This task will help set up future work that will be poised to explore key questions such as:

* How do carbon prices direct the behavior across the U.S. (bio) economy, and how might this differ with different carbon market structures?
* How do carbon prices across the energy system (i.e., outside the bio-economy) affect bioenergy competitiveness and deployment, considering competition with hydrocarbon fuels and carbon-free electricity generation, with the associated new opportunities for electricity demand?
* What effects might carbon prices have on the U.S. biofuels deployment?
* What are the effects of carbon pricing scenarios on the needs of enabling technologies for biofuels for additional incentives, R&D, or both?
* How can biofuels R&D maximize the potential co-benefits of carbon markets related to use of resources (biomass, land, water, etc.) for different applications within the bioeconomy (biopower, biofuels, biochemicals)?

We will define and parameterize a set of scenarios that will serve as the basis for model runs and interactions. Scenario development will include identifying analytical scope and collecting necessary data. Additionally, we will refine the analytic plan to answer selected key questions for the go / no-go decision point, technology scope, data sources, and analytic tools.

From Danny

Below is a short list of GCAM factors that I think may be used to inform BSM:

1. Agricultural production levels and prices – посмотреть на сайте про границы
2. Domestic energy consumption and prices (biofuels, bioenergy, petrol fuels)-
3. Domestic biofuel production levels
4. Domestic vehicle markets (what does it include; BSM – light duty trucks)
5. International demand for biomass and bioenergy from the US
6. US energy imports
7. Carbon prices

Сайт:

Comparison at national level…

Call with Steve (10/10/19)

S: Import carbon prices from GCAM

Density

Compare vehicle GCAM with BSM

Fuel and carbon – compare results – compare results

Where we want to use GCAM as input? And as comparison?

Vehicles: drive BSM with some GCAM scenarios, think about their energy imports?

International demand: look at it. Demand stream we can play with. Wood stream – put in the model if it exists

L: oil price trajectory

Carbon price; petrol price import from GCAM-

Double check for me:

1. Look through the numbers – C intensity; energy intensity for different sources;
2. Comparison agriculture/ domestic energy prod and cons for biofuels/

Domestic oil prices and C prices and compare the results –

What should be done:

1. BSM – what are the specific BSM parameters that represents this concept in Danny list: names, what I want to see if I compare; Dive in BSM and see the different variables
2. GCAM – look how the parameters are formed

Steps

1. Petro + Carbon; they have enough; IPCC scenarios documentation;

Look at GCAM carbon scenarios;

1.5C scenario;

How do they organize scenarios; do they bunch of IPCC ones;

Do they have sets of scenarios for different levels of GHG mitigations? Sensitivity to GHG mitigation,

Do they have only IPCC or do they have sets of whatever?

Biofuels:

Energy density; carbon density – check – Emily was the one who put it there…

What we would

1. Vehicle
2. Energy imports

Co-product, – third bin;

From Laura:

Hi, Irina,

This article:

<https://www.nature.com/articles/s41558-018-0091-3>

…describes IPCC scenarios that were used in a model inter-comparison project. GCAM was part of this study. We might want to start with scenarios in the “Shared Socio-economic Pathway (SSP) -2” family, which is described as “middle of the road” socio-economics. There should be multiple GCAM scenarios in this family that vary in terms of what concentration of GHG they result in.

This one, that I sent before, specifies a $35/tonne carbon tax starting in 2022 and increasing 5% per year. <https://web.stanford.edu/group/emf-research/docs/emf34/Design2.pdf> . There should be a set of GCAM EMF-34 scenarios that match those specs. They might also be good to understand.

Assuming you find these two sets, I think it would be worthwhile for you to spend a little bit of time documenting what other attributes are varied within these GCAM scenario sets. For example, do the EMF-34 GCAM scenarios vary what’s shown in the table (oil price, gas supply, economic growth, etc), and do they vary other things? Is there a set of SSP-2 scenarios with different Representative Concentration Pathways (RCPs), and do they vary other things?  This documentation doesn’t have to be complicated, but would be useful to organize and document our thinking.

Maybe next meeting we can look at what you’ve found in these two categories (or others that look interesting to you).

Thanks!

