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Carbon Capture and Storage (CCS) and Negative Emissions in Integrated Assessment Models

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Introduction & Agenda

Matteo's research interest:

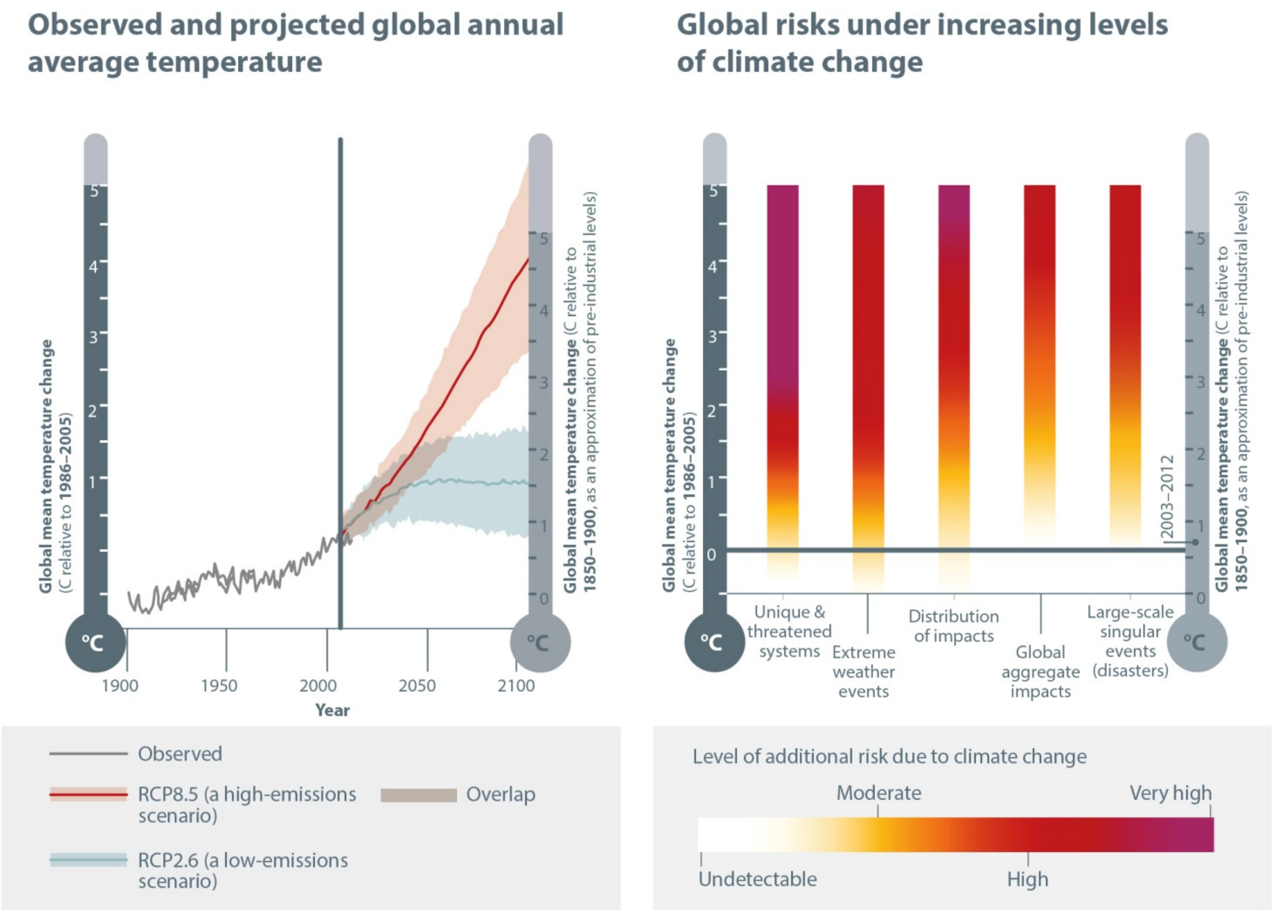
- **Energy:**
  - Shaped the evolution of modern society.
  - The energy industry accounts for **~10% of the global economy.**
  - Excessive **environmental impact**, including anthropogenic climate change.
  - Pivotal role in **geo-politics**, national security, and international climate change.
- **Transportation**:
  - **~30%** of energy use and GHG emissions.
  - Highly-diverse **mobile** energy systems, stringent requirements, limited fuel alternatives.
  - Intertwined and **connected** to other systems (land, water, infrastructure, electricity).

Today's talk:

- Integrated Assessment Modeling (**IAM**) and the Global Change Assessment Model (**GCAM**).
- Role of carbon capture and storage (**CCS**) across sectors and fuels.
- Global economic consequences of deploying bioenergy with carbon capture and storage (**BECCCS**) and **net negative emissions** in long-term transformation pathways.

Integrated Assessment Modeling

Climate change mitigation has become a **cornerstone of energy policy**, and a major driver of the development and adoption of **new technologies** worldwide.

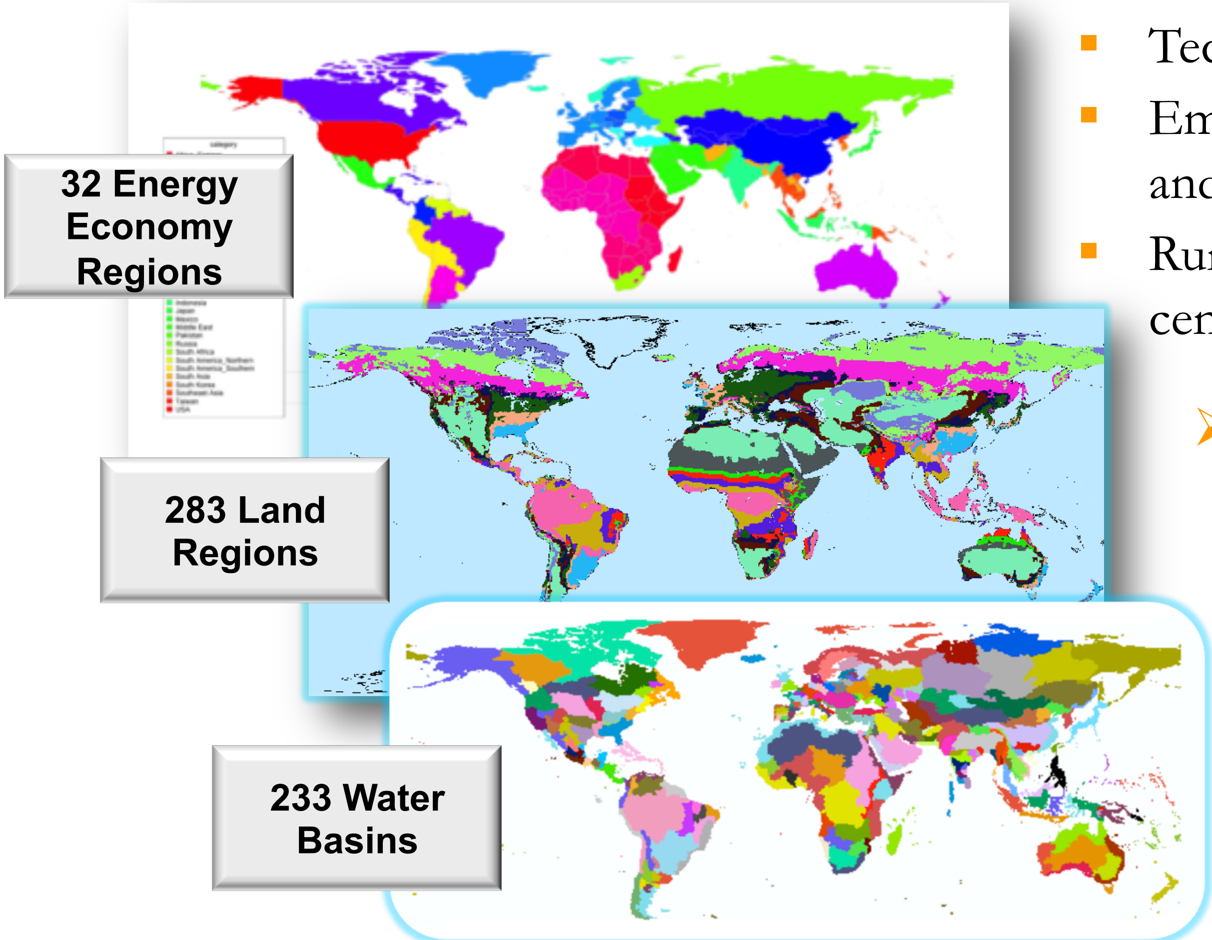


Source: 2014 IPCC Assessment Report

The Global Change Assessment Model (GCAM)

