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Bioenergy and Deep Decarbonization

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Outline

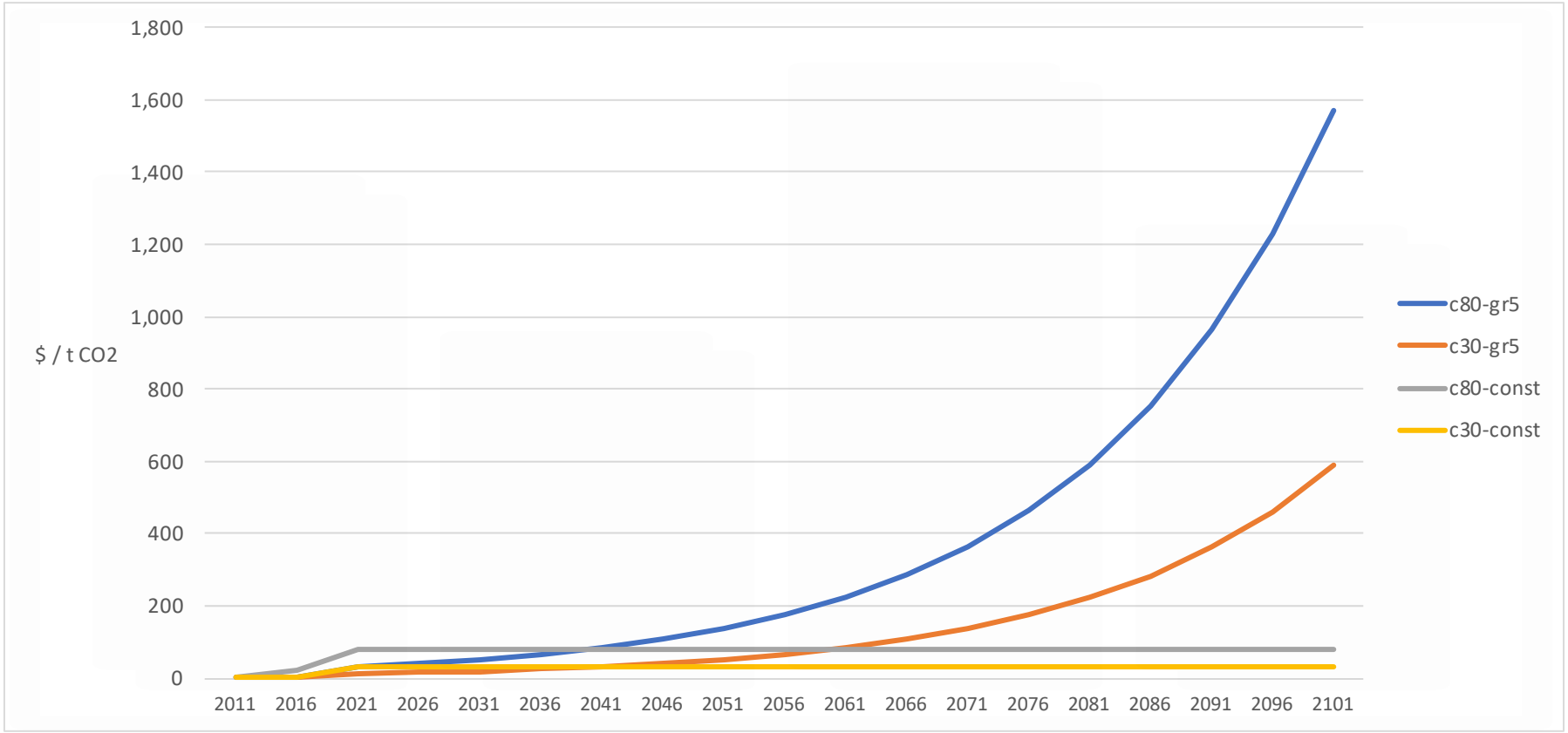
- Scenarios based on NAVIGATE and AgMIP deep decarbonization studies
- Mitigation scenarios simulated in Future Agricultural Resources Model (FARM)
  - Computable general equilibrium
  - 13 world regions
  - Five-year times steps beginning in 2011 (base year for GTAP 9 social accounting matrix) through 2101
- Bio-electricity with CO_2 Capture and Storage (BECCS) and Afforestation become major land uses
- Implications for land use and agricultural intensification

Mitigation scenarios

Scenario	Economy-wide CO_2 price	BECCS	Afforestation
Reference			
C30-gr5 with Afforestation and BECCS	X	X	X
C80-gr5 with Afforestation and BECCS	X	X	X
C80-gr5 with Afforestation	X		X
C80-gr5 with BECCS	X	X	

The Reference scenario is based on Shared Socio-economic Pathway 2 ("middle-of-the-road).
C30-gr5: CO_2 prices reach \$30 / t CO_2 in 2040 and increase 5% per year thereafter.
C80-gr5: CO_2 prices reach \$80 / t CO_2 in 2040 and increase 5% per year thereafter.

