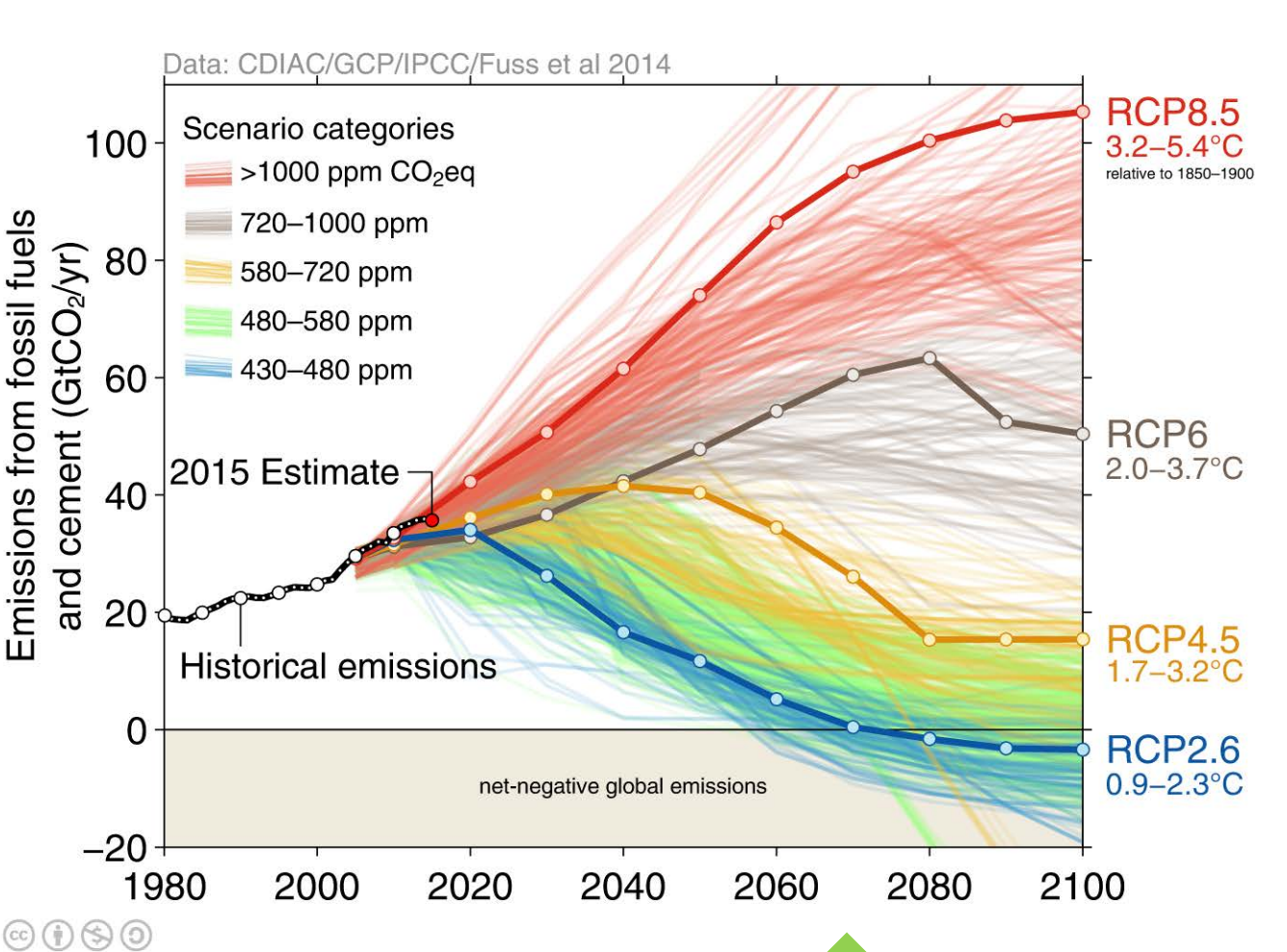