GCAM is a global long-term integrated assessment model

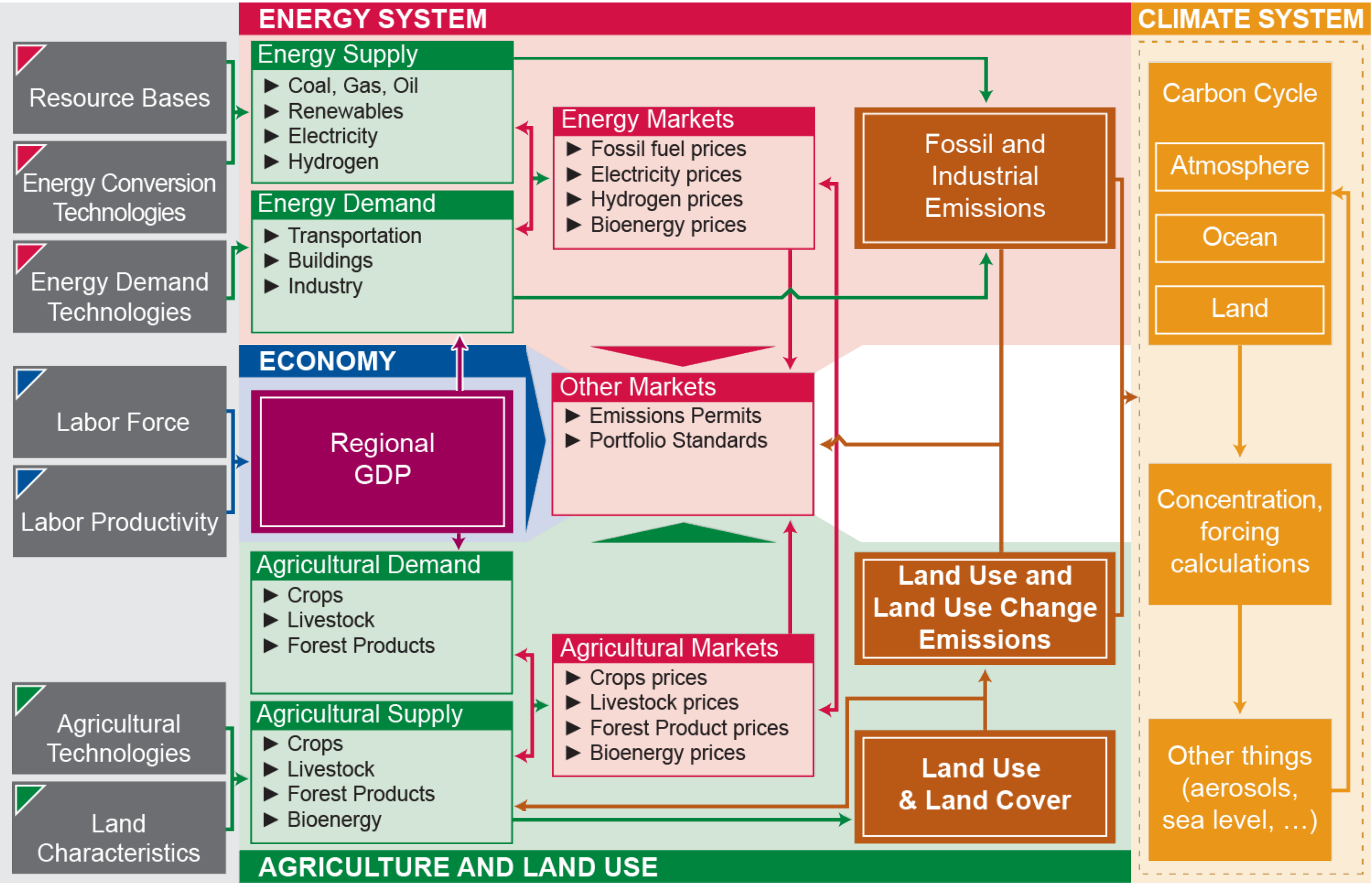
GCAM links **Economic**, **Energy**, **Land-use**, **Water**, and **Climate** systems



- Technology-rich model
- Emissions of 16 greenhouse gases and short-lived species.
- Runs through the end of the century in 5-year time-steps.

  - Dedicated to integrated, interdisciplinary research, modeling and analysis of Human-Earth systems to inform policy, strategy and decisions.

The Global Change Assessment Model (GCAM)



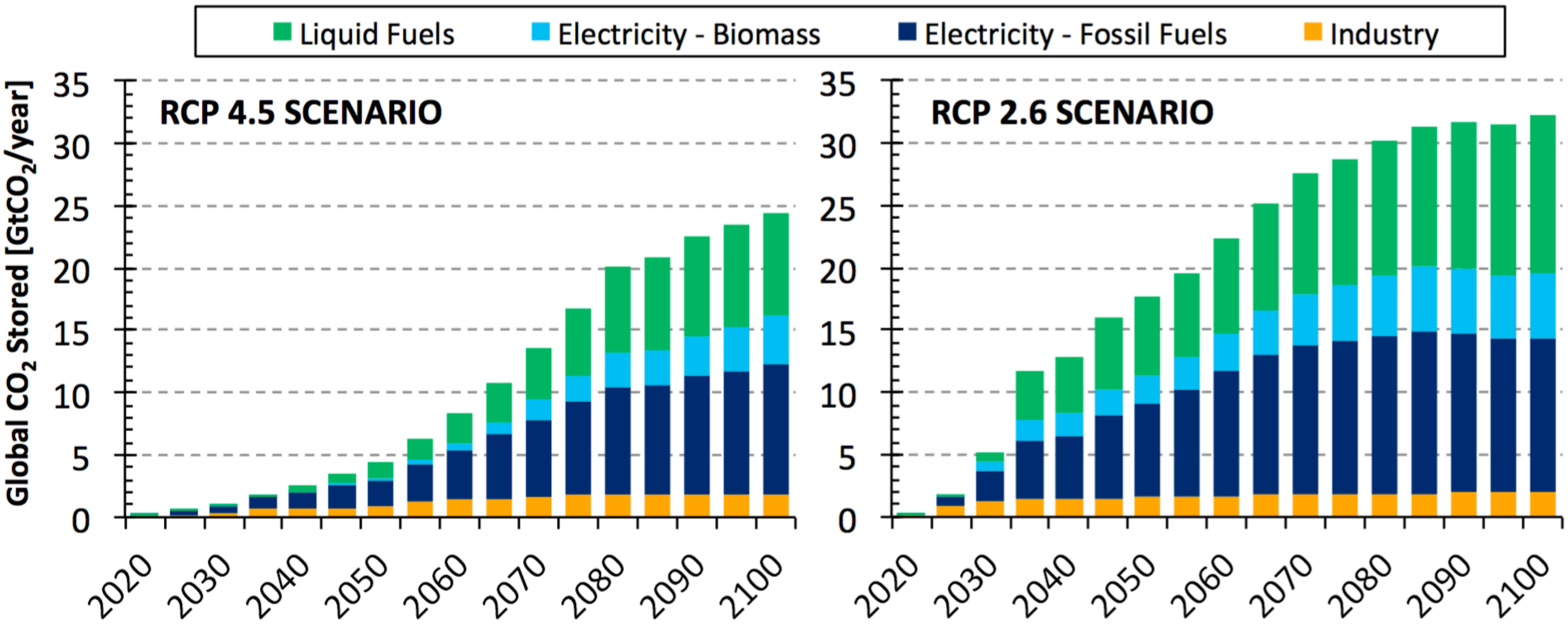
The Role of CCS across Fuels and Sectors

- **Carbon capture and storage (CCS)** has been proposed as one option for reducing CO_2 emissions from large stationary point sources.
- Recent studies have indicated that CCS can **limit climate change mitigation costs** and more generally make it easier to **meet ambitious goals** also by introducing negative emissions that allow for continued emissions in those sectors that are harder to decarbonize.
- The conventional wisdom suggests that CCS will **primarily be coupled with power plants** and used mainly in conjunction with fossil fuels.
- However, CCS deployment is **currently very limited**.

