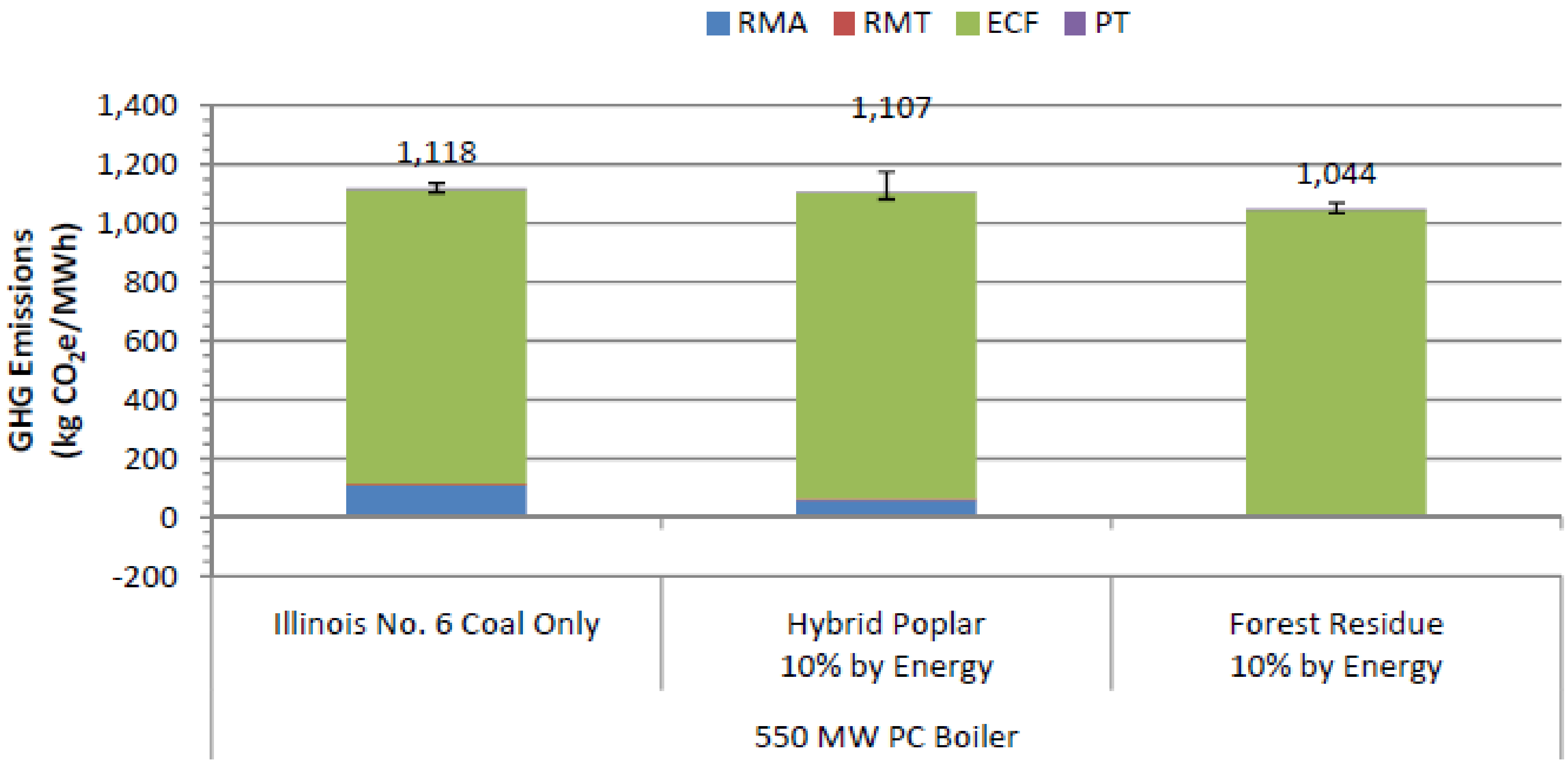
BECCS in nexus context

- Competition between food and bioenergy crops
- Shift of GHG/CO_2 emissions from one sector to another (“carbon leakage”)
- Impact of large-scale biomass infrastructure, trade, and supply chains
- Impact of climate change on crop yields
- Water footprint of BECCS systems
- Effects of increased fertiliser use
- Land availability and lock-in
- Land use change (LUC) impacts
- Biomass sustainability

Main nexus concerns



Life cycle assessment (LCA)

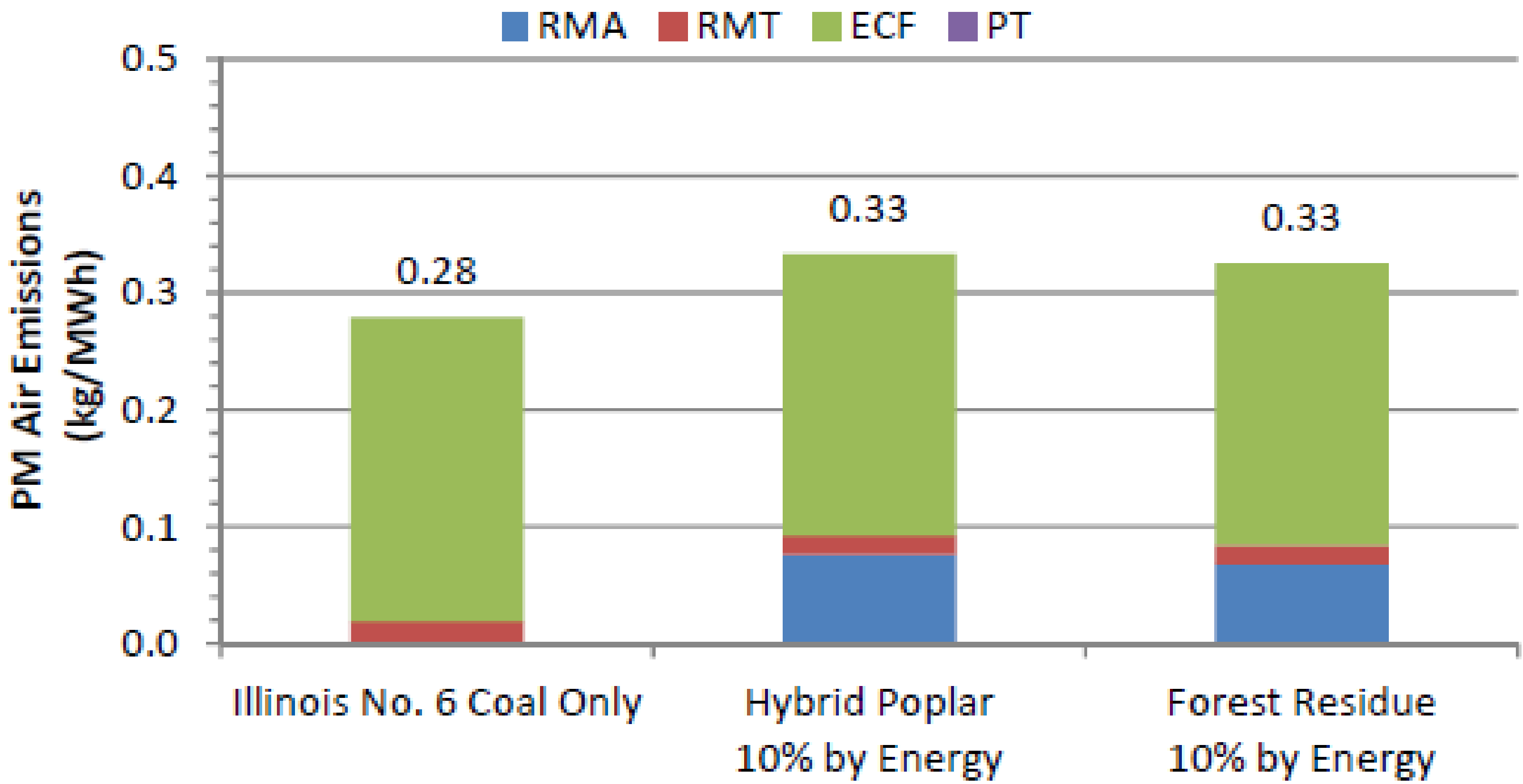


RMA = raw material aquisition
RMT = raw material transport
ECF = energy conversion facility
PT = product transport

Biomass co-firing without CCS

NETL 2012

Life cycle assessment (LCA)