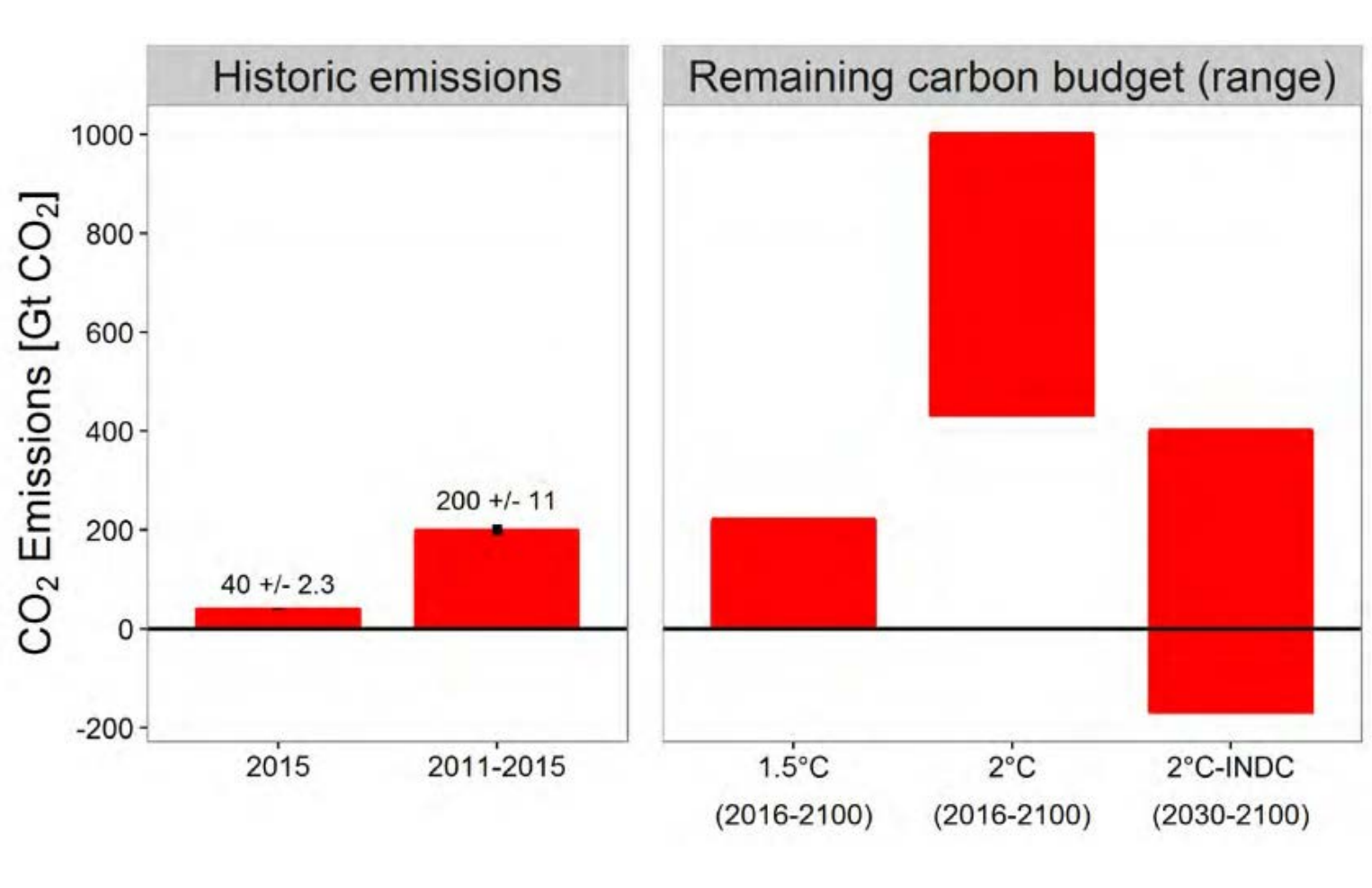