In this study we explore the **deployment path of CCS in different sectors** (electricity, liquid fuels, industry), which is driven by **technology cost** projections that are affected by **significant uncertainty**, with current cost projections higher than those from the last decade.

CCS Deployment in GCAM

- The **scale** of CCS deployment in GCAM largely depends on the **stringency of the climate change mitigation goal.**
- The deployment of CCS technologies is **not limited to fossil fuels, nor to power plants**, as suggested by some studies.



The Role of CCS across Fuels and Sectors

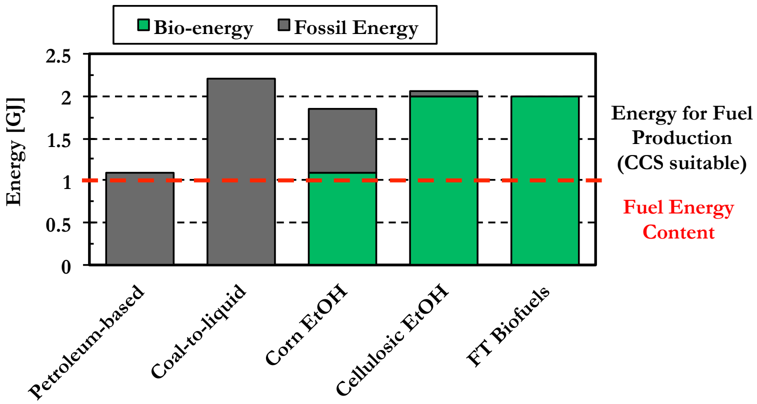
- **<u>Industrial applications</u>** may serve as **early applications** of CCS, but deployment of CCS at a scale that contributes significantly to climate change mitigation over the 21st century requires deployment in **sectors with greater emissions**.

- Deployment of CCS coupled to electricity and fuel production is driven by their **relative cost and CO_2 emissions savings compared to a baseline**.

- In the **<u>electricity sector</u>** this is largely **driven by CCS cost adders**, measured by cost of CO_2 avoided (\$/tCO_2).

- In the production of **<u>liquid fuels</u>** the use CCS becomes effective only when coupled to the production of biofuels.

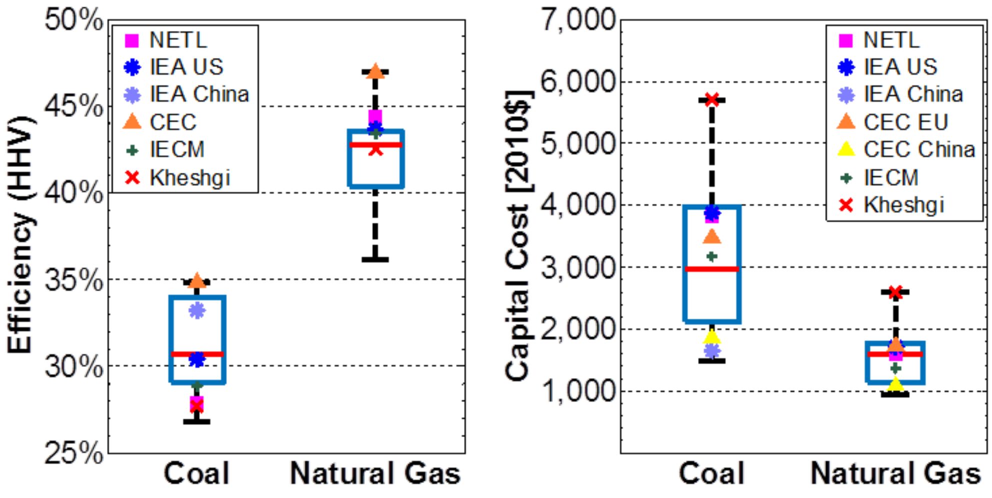
- Compared to oil refining, the cost of biofuels with CCS is driven by the **biofuel production cost**: CCS cost adders are responsible for a limited cost increase.



The Role of CCS across Fuels and Sectors

Carbon capture and storage technologies coupled to power plants show a **major degree of uncertainty** regarding both efficiency and cost.

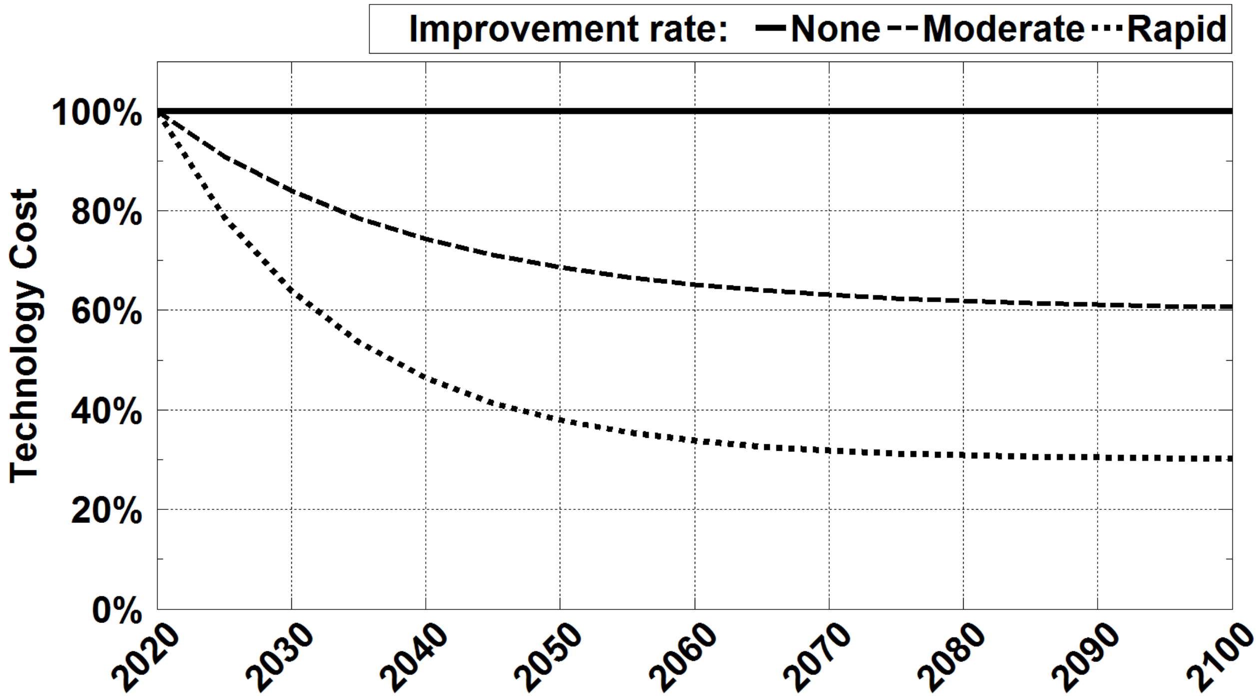
Even **larger uncertainty is associated with production of biofuels** coupled with CCS.