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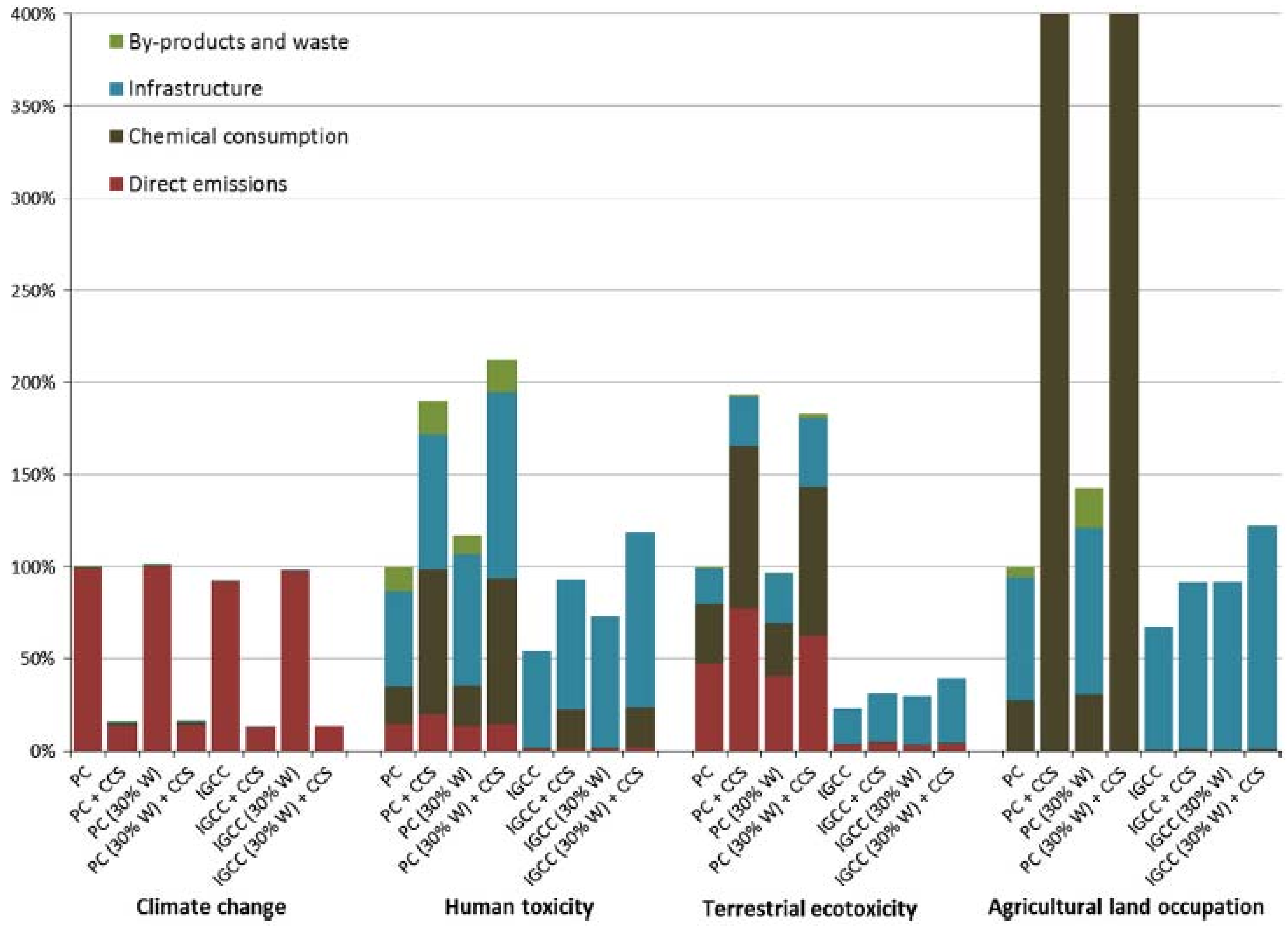
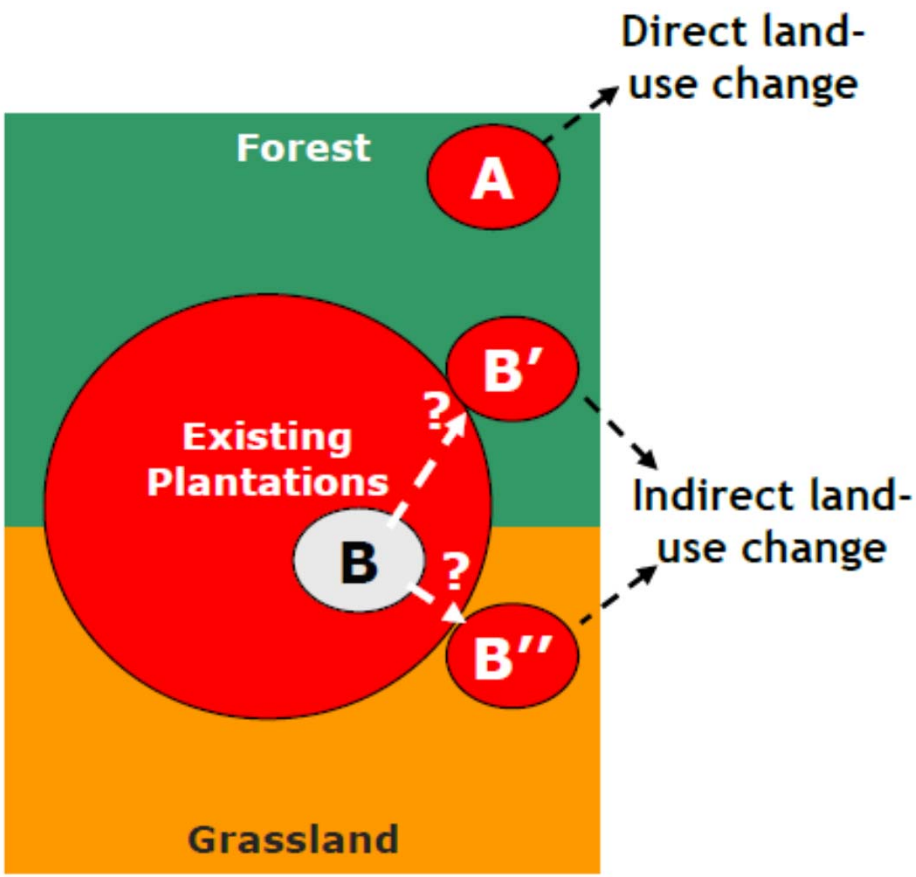


Schakel 2014

Land use change (LUC)

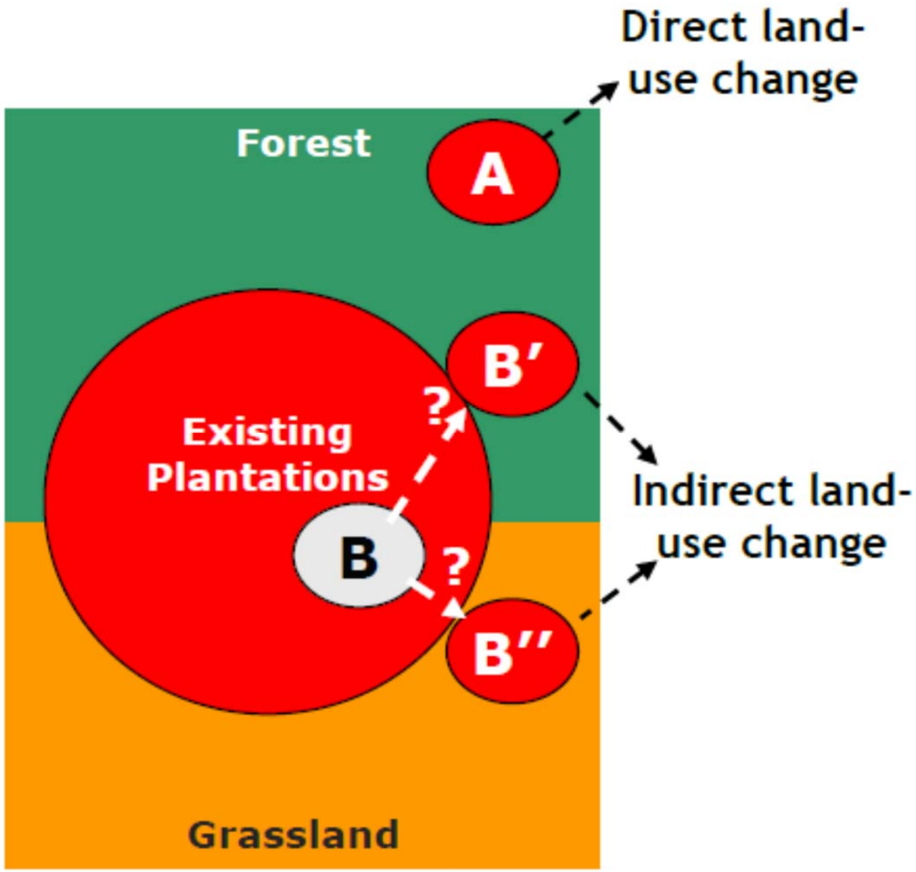
1. **Direct LUC (dLUC)** occurs when additional biomass feedstock demand leads to the cultivation of new areas (see circle A in figure) for biomass production
2. **Indirect LUC (iLUC)** occurs when existing production areas cover the additional feedstock demand (see B), displacing the previous production function of the land, which can trigger expansion of land to new areas (e.g. to B' and/or B'').