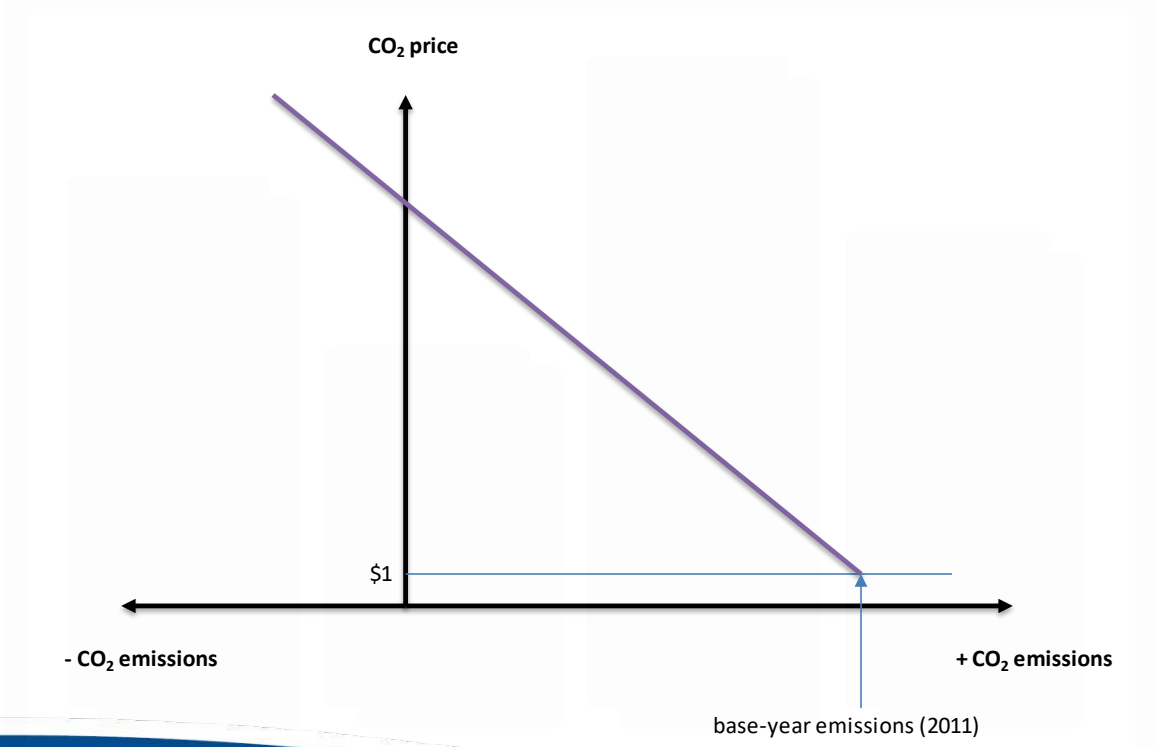
CO_2 price scenarios



Source: NAVIGATE model intercomparison project

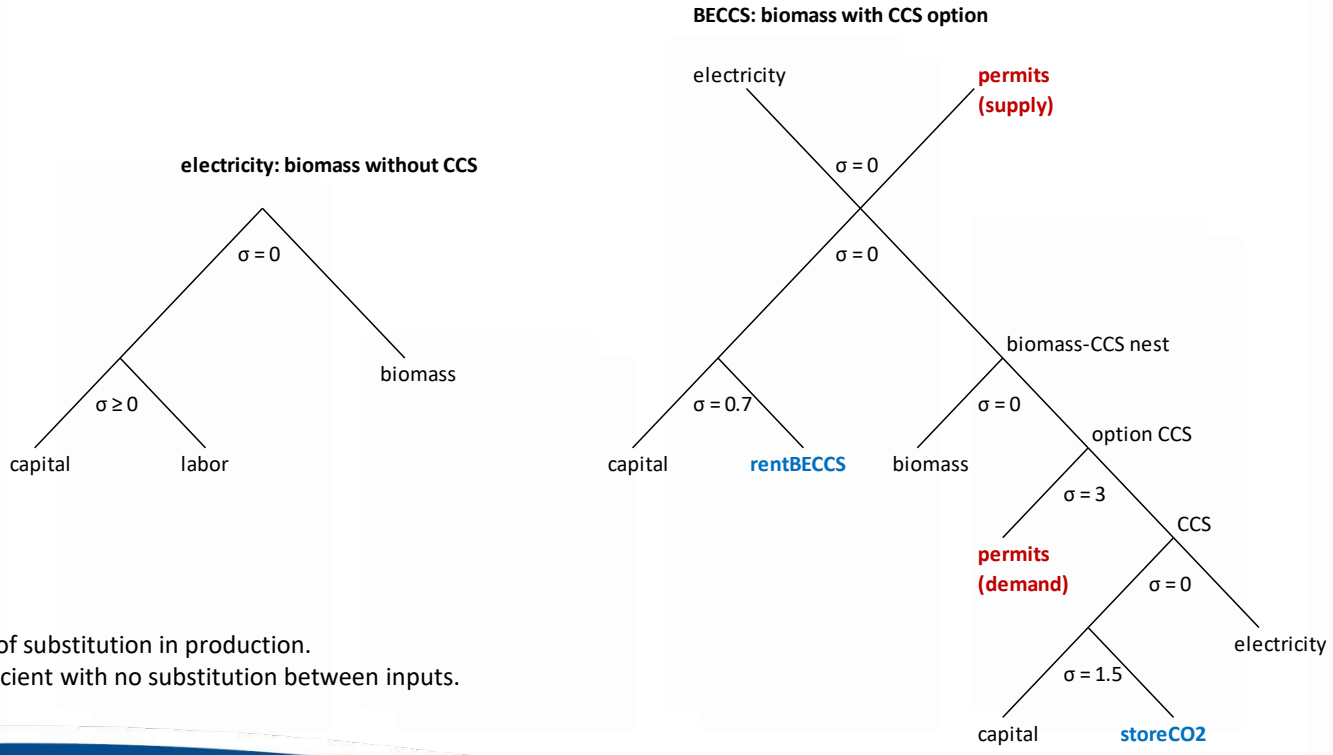
Conceptual demand for “negative emissions”

- “Negative emissions” is not the best term because the general public will not understand what this means. “Carbon dioxide removal” is clearer.
- As the CO_2 price increases, economy-wide demand for emissions decreases and eventually becomes negative
- Can the NAVIGATE price scenarios drive net global CO_2 emissions below zero by 2100 in the FARM model? What model structure can simulate this behavior?