Laura

PLAN:

1. Look through the articles (abstract+introduction+conclusion)
2. Find GCAM on the gitHUB
3. Find and understand what the 7 parameters Danny sent are represented in the GCAM and what do they include
4. Try to find the analogy between 7 parameters in GCAM with BSM and how they can be implemented in BSM or represented in BSM or converted into format that BSM would understand
5. the numbers behind energy density and carbon intensity in OI module and check the numbers (Emily put them in the past) – Emily text about the values
6. Find Carbon price scenarios used in the GCAM and how they implemented
7. Understand how these scenarios correlate and represent Carbon scenarios of IPCC
8. Petrol prices in the IPCC

**Scenarios towards limiting global mean temperature increase below 1.5 °C**

Shared Socio-economic Pathways

with which we attempted to model scenarios that limit end-of-century radiative forcing to 1.9 W m−2 under various SSPs (hereafter called ‘SSP*x*–1.9’ sce- narios, with SSP*x* indicating the specific SSP assumed by the sce- nario and 1.9 the radiative forcing target in 2100, Methods).

development under a green-growth paradigm9 (SSP1) - all teams were able to produce 1.9 W m−2

a middle-of-the-road development along historical patterns10 (SSP2) - four teams four teams 1.9 W m-2

a regionally heterogeneous development11 (SSP3)

a development that results in both geographical and social inequalities12 (SSP4) – 1 1.9

development path that is dominated by high energy demand supplied by extensive fossil-fuel use13 (SSP5) -2 1.9

all- By 2050, annual CO2 and GHG emissions are in the range of −9–6 and 1–13 billion tons of CO2-equivalent emissions (gigaton GtCO2eyr−1, Methods

All scenarios keep warming to below 2 °C with more than 66% probability (Fig. 1d), and maximum (peak) median temperature estimates vary from 1.5 °C to 1.8 °C

The probability of limiting peak warming to below 1.5°C relative to pre-industrial levels is approximately halved and peak temperature about 0.2°C higher if emissions are at the high (>45 GtCO2e yr−1) instead of the low (<30GtCO2eyr−1) end of the available range in 2030 (Fig. 1e). By 2100, this variation disappears and all scenarios limit warming below 1.5 °C with about 66% probability (Supplementary Figs. 8, 9)

Across all 13 available scenarios, net zero GHG emissions are reached around 2055–2075

Cumulative CO2 emissions over the 2016–2100 period range from −175 to 475 GtCO2 (SSP2 median: 250 GtCO2, rounded to the nearest 25 GtCO2)

Potential feedbacks that are currently not included, such as CO2 and CH4 release from permafrost thawing or changes in other natural sources, can reduce carbon budgets further2

Even in these very stringent mitigation pathways, sizeable remaining CH4 and N2O emissions are projected by all models (Fig. 1c, Supplementary Fig. 6), and in 2100, respectively, 53–85% and 59–95% of these emissions originate from agriculture.

All 1.9 Wm−2 scenarios in this study strongly limit energy demand growth (Fig. 2d, Supplementary Fig. 11), with energy intensity reduction rates of 2–4% yr−1 from 2020 to 2050 (Fig. 2d). In SSP2, final energy demand in 2050 is limited to 10–40% above 2010 levels (rounded to the nearest 5%). This compares to 10% below to 30% above, and 45–75% above 2010 levels in SSP1 and SSP5, respectively.

upscaling of bioenergy and renewable energy technologies

Non-biomass renewables (solar, wind, hydro and geother- mal energy) scale up rapidly over the twenty-first century (Fig. 2a), reaching mid-century electricity shares of 60–80% and 32–79% in SSP1 and SSP2, respectively (Supplementary Fig. 12). In the marker SSP scenarios, these shares are 79%, 60% and 61% in SSP1, SSP2 and SSP5, respectively. Both solar and wind energy is projected to scale up consistently across the different SSPs

SSP2 and SSP5 1.9Wm−2 scenarios see a strong upscaling of nuclear power, whereas in SSP1, and particularly its marker implementation, the contribution of nuclear energy use decreases compared to today’s levels

SSPs, 1.9 W m−2 scenarios show a clear shift away from unabated fossil fuels (that is, without CCS

marker implementations exhibit rapidly declining contributions of coal until 2040 (less than about 20% of its 2010 contribution in 2040), followed by a phase-out of oil until 2060 (Supplementary Figs. 14, 15). The potential contribution of natural gas to the primary energy mix is the most uncertain, with mid-cen- tury contributions ranging from 22 to 267 exajoules (EJ) yr−1 across all scenarios compared to about 100–110 EJ yr−1 in 2010

Bioenergy is used in large amounts in all 1.9Wm−2 scenarios

Bioenergy use is increased by 1–5% per year between 2020 and 2050 in 1.9 W m−2 scenarios. Total bioenergy use in 2050 is kept below about 300EJyr−1, and in most cases below 150 EJ yr−1

In 1.9 W m−2 scenarios, land for energy crops and forest area is gen- erally projected to expand during the twenty-first century, with large variations across models, and this can impact land for agriculture and water availability

Pasture is one of the activities most affected by expanding other land uses and declines robustly across models and SSPs

In the middle-of-the-road SSP2 world, pastures decreases by 1–20% in 2050 compared to 2010 levels, and in SSP1, pastures also decrease by 8–16%. In a fossil-fuel intensive SSP5 scenario, it declines by 15–25%. It is important to note that SSP1 baseline scenarios already project a pasture-land decrease of 1–11% due to shifts towards less meat-intensive diets, limited food waste and a return of the world population to 7 billion people by 21005,9,31.