Hamelinck 2014, adapted from Dehue 2006

Land use change (LUC)

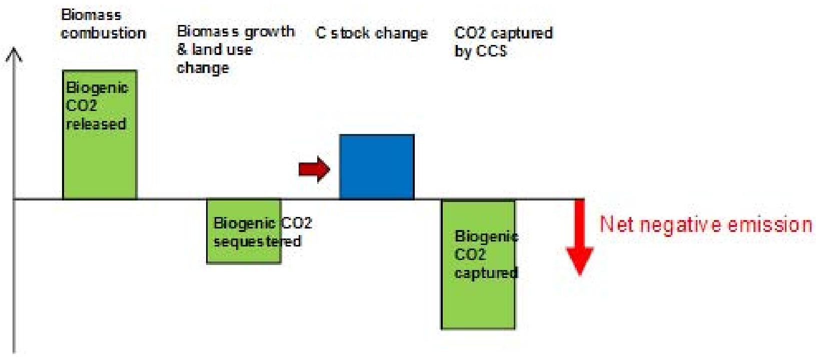
- Factors include:
  - Labour conditions
  - Protection of areas with high ecological, historical or cultural value
  - Food prices and security
  - Avoidance of direct and indirect land use change (dLUC & iLUC)
  - Water supply and quality
  - Land rights of local communities
- GHG emissions from LUC can be substantial
- Role of "additional biomass"
- Bioenergy crops with low life cycle emissions exist



Hamelinck 2014, adapted from Dehue 2006

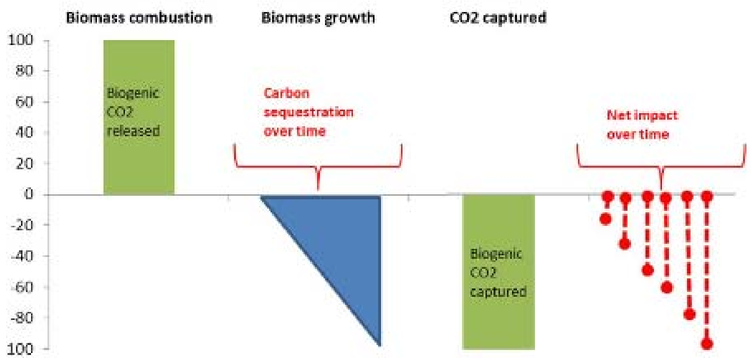
Carbon debt

Land use change and carbon stock changes?

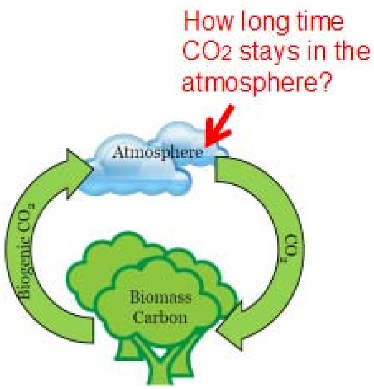


”Non-sustainable” bioenergy due to land use change

- Direct land use change
- Indirect land use change (ILUC)

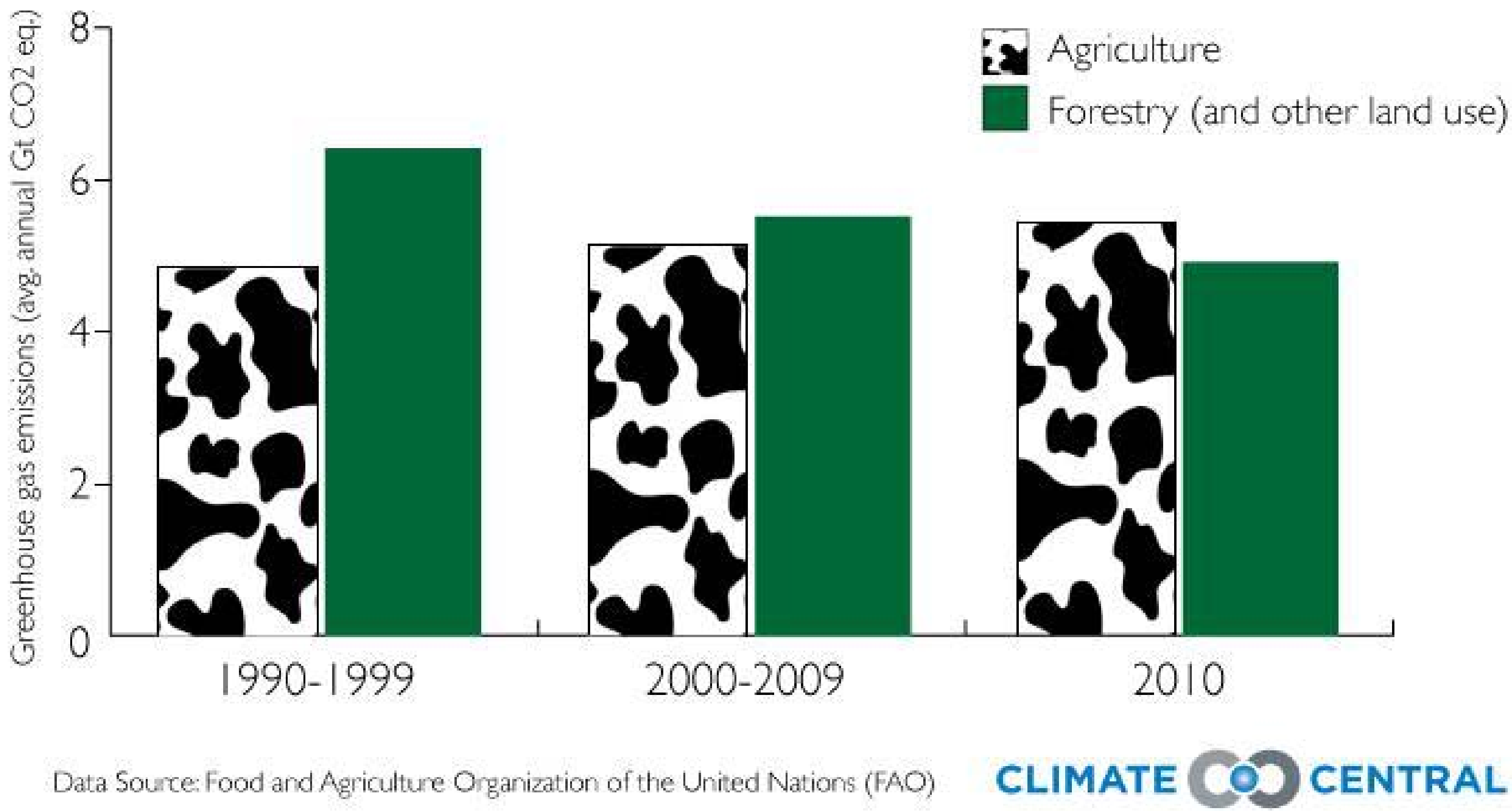


Impact of temporal scale?