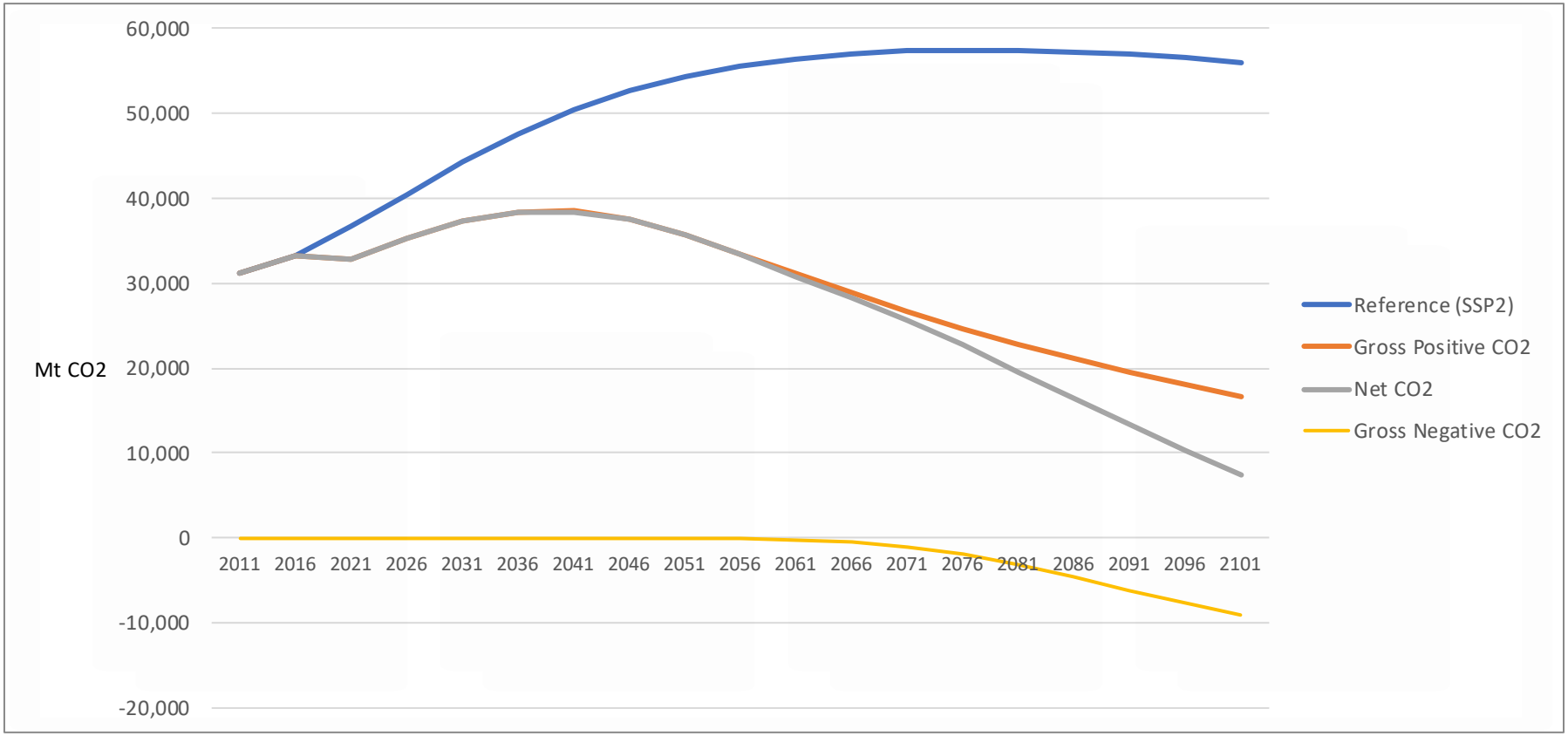
Bioenergy with CO_2 capture and storage (BECCS)

- Bio-electricity used with CO_2 Capture and Storage (CCS)
- Energy crop (switchgrass) as feedstock
- Joint products of electricity and CO_2 removal
- CCS becomes active at high CO_2 prices, when it is cheaper to capture and store CO_2 than pay CO_2 price
- At low CO_2 prices, the supply of permits cancels demand for permits, and the model operates as if CCS is not an option