- We explore this technology uncertainty by simulating **different scenarios assuming current best estimates for CCS technologies and different improvement rates over time**, so as to bound potential future technological improvements for CCS technologies coupled to power plants or biofuel production facilities.

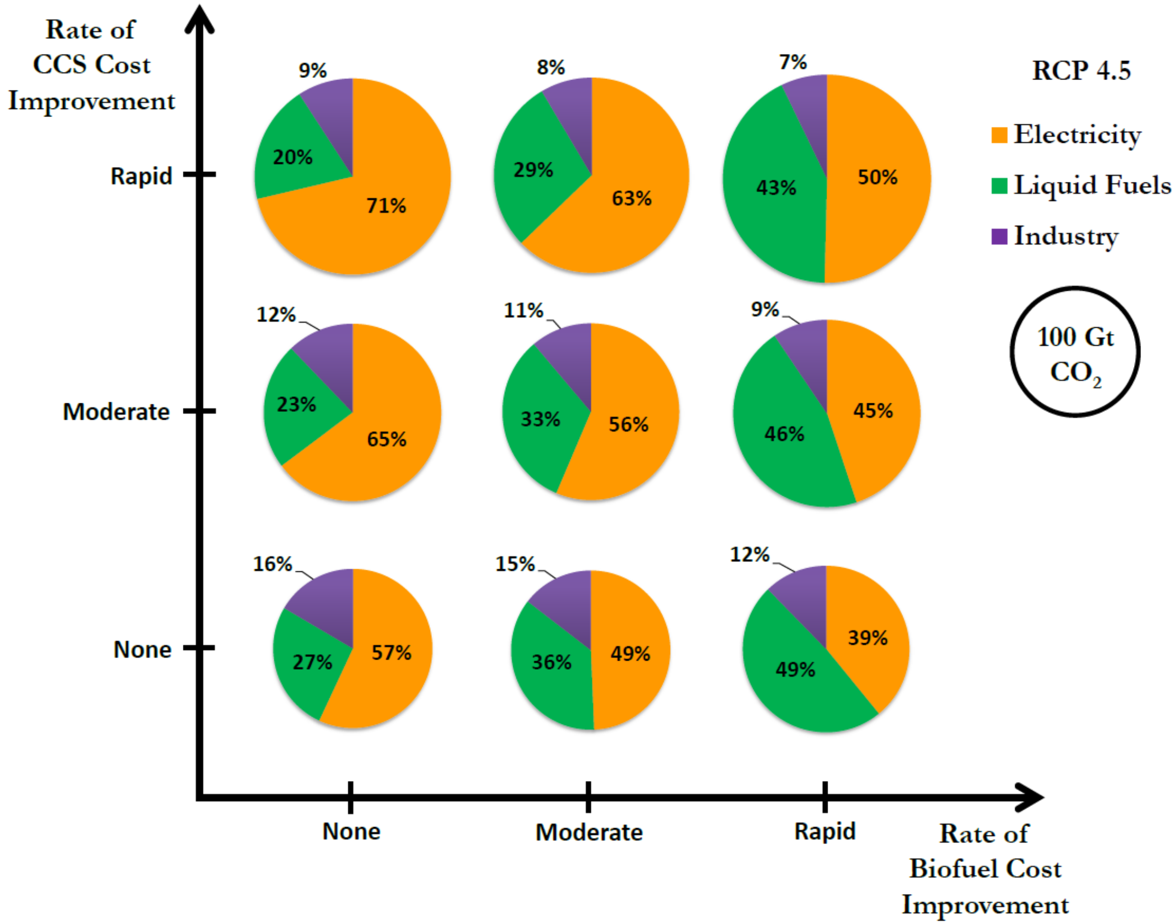
The Role of CCS across Fuels and Sectors

- In particular, we assume that *Nth-of-a-kind* CCS technologies coupled to production of electricity and liquid fuels become available in 2020, at the current best estimate cost.
- Starting from 2020 we consider **3 scenarios of cost reduction over time** for CCS, so as to represent possible technology improvements until the end of the century:



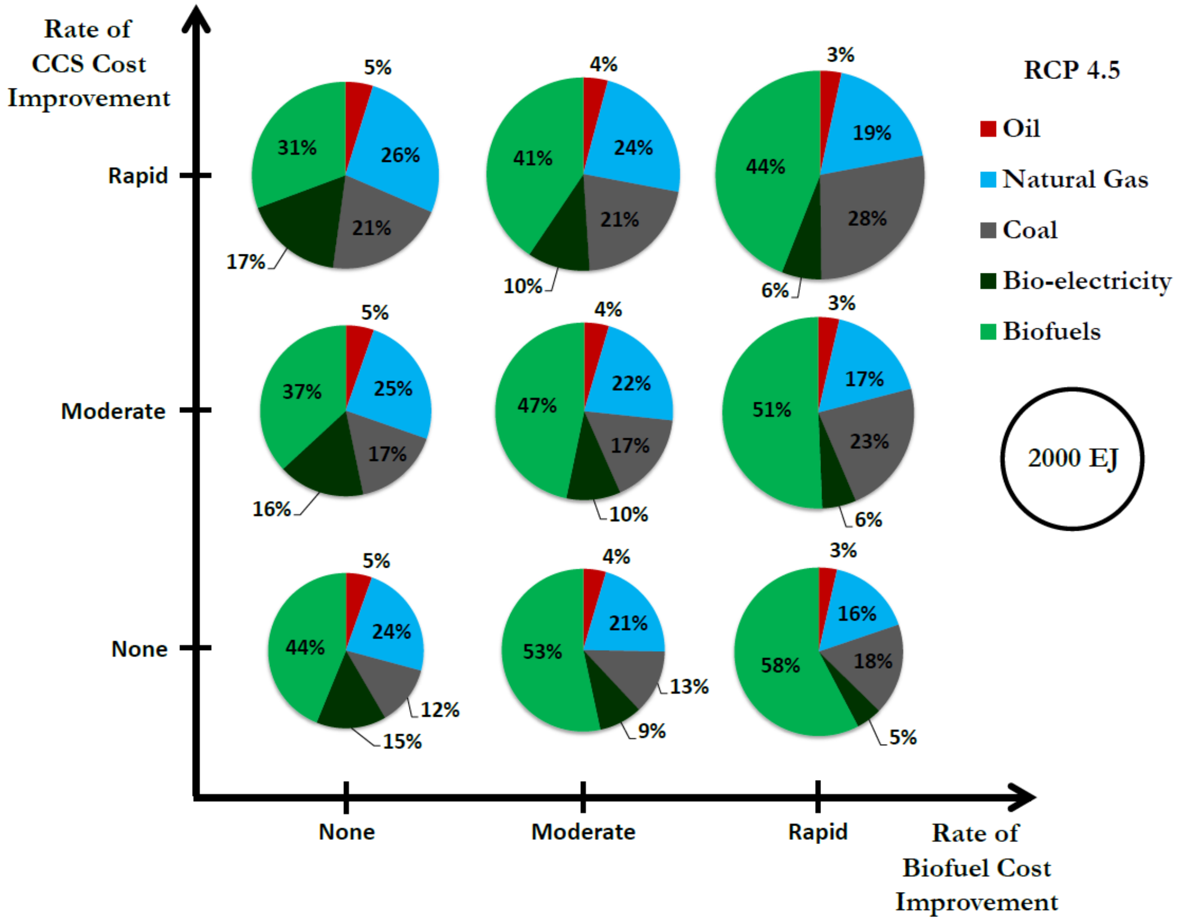
CCS across Sectors

- CCS technologies are **not only coupled to electricity** generation but also to the production of biofuels **across a range of technology cost assumptions** and different **levels of climate change mitigation**.