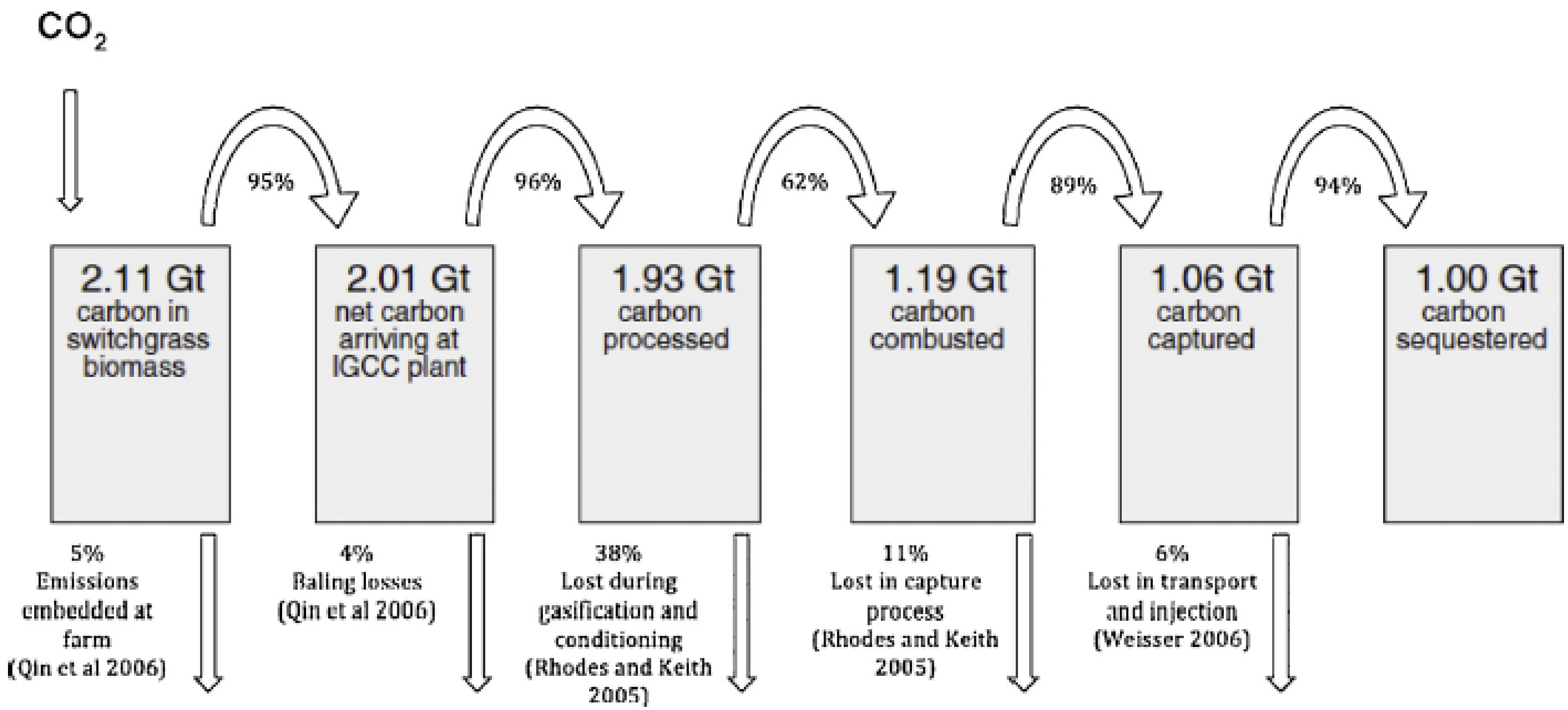


Koponen 2016

Land based GHG emissions



Carbon losses in BECCS chain



Example: switchgrass gasification plant with BECCS

- **Capturing and storing 1 GtC = 3.67 $GtCO_2$ could need fixation of up to 2.11 GtC = 7.7 $GtCO_2$**

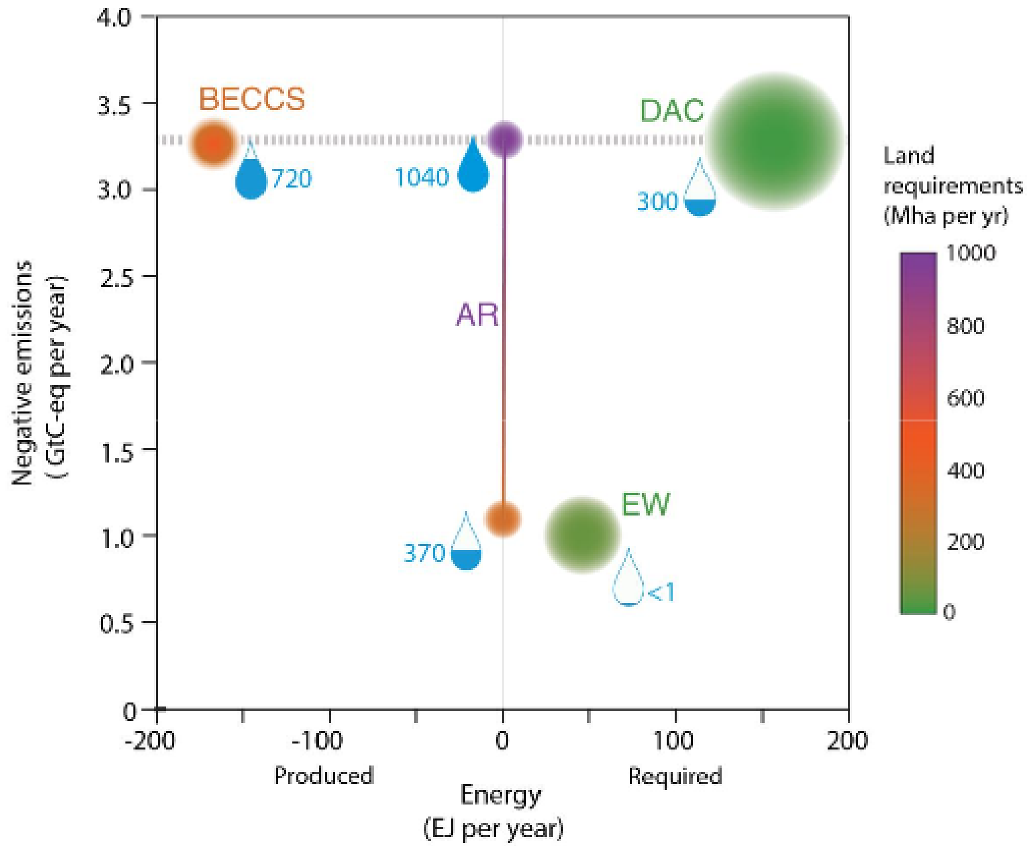
Smith and Torn 2013

Resource demand of NETs

~3% of the freshwater currently appropriated for human use

380–700 Mha

138 billion



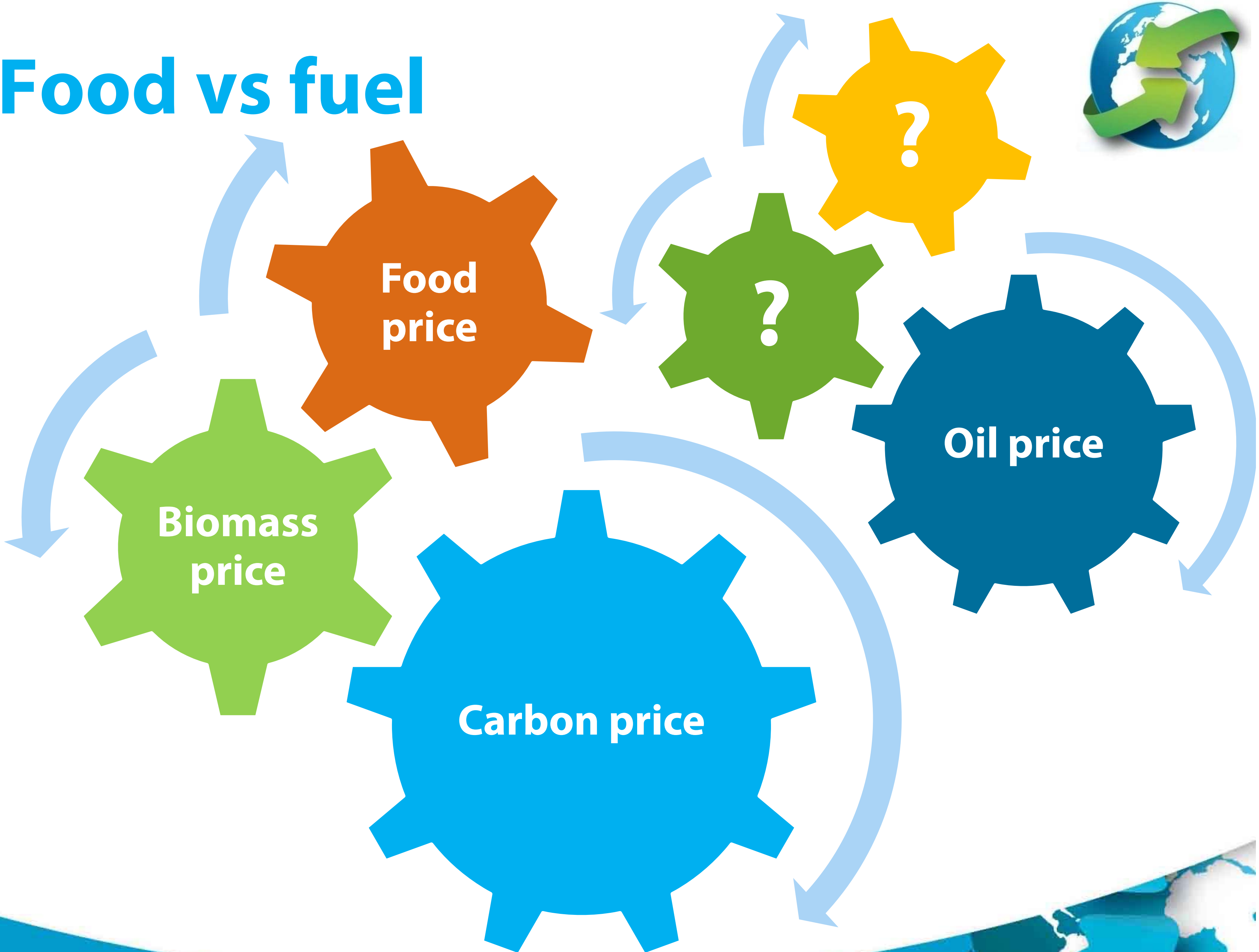
Water requirement is shown as water droplets, with quantities in km[3] per year.
All values are for the year 2100 except relative costs, which are for 2050
Source: Smith et al 2015; Global Carbon Budget 2015