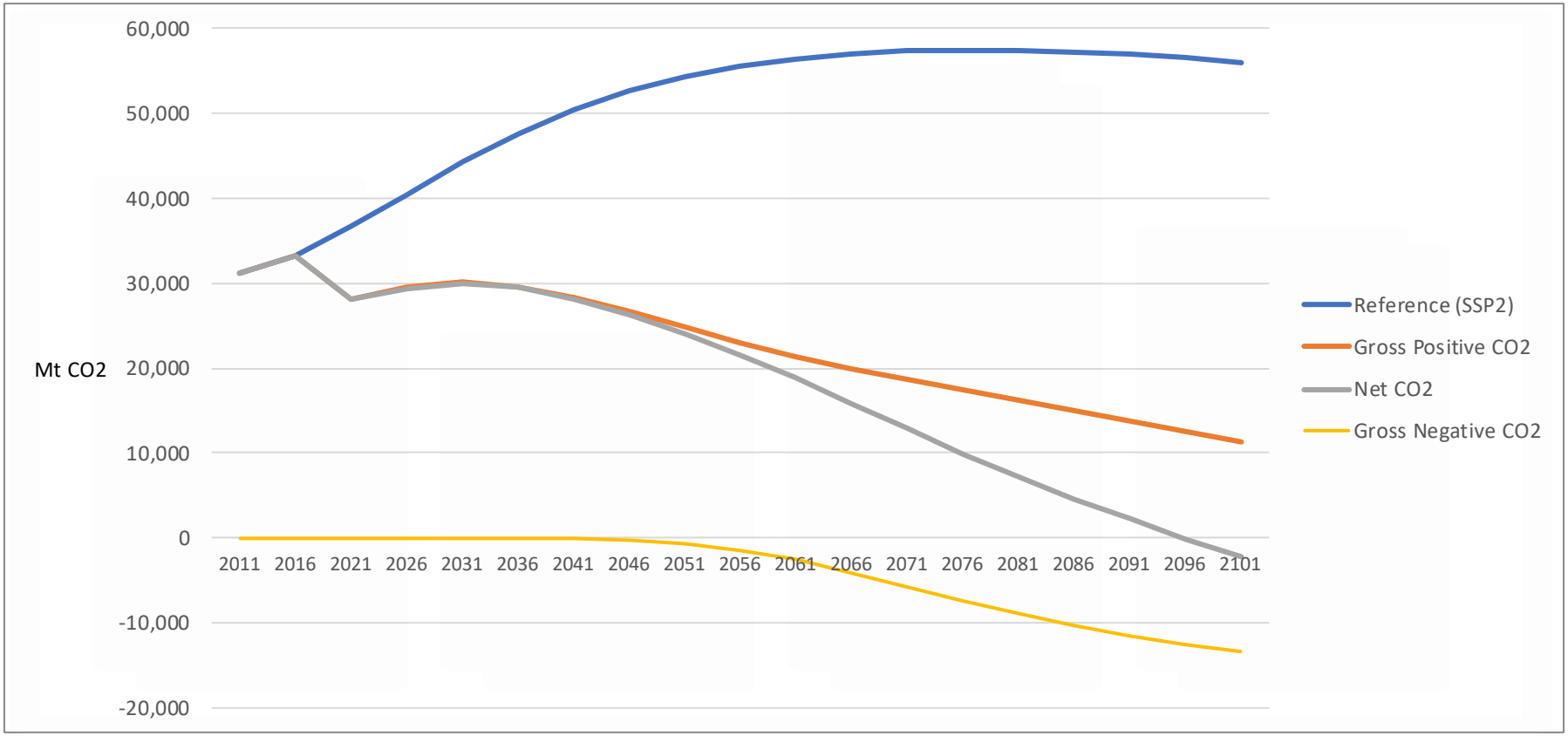
Note: σ is the elasticity of substitution in production.
σ = 0 means fixed-coefficient with no substitution between inputs.