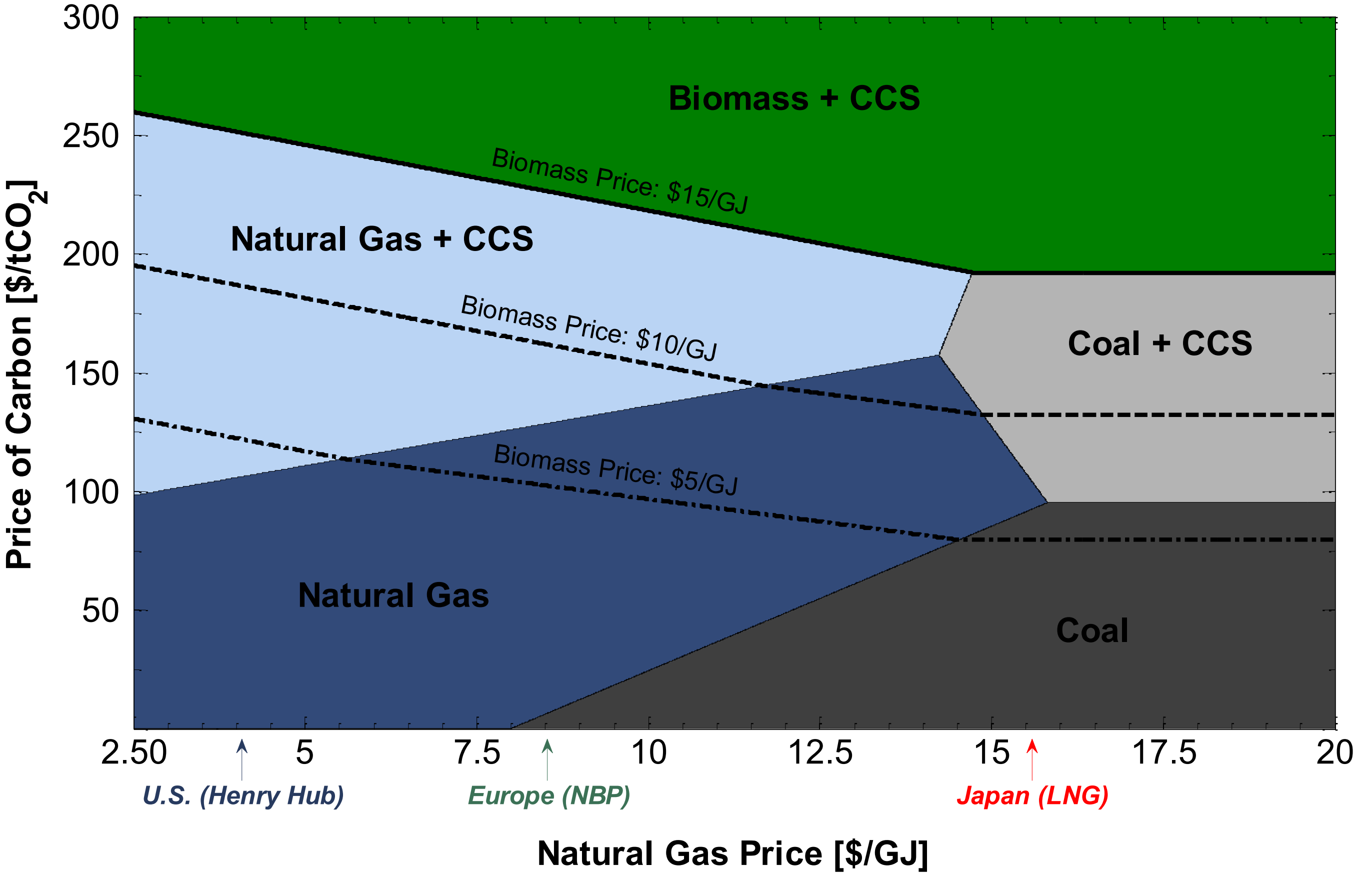
CCS across Fuels

- CCS coupled with **biomass becomes increasingly competitive as the carbon price increases** because of the negative emissions resulting from the capture and storage of the CO_2 contained in biomass.



CCS in the Electricity Generation Sector

- The fuel choice for CCS applications in the electricity sector in GCAM is driven by the **levelized costs of electricity** (LCOE)
- CCS technologies become competitive at a **sufficiently high carbon prices**.



CCS Deployment: Conclusions

- Deployment of CCS depends on **future technology characteristics**, subject to significant **uncertainty**.
- CCS is **not limited to power plants**, as the conventional wisdom suggests. There is significant potential for long-term climate change mitigation from the use of CCS in both the **electricity and liquid fuels** sectors.
- When all sectors are considered, **CCS is coupled to bioenergy** more than to fossil fuels in most of the scenarios over the 21^{st} century
- The **future energy system may look very different** than the energy system of today, thus potential applications for CCS may be very different than those that are apparent. B**ioenergy** is currently a small portions of the global energy mix, but it could **potentially have a substantially larger role over the 21^{st} century**, particularly when used in conjunction with CCS.
- Future research on energy transformation pathways should focus more heavily on the practical implications of **widespread CCS and BECCS deployment** to evaluate feasibility of proposed scenarios.

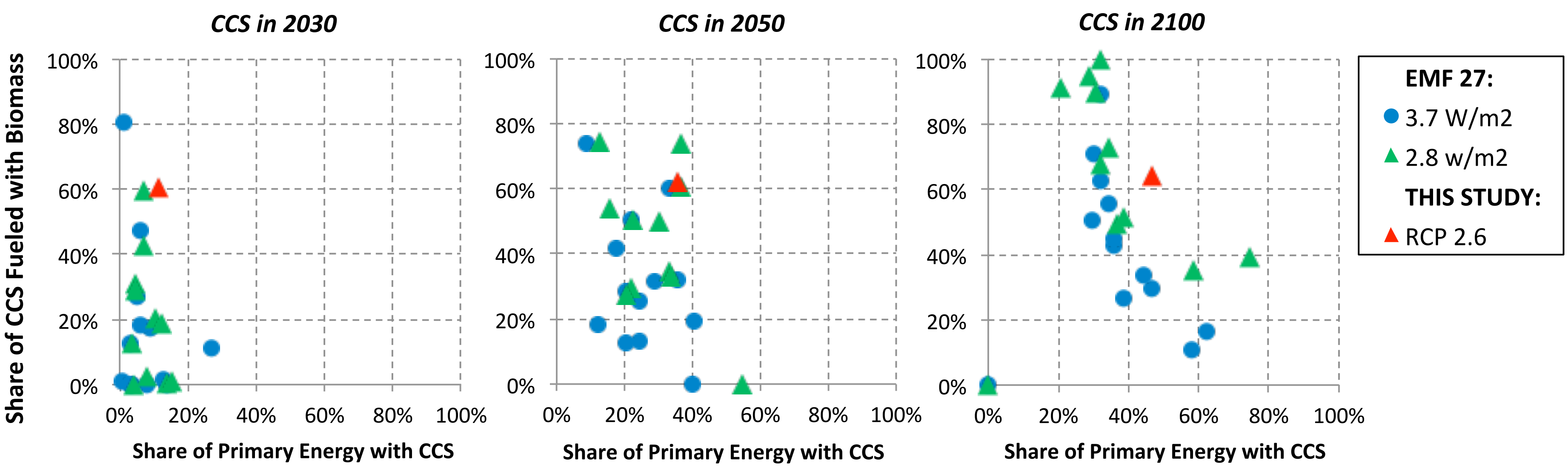
Bioenergy with Carbon Capture and Storage (BECCS)

- The latest **IPCC** Assessment Report (AR5) concludes that achieving climate stabilization at levels consistent with **less than 2°C temperature increase** above the pre-industrial level will require sustained greenhouse gas (GHG) emission reductions, leading to **near-zero or negative emissions towards the end of this century.**
- **Bioenergy with carbon capture and storage (BECCS)** is considered a potential source of net negative carbon emissions.
- However, **little is known empirically about BECCS**. Although BECCS could allow recovery from an emissions overshoot, **the effectiveness of BECCS has not been proven at large scales**, and BECCS might never reach technological maturity.