Food vs fuel

TIMES-GAZETTE

Shelbyville, Tennessee – Saturday, April 19, 2008

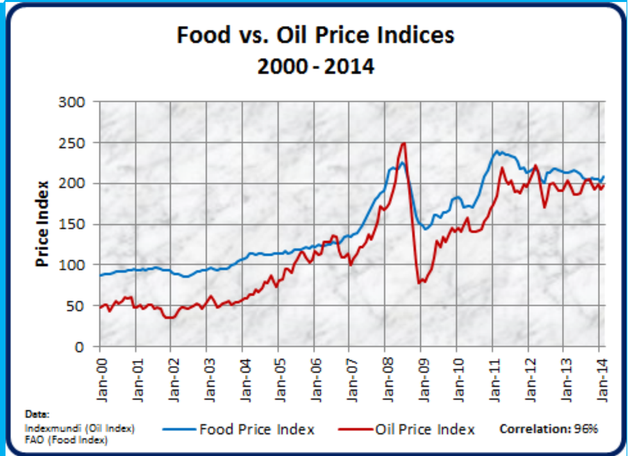
Food vs fuel

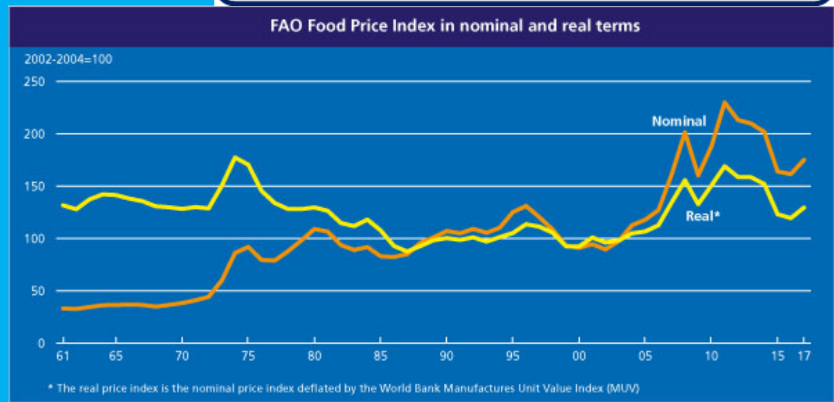


2007/11 food price crises

Several contributing aspects:

- Crude oil price
- Natural disasters (e.g. droughts, storms, floods)
- Financial speculation
- Declining stockpiles
- Demand/dietary changes
- Bioenergy
- Trade liberalisation
- Subsidies
- Pest and diseases
- Soil losses
- Decreasing productivity and yields
- Increase in ozone levels

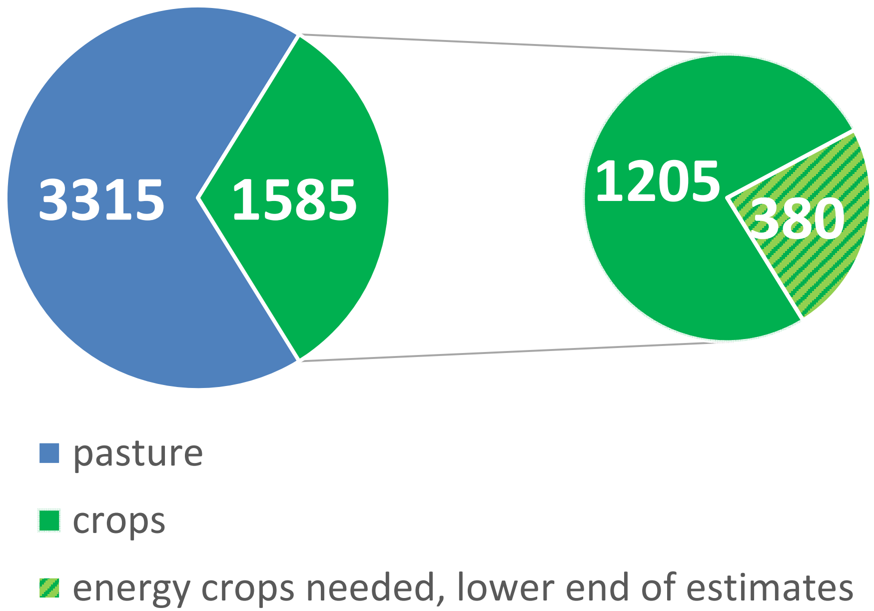




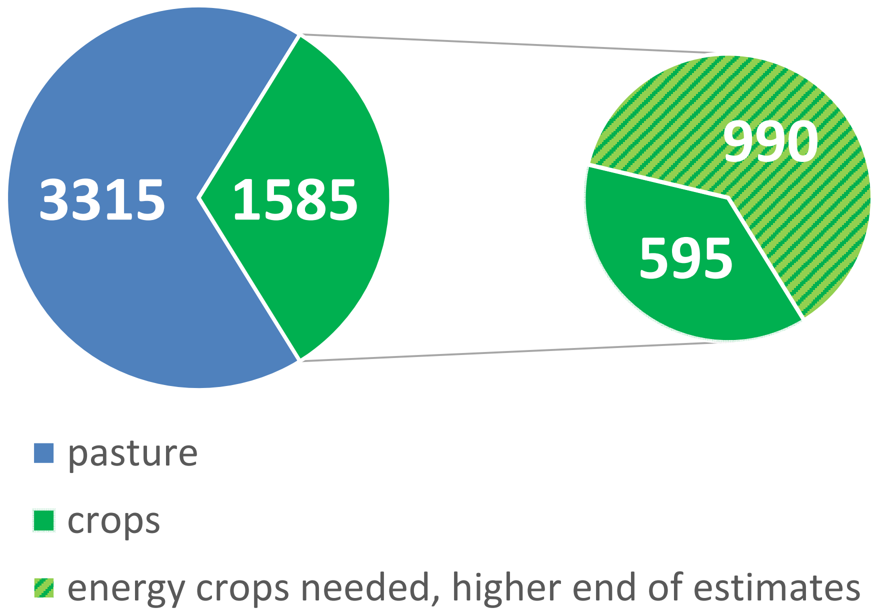
FAO 2017, Chefurka 2014

Current land use

Agricultural land area in 2014 in Mha (FAOSTAT 2016), BECCS min. Land requirement



Agricultural land area in 2014 in Mha (FAOSTAT 2016), BECCS max. land requirement

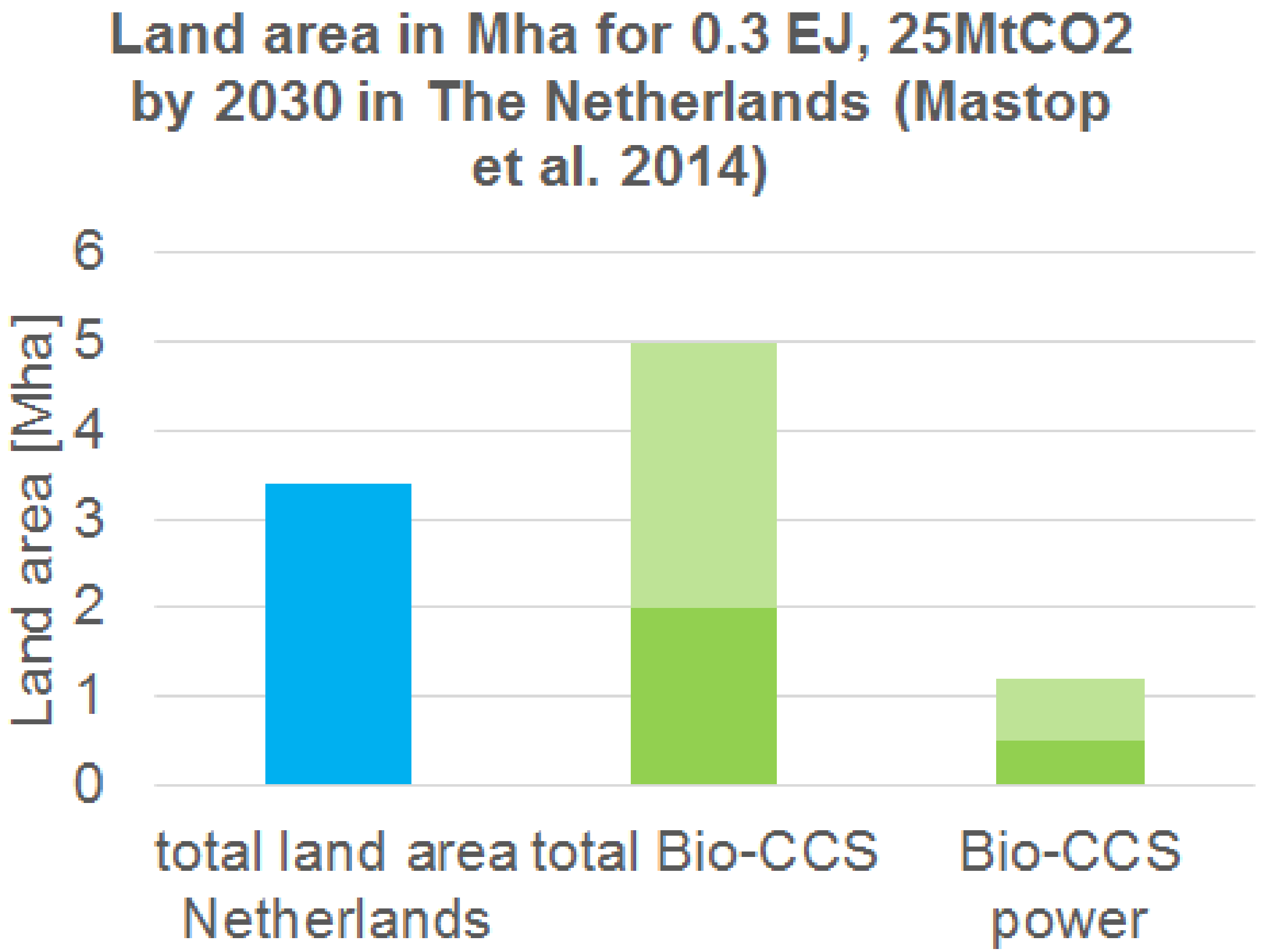


- **Global land area ~13,000 Mha**
- **Marginal lands ~428-1,035 Mha**

How to overcome the "lack" of land?