1.5°C and 2°C scenarios



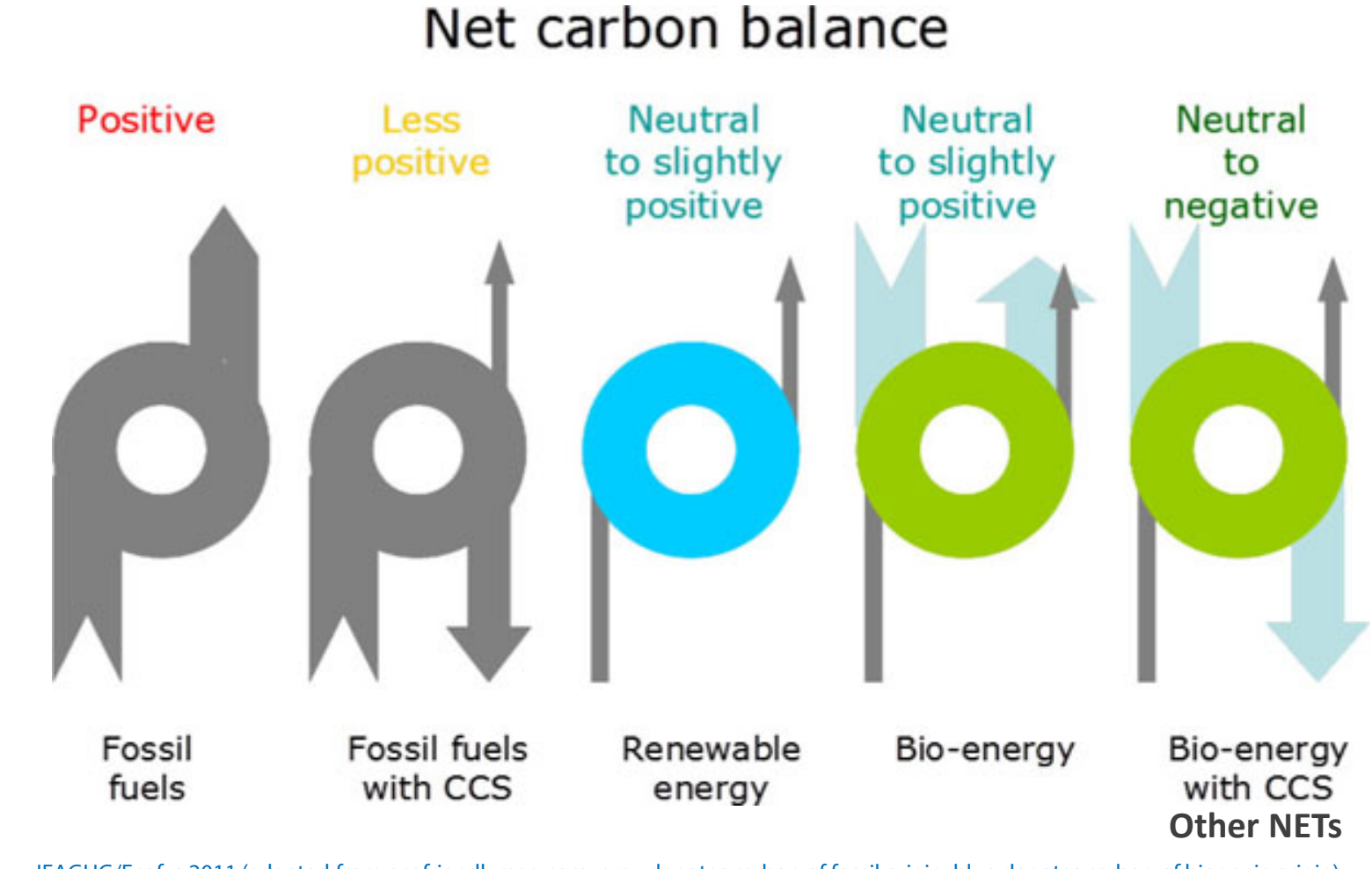
➤ **Net negative emissions are crucial for achieving a 1.5°C target**

Carbon budget



- Carbon budgets usually include fossil sources as well as land use change (LUC)
- Non-CO₂ greenhouse gases (GHGs) can contribute up to 33%
- Carbon budget 1750-2500 is ~3670 GtCO₂ → already used up half of this until 2009 → only 1800 GtCO₂ 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 GtCO₂/yr → quick erosion of carbon budget

Carbon 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

What are CCS, NETs and Bio-CCS/BECCS?