World CO_2 emissions: C30-gr5 scenario



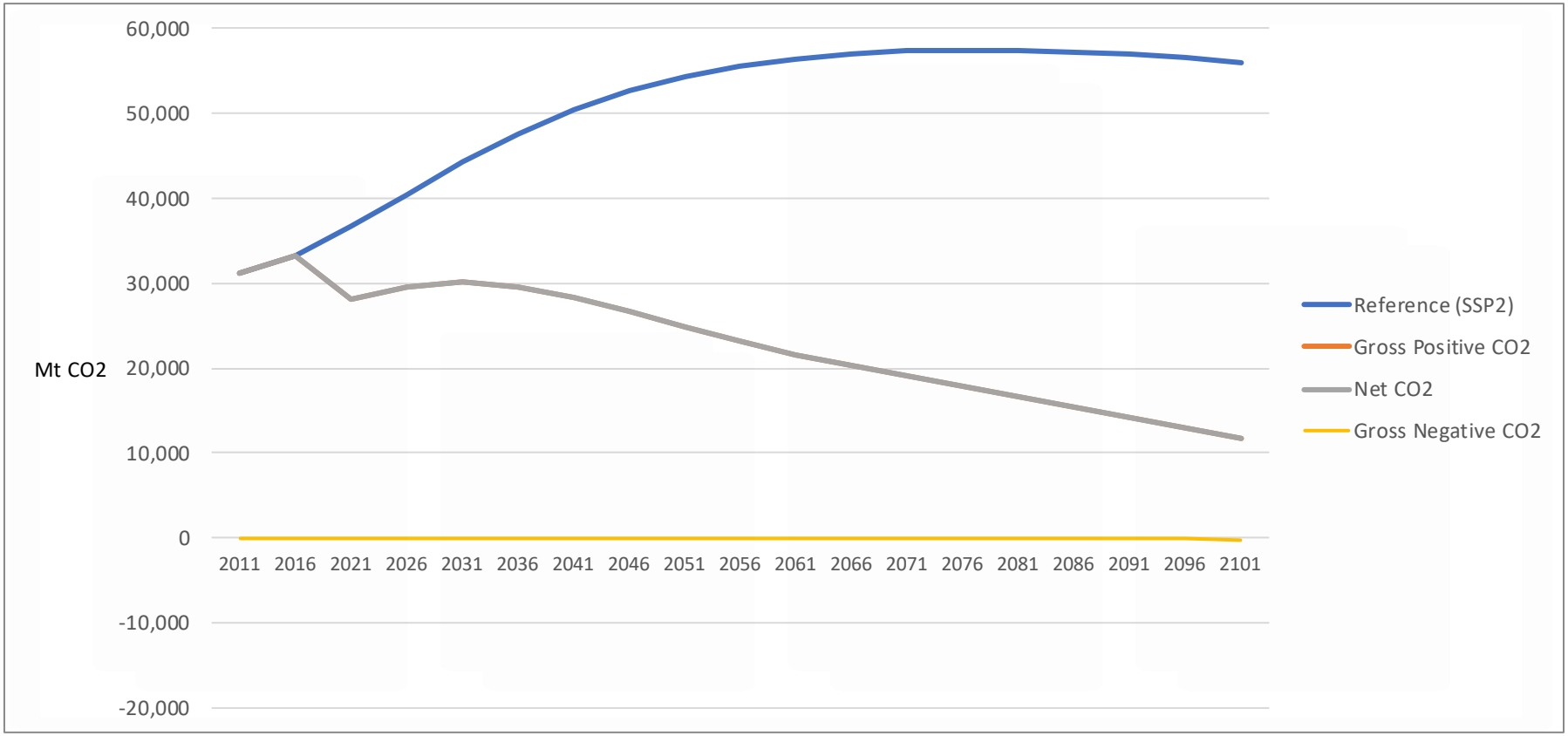
Notes: CO_2 prices reach \$30 / t CO_2 in 2040 and increase 5% per year thereafter. Simulations using the Future Agricultural Resources Model (FARM). Gross negative CO_2 emissions are from BECCS only. This figure does not include CO_2 removal by afforestation.

World CO_2 emissions: C80-gr5 scenario



Notes: CO_2 prices reach \$80 / t CO_2 in 2040 and increase 5% per year thereafter. Simulations