- **Demand-side changes**
- **Yield increases**
- **Marginal land**

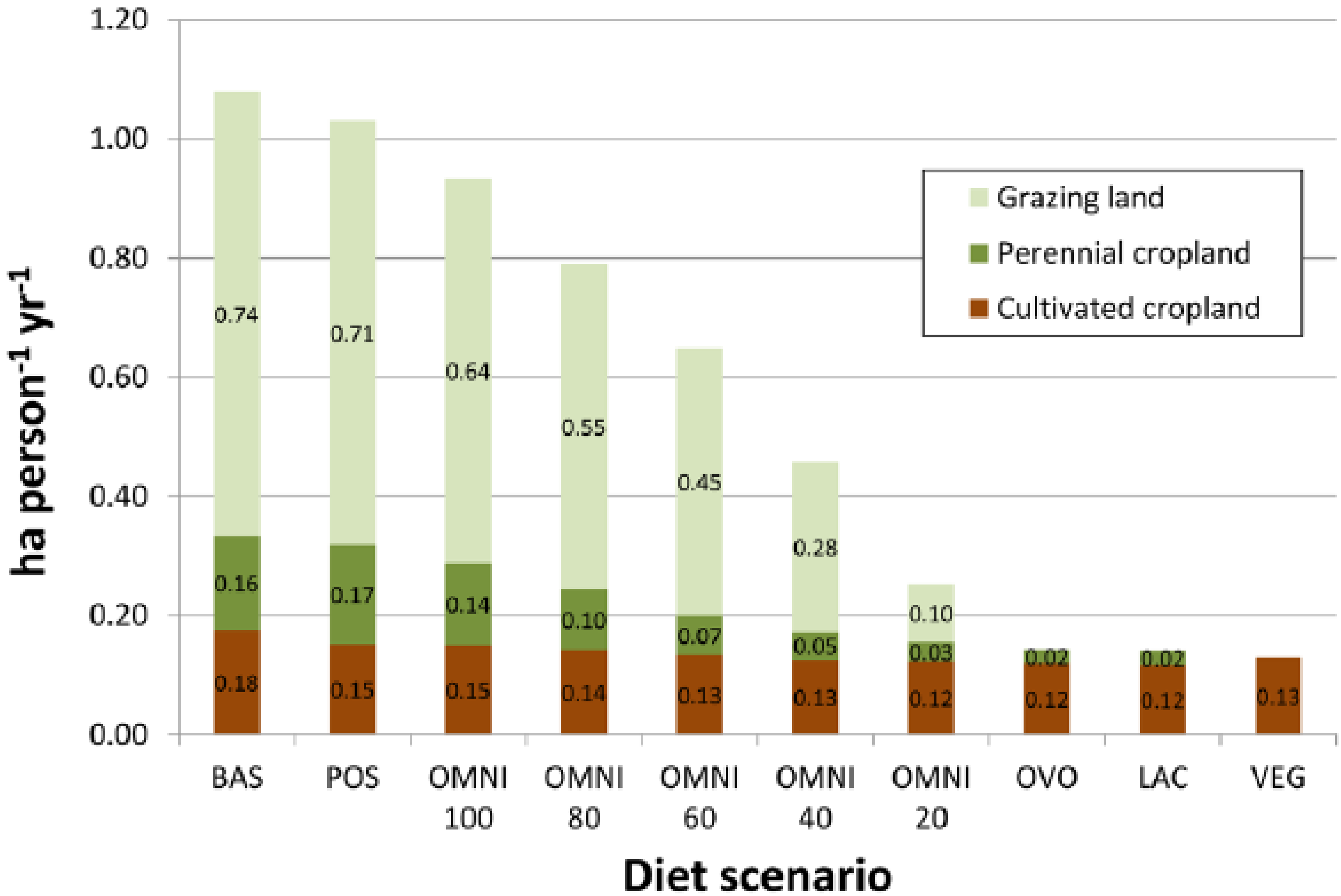
Case study: BECCS in NL



- 1.9 Mha in use for agriculture in 2010 (Eurostat 2012)

- **Biomass imports very likely necessary in this case**
- **Very specific case, results for other countries can be very different**

Freeing land via diet change



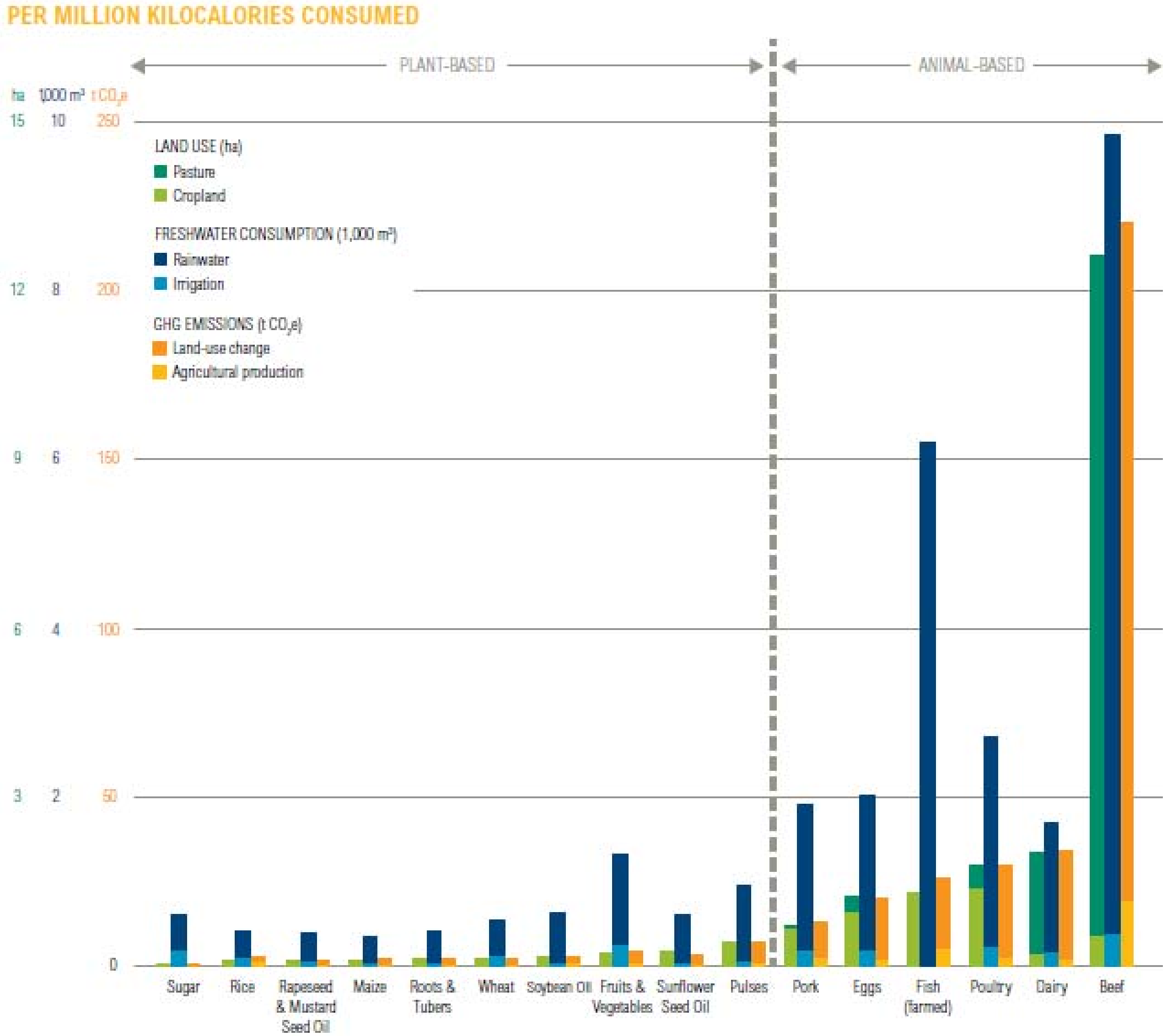
Peters 2016

Freeing land via diet change

Group	Description	Name	Symbol	Key attributes
Current consumption	Based on USDA estimates of per capita loss-adjusted food availability.	Baseline	BAS	Food intake equals loss-adjusted food availability for individual food commodities.
		Positive control	POS	As above, except intake of fats and sweeteners is reduced to make diet energy-balanced.
Healthy diet, omnivorous	Complies with 2010 Dietary Guidelines for Americans. Includes animal flesh.	100% healthy omnivorous	OMNI 100	100% of person-meals follow an omnivorous healthy diet pattern.
		80% healthy omnivorous	OMNI 80	80% of person-meals follow an omnivorous healthy diet pattern and 20% follow a ovo-lacto vegetarian healthy diet pattern.
		60% healthy omnivorous	OMNI 60	60% of person-meals follow an omnivorous healthy diet pattern and 40% follow a ovo-lacto vegetarian healthy diet pattern.
		40% healthy omnivorous	OMNI 40	40% of person-meals follow an omnivorous healthy diet pattern and 60% follow a ovo-lacto vegetarian healthy diet pattern.
		20% healthy omnivorous	OMNI 20	20% of person-meals follow an omnivorous healthy diet pattern and 80% follow a ovo-lacto vegetarian healthy diet pattern.
Healthy diet, vegetarian	Complies with 2010 Dietary Guidelines for Americans. Excludes animal flesh.	Ovolacto vegetarian	OVO	Includes both eggs and dairy products.
		Lacto vegetarian	LAC	Includes dairy products. Excludes eggs.
		Vegan	VEG	Excludes all livestock products.