Large-scale afforestation and reforestation can make an impor- tant contribution to the overall CDR effort. In the sustainable SSP1 world, pressure on land is relatively low, and the forest area in 2050 can therefore expand by 0–24% relative to 2010. However, in the middle-of-the-road SSP2 scenarios, results are mixed, with some models projecting forest area to decrease by 2% and oth- ers report an increase of up to 18%. SSP5 sees a change of 0–16% (Supplementary Table 6)

However, in all 1.9 W m−2 scenarios climate policy leads to a net forest expansion compared to no-climate-policy baselines

BECCS contributes the largest part of CDR in 1.9 W m−2 scenar- ios (Supplementary Fig. 20). Between 150–1,200 GtCO2 (rounded to nearest 25 GtCO2), equivalent to about 4–30 years of current annual emissions, is removed from the atmosphere via BECCS during the twenty-first century, with important variation between models and across SSPs

SSP1 shows the lowest BECCS deployment over the twenty-first century (150–700GtCO2) owing to its lower final energy demand and baseline emissions, compared to SSP2 (400–975GtCO2) and SSP5 (950–1,200GtCO2). None of the SSPx-1.9 scenarios explicitly attempted to limit the contribu- tion from BECCS. The numbers reported here therefore represent projections of estimated cost-effective BECCS deployment in 1.9 Wm−2 scenarios, but do not represent minimum BECCS require- ments in a strict sense.

A previous study43 has identified characteristics of 1.5 °C pathways in comparison to 2°C pathways. These characteristics were (i) greater mitigation efforts on the demand side; (ii) energy efficiency improve- ments; (iii) CO2 reductions beyond global net zero; (iv) additional GHG reductions mainly from CO2; (v) rapid and profound near-term decarbonization of energy supply; (vi) higher mitigation costs; and (vii) comprehensive emission reductions implemented in the com- ing decade. Using our 1.9 W m−2 and 2.6 W m−2 scenarios as prox- ies for 1.5 °C and 2 °C pathways, these characteristics still hold when assessed with four additional models and varying socio-economic assumptions

None of the 1.9 W m−2 scenarios show a peak of emissions after 2020, and 82–98% of additional cumulative mitigation over the 2020–2100 period is achieved through CO2 reductions

Mitigation costs increase substantially between 1.9 and 2.6 W m−2 scenarios reflecting higher marginal abatement costs (Figs. 4,5). The relative carbon price increase is largest in SSP2 (Fig. 4) and also SSP1 sees large relative increases across all model

prices (Fig. 5), consumption losses and energy supply mitigation investments (Supplementary Fig. 26) are highest when assuming the less favourable socio-economic conditions of SSP2, SSP4 and SSP5

For instance, the average discounted carbon prices (discounted to 2010 over the 2020–2100 period; Fig. 5) are estimated to be about 50–165 US$ per tCO2e in SSP2 (rounded to the nearest 5). They are approximately 35–65% lower in SSP1, and for the two reported SSP5 scenarios the change is −30% and +5%, respectively. The large range of carbon prices is mainly driven by model uncertainties, which were already identified for 2.6 W m−2 scenarios5, but are more pronounced here owing to the more stringent target.

Our results show that some socio-economic developments and assumptions about policy effectiveness preclude achieving strin- gent mitigation futures (Fig. 5). Such failures were anticipated

Our results show that some socio-economic developments and assumptions about policy effectiveness preclude achieving strin- gent mitigation futures (Fig. 5). Such failures were anticipated

for SSP3, in which very heterogeneous regional development and debilitating policy assumptions already rendered limiting end-of- century radiative forcing to 2.6Wm−2 unachievable in the models5 (Supplementary Text 2). However, in SSP4 and SSP5 limiting radia- tive forcing to 1.9 W m−2 proved difficult too. In SSP4, a world that promotes both geographical and social inequalities, only one out of three models attempting a 1.9 W m−2 scenario was successful. Weak mitigation is achieved rather easily in SSP45,12. However, the lack of control over land-related emissions in developing countries and lower acceptability of CCS in developed countries in SSP4 make very low emissions pathways unachievable12. Also in SSP5, a world dominated by high economic growth and fossil-fuel development, challenges to mitigation are high13. Finally, under a middle-of-the- road development (SSP2) and under a green-growth paradigm (SSP1) four and six models, respectively, were able to produce a 1.9 W m−2 scenario (Supplementary Table 1).