In this study we use the Global Change Assessment Model (GCAM) to explore the **global economic implications of large-scale negative emissions related to bioenergy with CCS** in scenarios limiting global temperature rise to **2°C**.

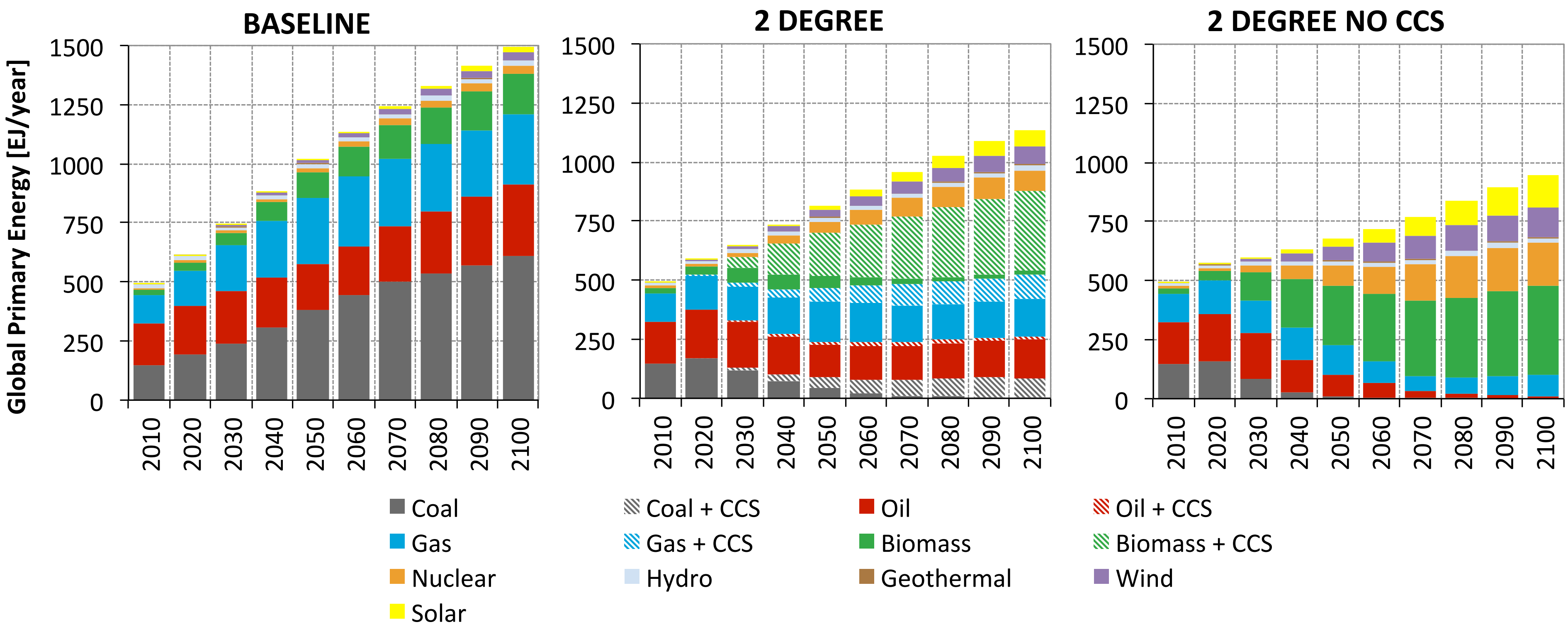
Use of BECCS in IAM

- IA models project a **significant share of primary energy with CCS** technologies by the end of the century, especially in stringent climate scenarios, **with high reliance on BECCS**.



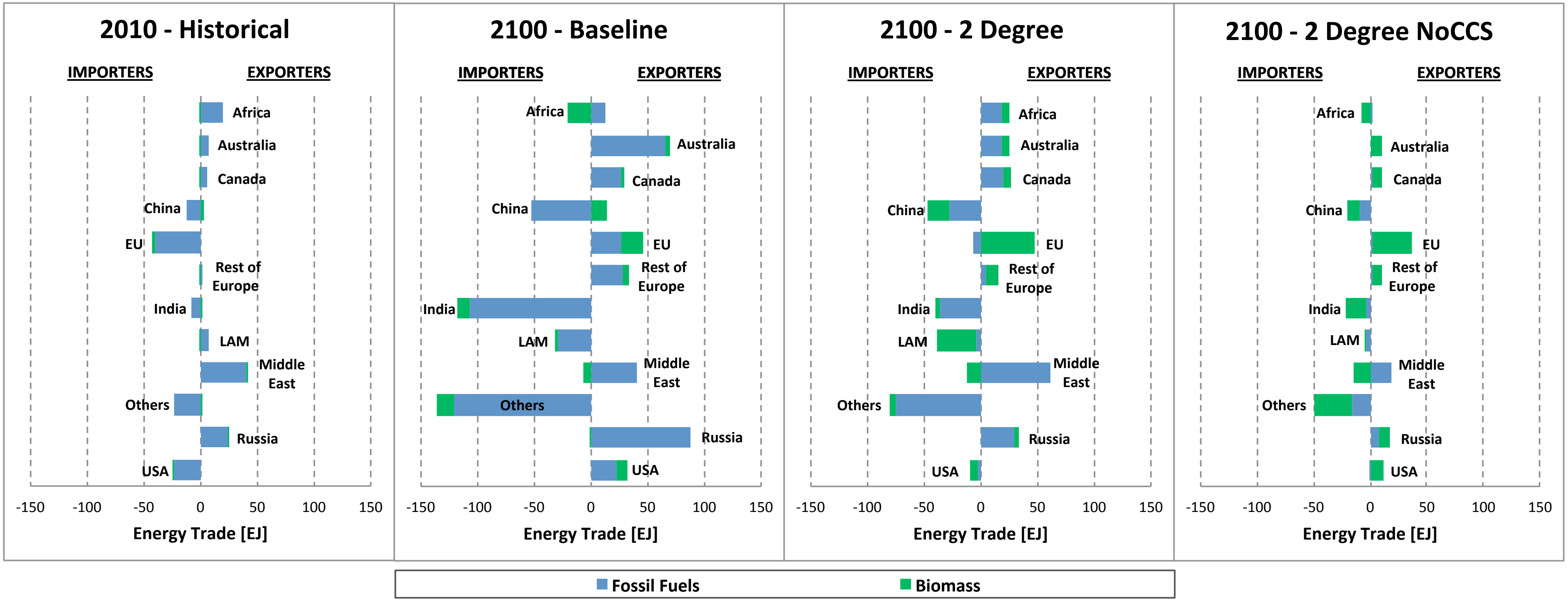
Global Energy Use in 2 °C Scenarios: CCS Focus

- In a 2°C scenario (RCP 2.6) primary energy use is **considerably reduced** compared to a baseline, with **significant CCS** deployment (>50% BECCS by 2100).
- If **CCS is not available the energy reduction is more pronounced and more biomass is used.**