Peters 2016

Freeing land via diet change

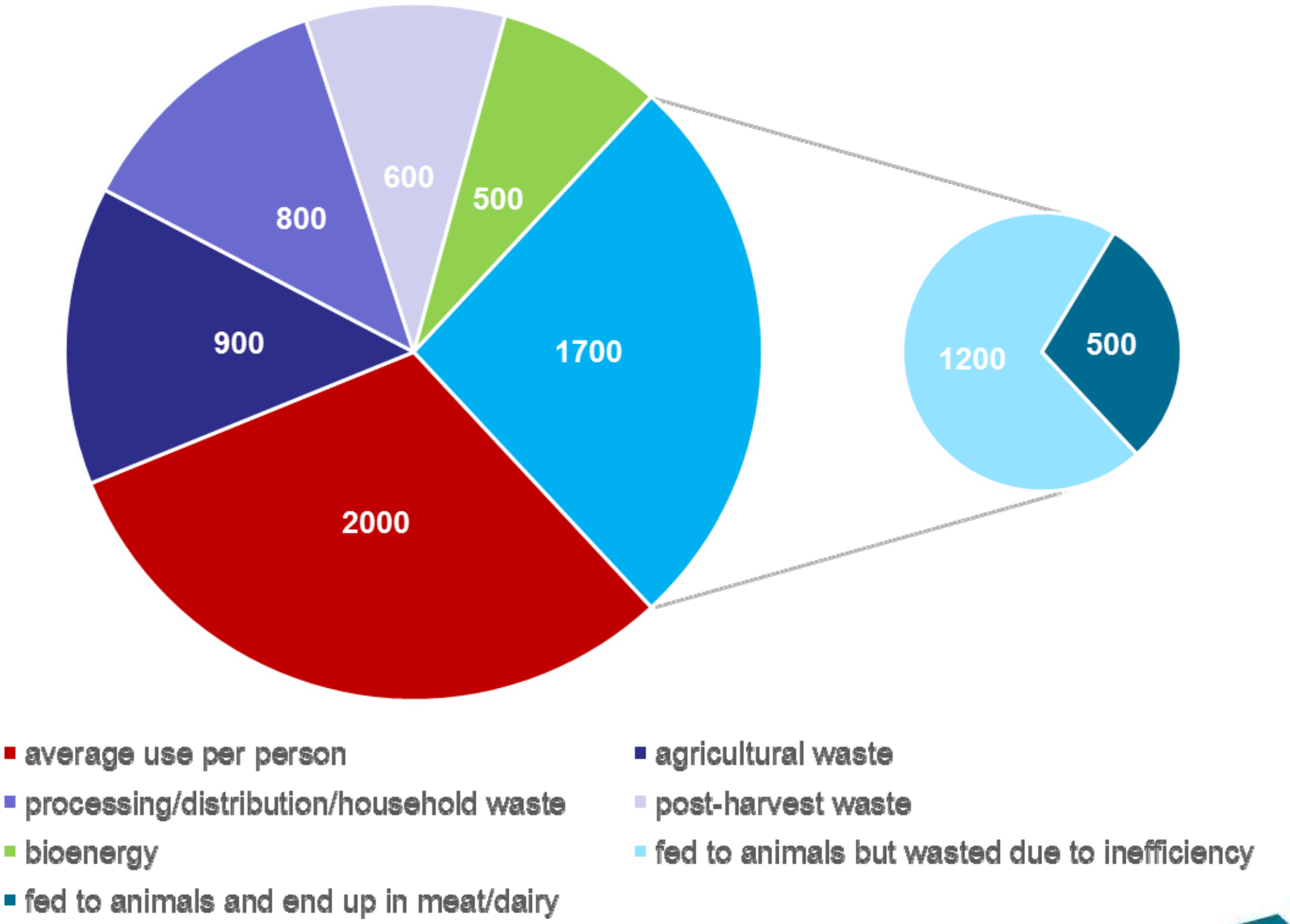


Sources: GlobAgri model (land use and greenhouse gas emissions), authors' calculations from Mekonnen and Hoekstra (2011, 2012) (freshwater consumption), and Waite et al. (2014) (farmed fish freshwater consumption).

WRI 2016

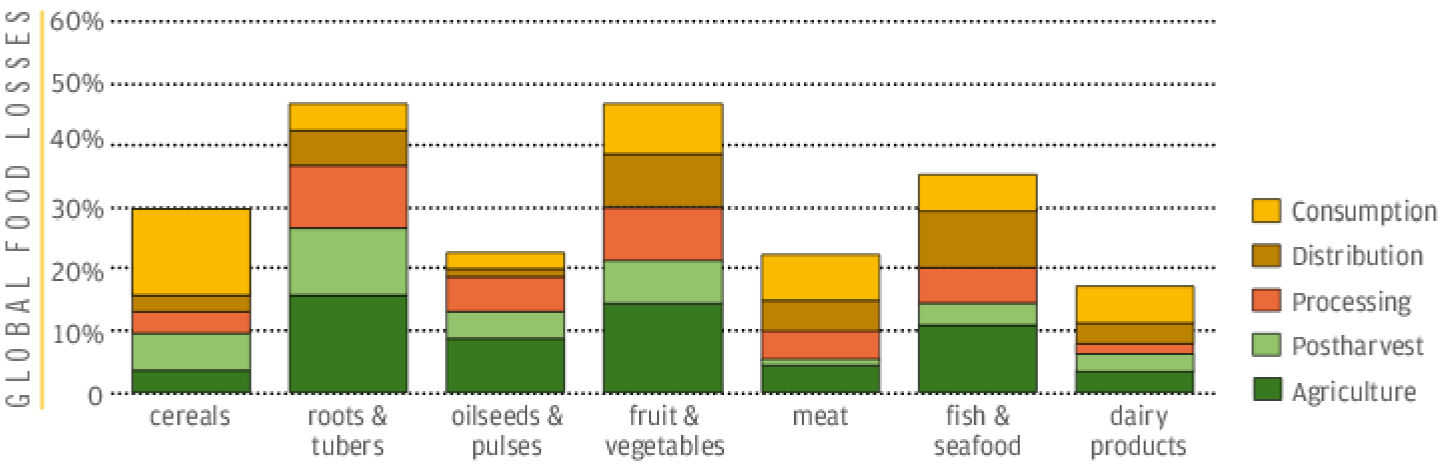
Freeing land by reducing waste

Grown kcals per person and day are ~6000 (Berners-Lee 2016)