using the Future Agricultural Resources Model (FARM). Gross negative CO_2 emissions are from BECCS only. This figure does not include CO_2 removal by afforestation.

World CO_2 emissions: C80-gr5 no BECCS scenario



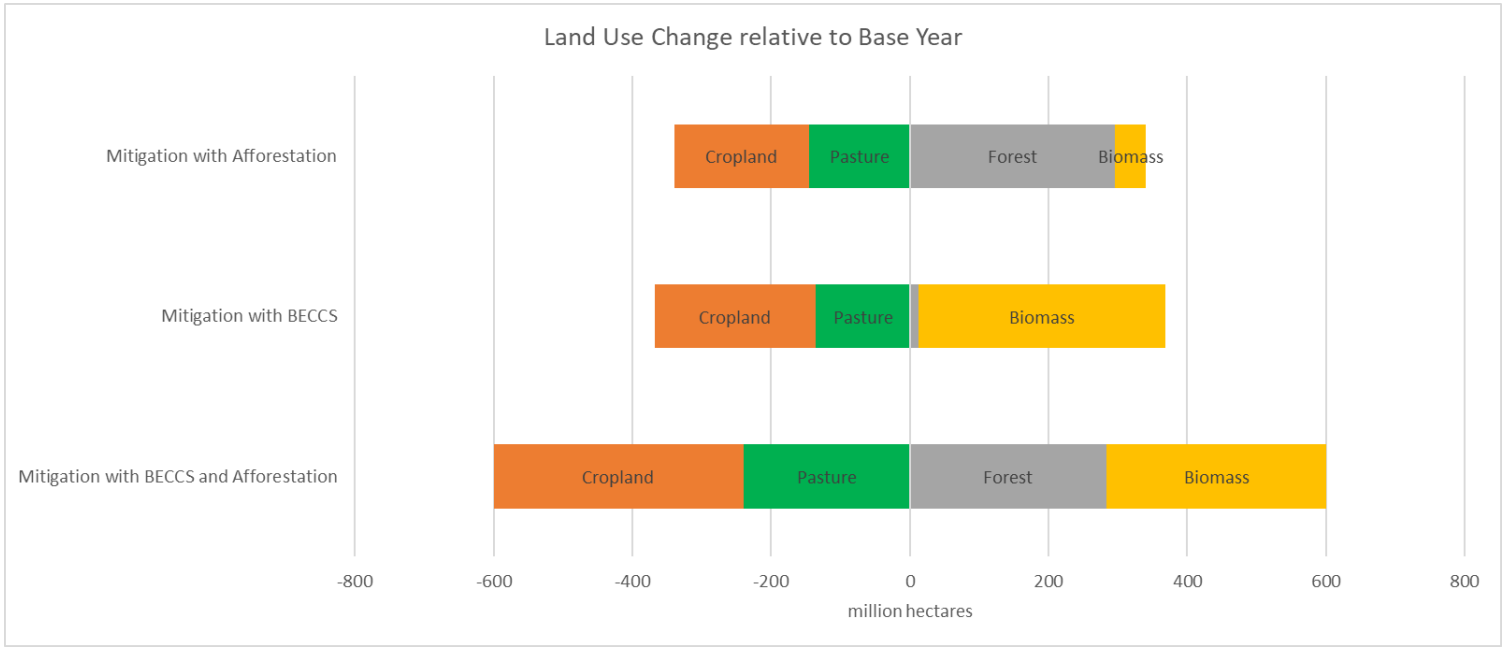
Notes: CO_2 prices reach \$80 / t CO_2 in 2040 and increase 5% per year thereafter. Simulations using the Future Agricultural Resources Model (FARM). This figure does not include CO_2 removal by afforestation.