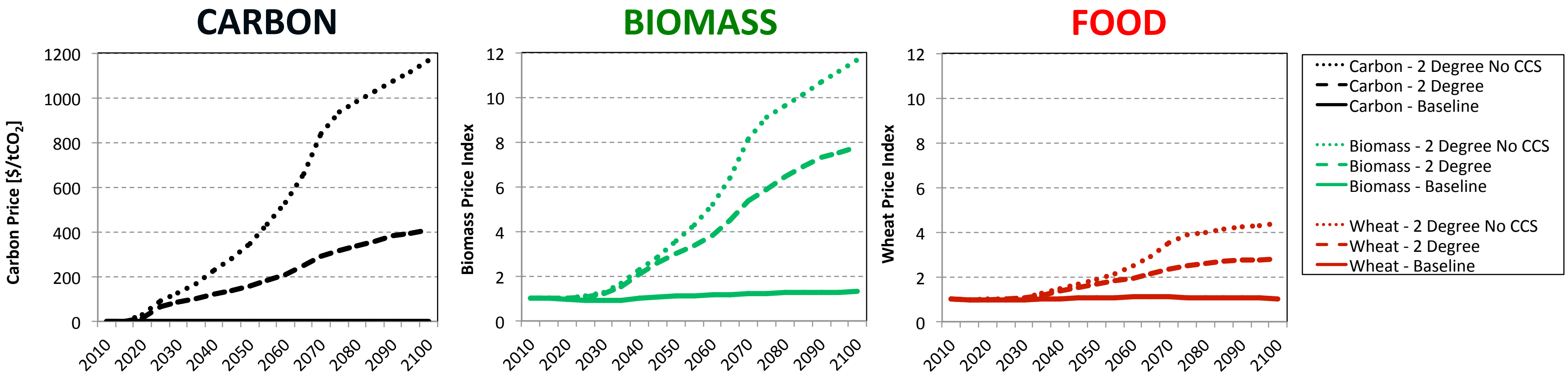
Global Energy Flows

- The imposition of a **mitigation policy increases biomass use and reduces fossil fuel use** compared to the Baseline scenario; however, **the extent of that reduction depends on the availability of CCS**.
- **Without CCS energy trade is almost entirely bioenergy trade** by 2100: fossil fuel use and therefore trade are effectively extinguished.



Carbon Price: Impact of Biomass and Food Prices

- The increased use of biomass due to the climate change mitigation policies leads to a **greater competition for the use of arable land**, putting **significant pressure on the price of biomass and various food products.**
- CCS availability, and BECCS in particular, **reduces the upward pressure on food crop prices** by lowering carbon prices and lowering the total biomass demand.



Implications of BECCS Deployment

- The availability of CCS, and BECCS in particular, has a substantial effect on the **carbon price required to mitigate climate change**, and could reduce the cost of mitigating climate change. However, both bioenergy and CCS face **technological and institutional challenges** in their deployment.
- Energy trade: **limiting climate change reduces fossil fuel use**. However, **CCS tends to temper the decline in fossil fuel trade** by reducing emissions when coupled to fossil fuels and offsetting them when coupled to bioenergy.
- **Without CCS energy trade is almost entirely bioenergy trade** by 2100: fossil fuel use and therefore trade are effectively extinguished.
- The introduction of a **carbon price and the large-scale use of bioenergy** trigger a response in the land-use and agricultural system that **increases revenues from the use of land**.
- **Technological and institutional challenges** related to large-scale bio-energy and CCS deployment **need to be addressed before scenarios such as the ones presented here could be confidently relied upon.**

References & Acknowlegements

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- M Muratori, K Calvin, M Wise, P Kyle, and J Edmonds. "**Global economic consequences of deploying bioenergy with carbon capture and storage (BECCS)**." *Environmental Research Letters* 11, no. 9 (2016): 095004.

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Questions?

Thank you!

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ABSTRACT

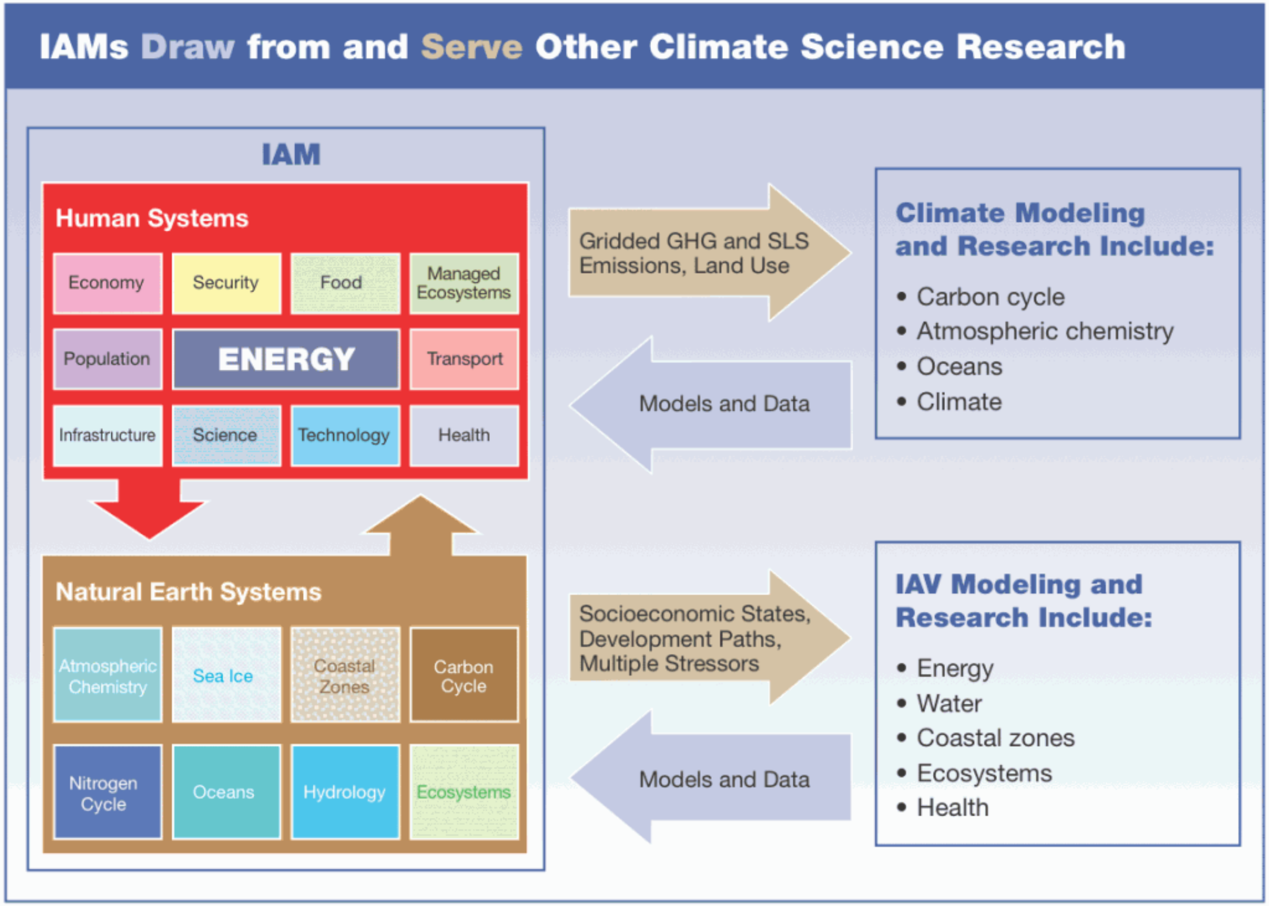
Carbon capture and storage (CCS) is broadly understood to be a key mitigation technology, yet modeling analyses provide different results regarding the applications in which it might be used most effectively. The GCAM model consistently shows significant deployment in electricity generation and in liquid fuels production, under different future technology cost assumptions, with bioenergy with CCS (BECCS) often the dominant application.

However, the viability and economic consequences of large-scale BECCS deployment are not fully understood. We explore the relationship between carbon prices, food-crop prices and use of BECCS, showing that the carbon price and biomass and food crop prices are directly related. We also show that BECCS reduces the upward pressure on food crop prices by lowering carbon prices (which also reduces climate change mitigation cost to society) and lowering the total biomass demand in climate change mitigation scenarios. All of this notwithstanding, many challenges, both technical and institutional, remain to be addressed before BECCS can be deployed at scale.