CCS (carbon capture and storage)

- Process of capturing, transporting and permanently storing CO₂ emission from anthropogenic large-point sources
- Capture**
 - Pre-combustion, post-combustion, oxy-fuel-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 MtCO₂/yr in operation, 7 with additional 11 MtCO₂/yr under construction (GCCSI 2016)

NETs (negative emission technologies)

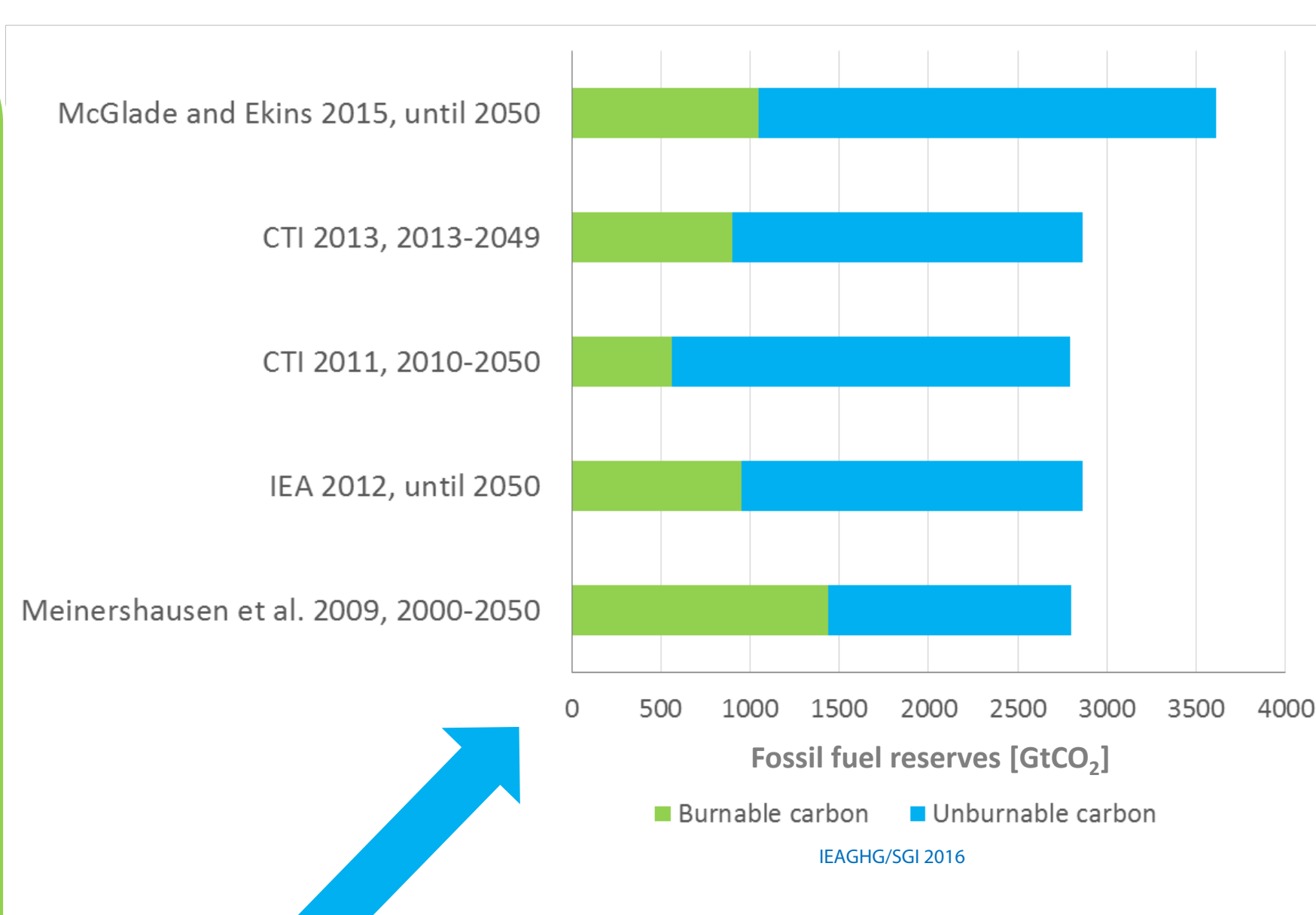
- Bio-CCS/BECCS (bioenergy with CCS)** – using biomass that has previously taken up CO₂ during growth to produce power/heat/fuels, then capturing and storing the emitted CO₂
- A/R (afforestation/reforestation)** – planting trees where previously (a) there were none or (b) they have been cut down
- DAC(S) (direct air CCS)** – capturing CO₂ directly from air
- EW/MC (enhanced weathering/mineral carbonation)** – spreading pulverised rock on land/water to take up CO₂ and form bicarbonate
- SOCS (soil organic carbon sequestration)** – storing CO₂ 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 CO₂ uptake by microorganisms for photosynthesis
- Cloud/ocean treatment** – (a) using alkalis to wash CO₂ out of the atmosphere, (b) using lime to absorb CO₂ from the oceans