Afforestation and carbon dioxide removal

- Typical range in literature is 0.5 to 3.6 billion tons CO_2 per year (*IPCC, 2018: Global Warming of 1.5°C. An IPCC Special Report*, page 270).
- Scenario in the FARM model
  - Exogenous increase in global forest area over the century
  - Not clear how this can be incorporated in a modeling framework
- Carbon pools
  - Above ground (forest, pasture)
  - Perennial roots (forest, pasture)
  - Soil (forest, pasture, cropland)
- Carbon stock calculation based on coefficients for each carbon pool and change in area
- Preliminary FARM afforestation scenario
  - Increase in forest area of 296 million hectares over 90 years (2011 – 2101)
  - Cumulative carbon dioxide removal of 109 billion tons CO_2 over 90 years
  - Average removal rate of 1.2 billion tons CO_2 per year
  - Forests are a potential source of feedstock for BECCS, but not included in this scenario

Land use change

- Net land use change sums to zero in each scenario.
- In afforestation scenario, the increase in forest land is comparable to increase in land for energy crops (by design).
- Afforestation is a major land use, but with much less carbon sequestered. However, there may be other benefits of afforestation such as biodiversity.



Land use and agricultural intensification

- Our measure of intensification is crop calories per hectare per year
- Calories as a common unit allows aggregation over food products and crop types, and provides a link from primary crop calories to final consumption of food calories
- 1 million kcal is approximately the quantity of food calories consumed per person per year
- Large-scale BECSS and afforestation is dependent on the crop yield required to maintain the same diet as in the reference scenario

Scenario	Food crop area (Mha)	Energy crop Area (Mha)	Change in Forest area (Mha)	Crop yield (million kcal / ha)
Reference (base year)	1,466	7	-	6.5
Reference (2101)	1,422	36	+ 22	9.4
Mitigation with BECCS (2101)	1,234	363	+ 12	10.6
Mitigation with BECCS and Afforestation (2101)	1,107	323	+ 284	11.8

Summary

- Negative emissions from BECCS offset gross CO_2 emissions that are very expensive to reduce (e.g., air transportation)
- At very high CO_2 prices, global net-CO_2 emissions can become negative, at least in model simulations
- Potential remains to reduce remaining gross CO_2 emissions (e.g., electric vehicles, hydrogen for industrial process heat)
- Preliminary results for afforestation show limited carbon sequestration potential relative to BECCS
  - Forestry is not easy to model and deserves more attention
  - Natural forests vs. plantation forests
  - Forests as a potential feedstock for BECCS
- Agricultural intensification over 90 years (2011 – 2101)
  - Crop yield per hectare increases by 44 percent in reference scenario
  - Crop yield per hectare increases by 80 percent in full mitigation scenario