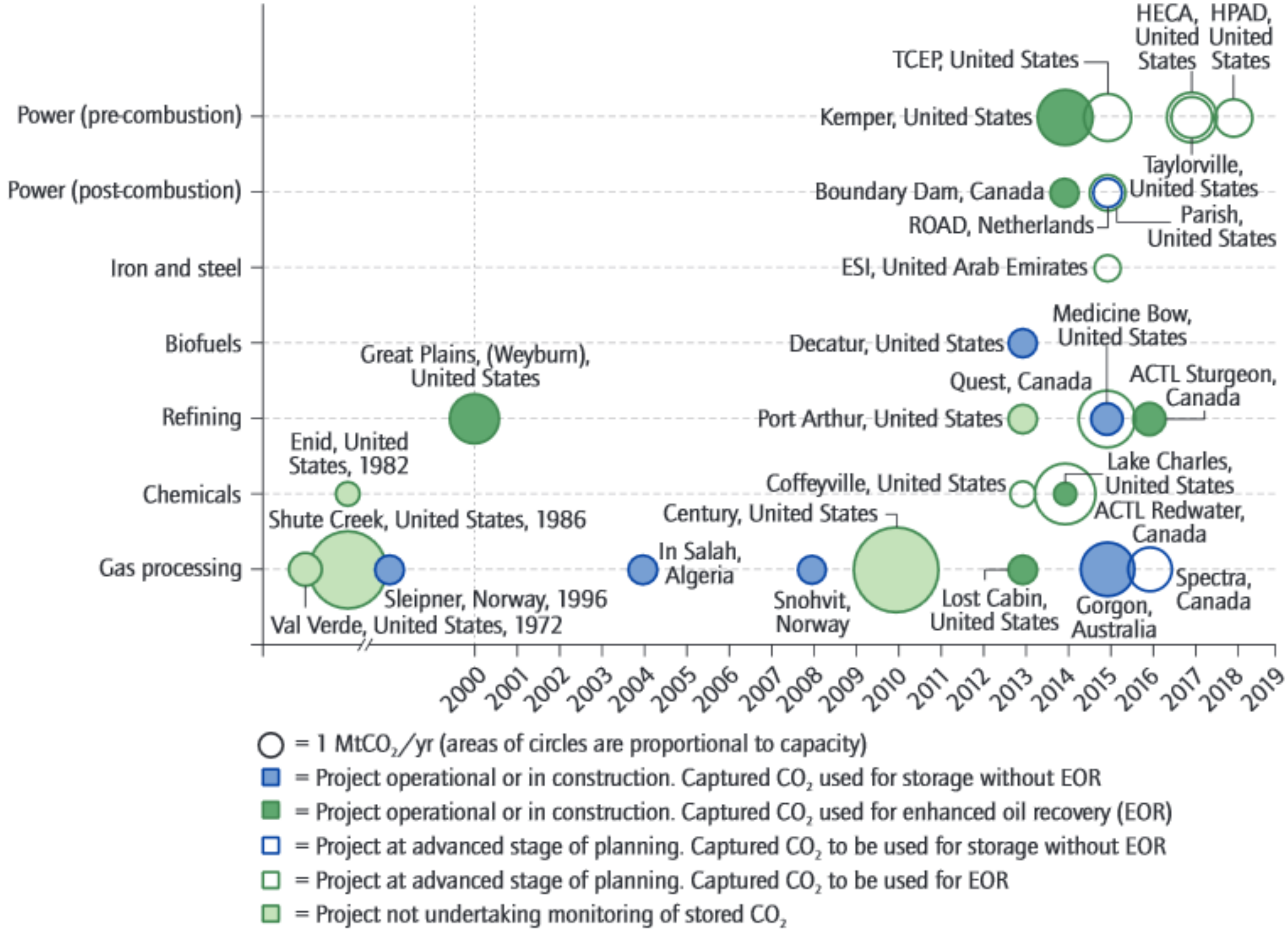
As such, this study challenges the view that CCS will primarily be coupled with power plants and used mainly in conjunction with fossil fuels, and suggests greater focus on practical implications of significant CCS and BECCS deployment to inform energy system transformation scenarios over the 21st century.

Integrated Assessment Modeling (Definition)

Integrated: combining knowledge from multiple domains into a single framework.
Assessment: generate scientific results and useful information for decision making.
Modeling: idealized representation of Human-Earth systems and their interactions.



Large-scale CCS projects in operation, under construction or at an advanced stage of planning as of end-2012:



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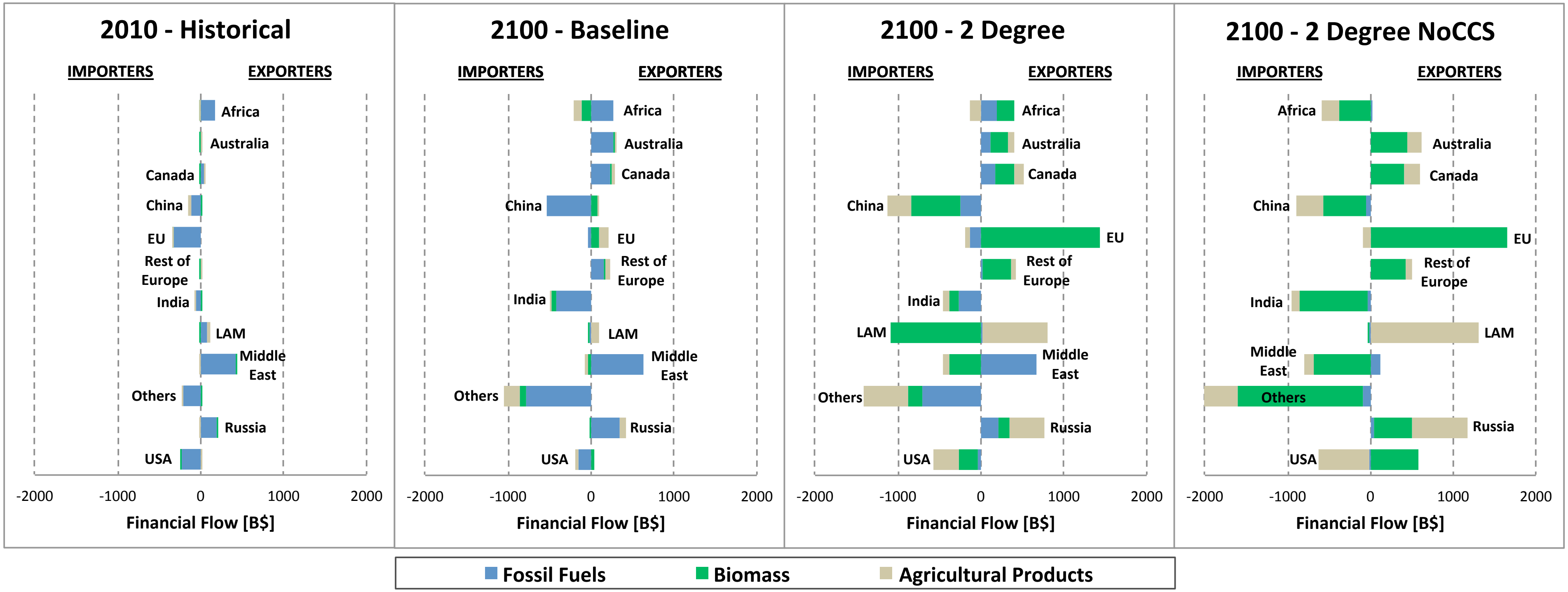

2010 - Historical
IMPORTERS
EXPORTERS
Africa
Australia
Canada
China
EU
Rest of Europe
India
LAM
Middle East
Others
Russia
USA
-2000
-1000
0
1000
2000
Financial Flow [B$]
2100 - Baseline
2100 - 2 Degree
2100 - 2 Degree NoCCS
Fossil Fuels
Biomass
Agricultural Products