Case study: Bio-CCS/BECCS

Bio-CCS/BECCS status

- Many studies conclude: Bio-CCS, incl. its CCS components, technically feasible as of today (TRL 3-7) (except microalgal biomass)
- Perceived „double benefit“: heat/power + negative emissions → would be less so for fuels due to release of CO₂ during combustion
- 5 operating Bio-CCS projects: 0.1-1 MtCO₂/yr (all ethanol based, 3 for EOR, 4 in US, 1 rather Bio-CCU), several more underway
- GHG accounting: only 2006 IPCC GLs, CDM/JI, Ca LCFS and EU RED/FQD cover Bio-CCS
- Plenty of research on public perception of CCS but very limited and contradictory on Bio-CCS
- Bio-CCS generally has lower profile than Fossil-CCS
- Main drivers/barriers for Bio-CCS:
 - CO₂/NG price, infrastructure/clusters, sustainable feedstocks, public perception

“Unburnable carbon” concept



“Unburnable carbon”:

- Carbon budget for emission scenarios implies → certain amount of fossil fuel reserves “unburnable”, i.e. their carbon not emittable, to stay within target
- CCS prevents/reduces emission of carbon to the atmosphere
- NETs can even remove historic emissions from the atmosphere
- Both are key to enable continued use of fossil fuels

Key messages from IEAGHG/SGI study:

- Investigated effect of CCS on unburnable carbon
- Impact of CCS is material until 2050 and further increases until 2100
- 11% resp. 32% more fossil fuels can be used with CCS in a 2°C scenario
- For scenarios < 2°C higher capture rates, i.e. >> 90%, might be necessary

Required negative emissions for 1.5°C until 2100:

~ 500-1000 GtCO₂ (6-12 GtCO₂/yr, when starting tomorrow!)

- Bio-CCS/ BECCS: 3.5-20 GtCO₂/yr
- SOCS: 2.5-4.5 GtCO₂/yr
- A/R: 4-12 GtCO₂/yr
- Biochar: 2.5-4.5 GtCO₂/yr
- EW: 0.7-3.6 GtCO₂/yr
- DAC(S): 3.6-12 GtCO₂/yr

Based on Smith et al. 2016

Most important NET trade-offs

- Impact on soil
- Energy demand
- Impact on albedo
- Water demand
- Costs
- Land demand

Main nexus concerns

- Competition: food vs bioenergy crops
- Shift of GHG/CO₂ 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 Bio-CCS systems
- Effects of increased fertiliser use
- Land availability and lock-in
- Land use change (LUC) impacts
- Biomass sustainability

Bio-CCS can reduce upward pressure on food prices by lowering carbon price and biomass demand (Muratori et al. 2016)

How to overcome the “lack” of land?