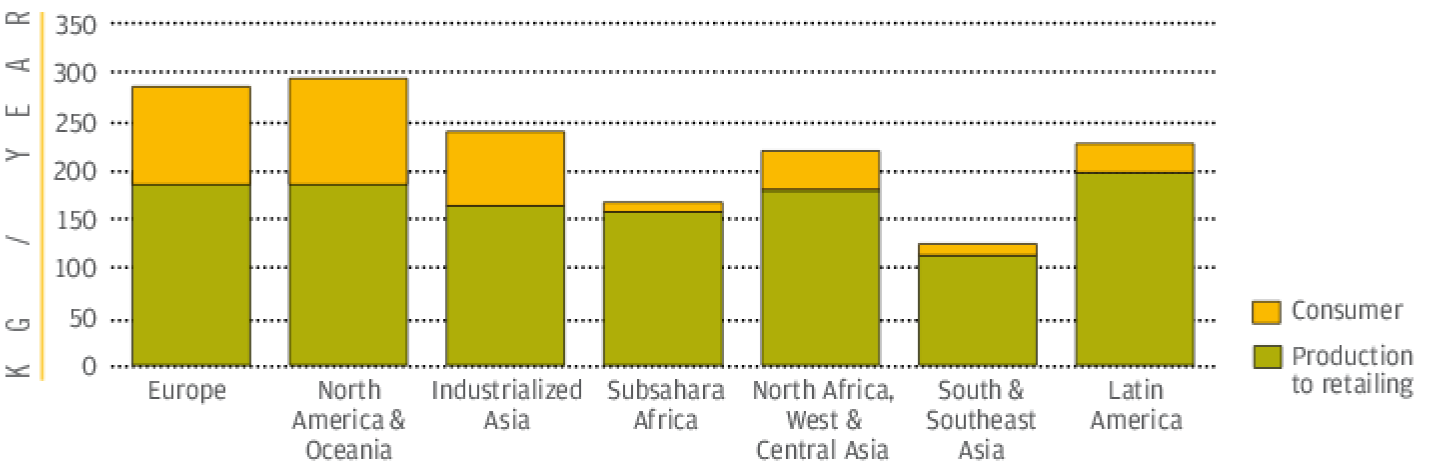


Freeing land by reducing waste

PART OF THE INITIAL GLOBAL PRODUCTION LOST OR WASTED



PER CAPITA FOOD LOSSES AND WASTE, AT CONSUMPTION AND PRE-CONSUMPTION STAGES



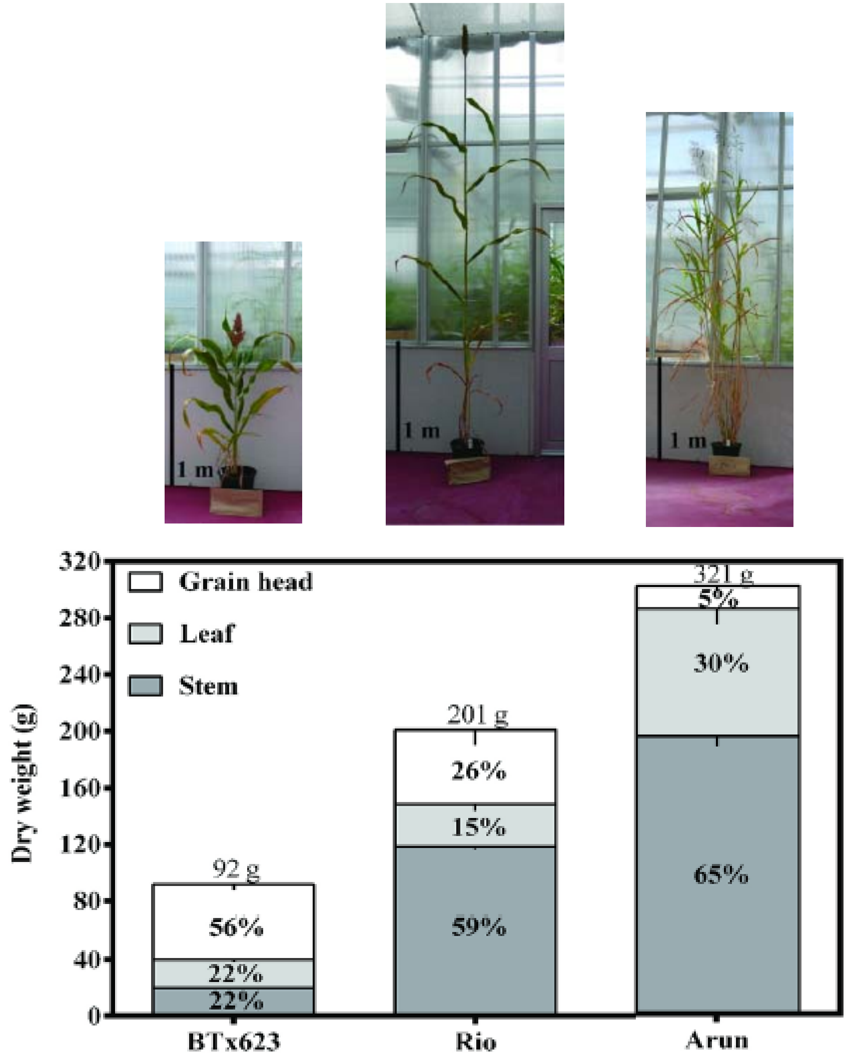
Food waste = 1.3 billion t (> 30% of total)

Land area associated with food waste = 1,400 Mha

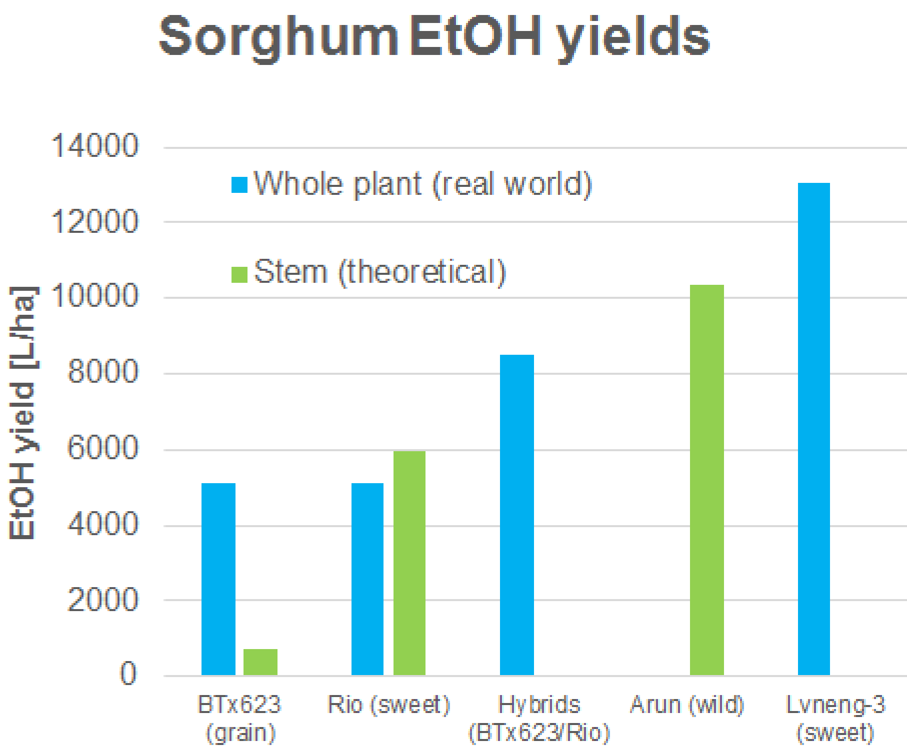
Footprint of food waste = 3.3 $GtCO_2$ (excl. LUC emissions)

FAO 2013, HLPE 2014, Wirsenius 2010

Improving yields



Byrt et al. 2016



- Improve using the non-food part of biomass
- 2nd/3rd generation biomass

BECCS – research needs

- More research on some gasification technologies necessary
- Verification for high amounts of co-firing >30% re pre-treatment and boiler modifications
- Bio-CCS scale-up issues
- Overcome uncertainty and lack of standard methodology for estimating bioenergy potentials and costs
- Inclusion of NETs/BECCS in more policies and accounting frameworks
- Clarify circumstances of double benefit (zero-carbon energy + negative emissions permits)
- Approaches to prevent carbon leakage
- Open question/debate: Does BECCS need more support than other NETs/Fossil-CCS?
- Need to explore other financial instruments than the CDM
- More research on impacts of BECCS on global trade and commodity markets

- Address the whole food-water-energy-climate nexus of BECCS, integrated approaches
- Water and carbon intensity of BECCS systems
- Address LUC issues, esp. iLUC (incl. measurement/quantification) and carbon debts
- Opportunities to free land for bioenergy production
- Monitoring systems for land management activities need improvement
- Investigating competition for land, feedstock and storage resources
- Supply chain optimisation for non-forest biomass
- Identify more “sweet spots” for BECCS
- Clarification of BECCS public perception and impact of CCS perception on BECCS, public outreach efforts, building up trust

Conclusions

- Ability of BECCS to deliver negative emissions important to achieve climate mitigation targets
- Majority of research suggests bioenergy potential of ~100 EJ/yr and BECCS potential of ~10 $GtCO_2$/yr
- Costs of BECCS comparable to Fossil-CCS, in the region of 60 – 250 $/$tCO_2$
- Several projects underway but lots more needed to build up confidence
- Policy, regulations and financial instruments for BECCS need development
- BECCS deployment will hinge on case-specific details, with sustainable biomass supply likely to be the linchpin
- Nexus-approach required due to complex sustainability issues

BECCS – good or bad thing?

My main conclusions:

- Will be very case-specific
- BECCS no silver bullet or complimentary ticket but deserves our fullest attention as we are running out of time and options

silverbulletbullion.com, 123rf.com, Mike Flanagan

ieaghg

Thank you, any questions?

Contact me at: jasmin.kemper@ieaghg.org

Website:	•	www.ieaghg.org
LinkedIn:	•	www.linkedin.com/groups/IEAGHG-4841998
Twitter:	•	https://twitter.com/IEAGHG
Facebook:	•	www.facebook.com/pages/IEA-Greenhouse-Gas-RD-Programme/112541615461568?ref=hl