- Demand-side changes
- Yield increases
- Better land management

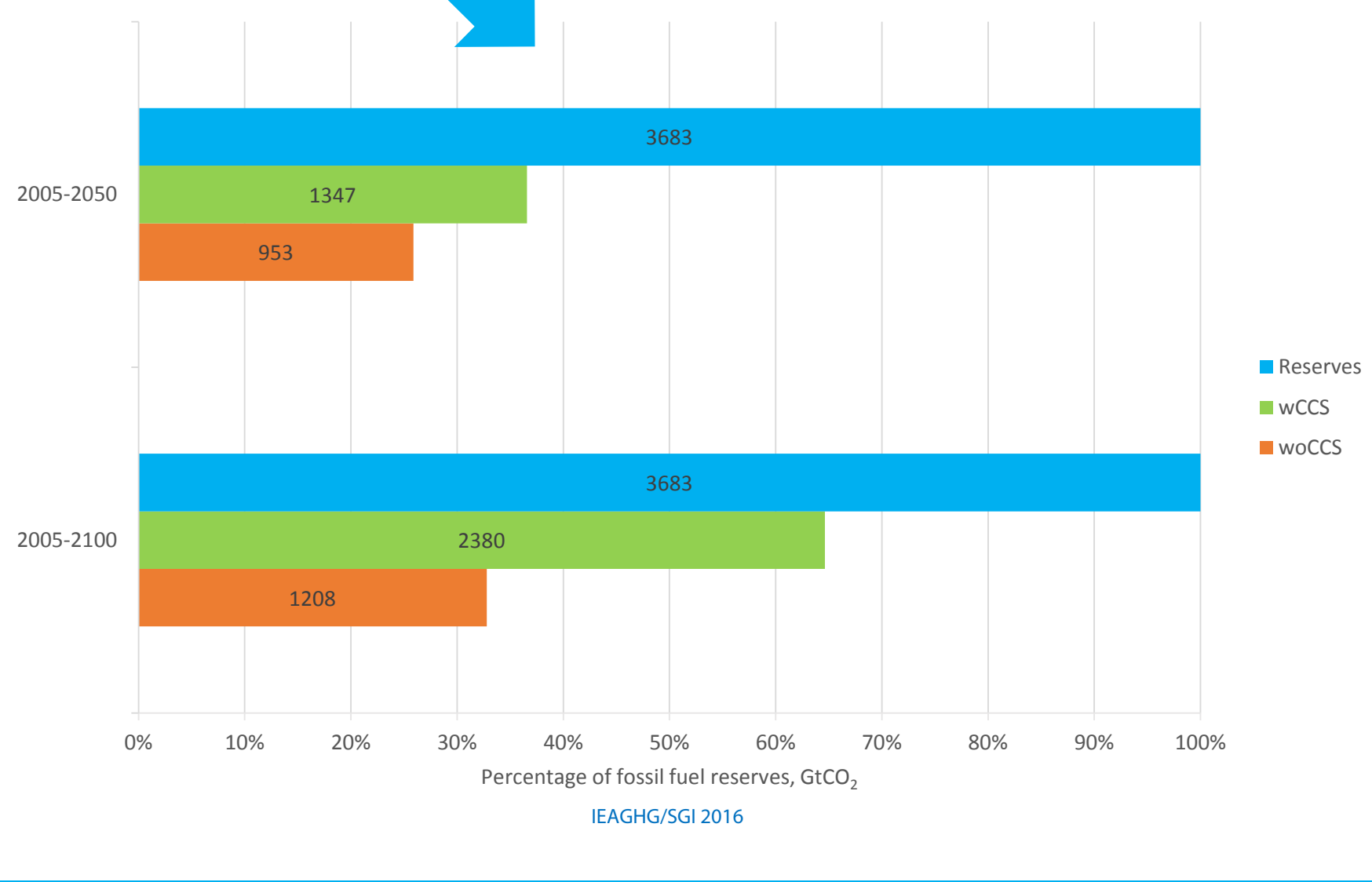
Land area in Mha (FAO 2010)

- pasture: 3600
- crops: 1100
- energy crops: 600

Needed for 100 EJ of bioenergy (NRC 2015)

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

- average use per person: 800
- increasing/decreasing household waste: 800
- bioenergy: 800
- not to animals and end up in meat/dairy: 800
- agricultural waste: 1000
- not to animals but wasted due to inefficiency: 1000
- not to animals but wasted due to inefficiency: 1000



Conclusions

- Due to quick erosion of remaining carbon budget for a 1.5°C scenario → timely action required!
- CCS technology components are mature and CCS can enable continued access to fossil fuels under carbon-constrained scenarios
- NETs, like Bio-CCS/BECCS, could make up for historic emissions and previous inaction
- Mitigation portfolio containing various options is best bet, as each has pros and cons
- Whole systems approaches required to address the food-water-energy-climate nexus

Further work requirements

- Evaluate/quantify the role of CCS and NETs on “unburnable carbon” under a 1.5°C scenario
- Quantification of Bio-CCS/BECCS nexus → water/land/carbon/energy intensities
- Identify the sweet spots for CCS and NET implementation
- For Bio-CCS/BECCS: develop/optimize supply chains for sustainable biomass
- Develop financial mechanisms and policy frameworks to support CCS and NETs

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