What can SSPx-1.9 scenarios teach us about the feasibility of limit- ing warming to 1.5 °C? Typically, feasibility refers to a multi-dimen- sional concept that considers aspects of geophysics, technology, economics, societal acceptance, institutions and politics, among other disciplines.

n this context, our scenarios can illustrate that multiple technologically salient options are available for limiting warming increase to 1.5°C, but that the risk of failure increases markedly in the high growth, unequal and/or energy- intensive worlds of SSP3, SSP4 and SSP5.

Links:

1. <http://www.globalchange.umd.edu/gcamrcp/>
2. <https://secure.iiasa.ac.at/web-apps/ene/SspDb/dsd?Action=htmlpage&page=about>
3. <https://secure.iiasa.ac.at/web-apps/ene/SspDb/dsd?Action=htmlpage&page=about>
4. <http://www.globalchange.umd.edu/data-products/>
5. <http://www.ipcc-data.org/guidelines/pages/glossary/glossary_lm.html>

Scenario description -

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | SSP1 | SSP2 | SSP3 | SSP4 | SSP5 |
| Description1 | Sustainability   * Good progress towards sustainable development * Stabilizing population * Decreasing income inequality * Early MDG achievement * Low resource intensity and fossil fuel dependency * Strong int’l governance and local institutions * Well managed urbanization * Environmentalism | Middle of the Road   * Current trends continue * Moderate population growth * Slowly converging incomes between industrialized and developing countries * Delayed MDG achievement * Reductions in resource and energy intensity at historic rates * Environmental degradation | Fragmentation   * Rapid population growth * Slow economic growth * Failing to achieve MDG * High resource intensity and fossil fuel dependency * Low investments in technology development and education * Unplanned settlements * Weak int’l governance and local institutions | Inequality   * Increasing inequality within and across countries * Effective governance controlled by a small number of rich global elites * Most of populations with limited access to higher education and basic services * Energy tech R&D made by global energy corporations * Low social cohesion | Conventional Development   * Rapid economic development * Stabilizing population * Consumerism * High fossil fuel dependency * Eradication of extreme poverty and universal access to education and basic services * Highly engineered infrastructure and ecosystems |
| Challenges to Mitigation1 | Low | Medium | High | Low | High |
| Challenges to Adaptation1 | Low | Medium | High | High | Low |
| Technical change on extraction cost (% per year) 1: |  |  |  |  |  |
| 1.Coal  2.Gas  3.Con oil  4.Unc oil | 1. 0.5%  2. 0.5%  3. 0.5%  4. 0% | 1. 0.5%  2. 0.5%  3. 0.5%  4. 0.5% | 1. 1%  2. 0.5%  3. 0.5%  4. 0.5% | 1. 1%  2. 0.5%  3. 0.5%  4. 1% | 1. 2%  2. 2%  3. 2%  4. 2% |
| Cost Adder in 2100 ($/GJ) 1: |  |  |  |  |  |
| 1.Coal  2.Gas  3.Con oil  4.Unc oil | 1. $1.37  2. $0.14  3. $0.20  4. $0.21 | 1. $0.27  2. $0.14  3. $0.20  4. $0.21 | 1. $0.00  2. $0.14  3. $0.20  4. $0.21 | 1. $0.27  2. $0.71  3. $0.98  4. $1.06 | 1. $0.00  2. $0.00  3. $0.00  4. $0.00 |

EMF 34

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Reference case 2 | Low Oil Price | High Gas Supply | High Macro Growth | High Intermittent Renewables Penetration | Cross-border Energy Infrastructure | Carbon Policy |
| U.S. crude oil production continues to set annual records through 2027 and remains greater than 14.0 million barrels per day (b/d) through 2040  tight oil and shale gas resources supports growth in natural gas plant liquids (NGPL) production reaches 6.0 million b/d by 20292  dry natural gas production from oil formations increased from 8% in 2013 to 17% in 2018 and remains near this percentage through 2050 in the Reference case2  The share of natural gas generation rises from 34% in 2018 to 39% in 2050, and the share of renewable generation increases from 18% to 31%.  Transportation travel is measured in three ways, depending on the mode: highway vehicle miles (light- and heavy-duty vehicles), passenger miles (bus, passenger rail, and air), and off-highway freight ton-miles (freight rail, air, and domestic shipping  The steepest decline in energy intensity is in the transportation sector, with the level of energy used per highway vehicle-mile traveled declining by 32% from 2018 to 2050 as a result of increasingly stringent fuel economy and energy  efficiency standards for light- and heavy-duty vehicles  Transportation carbon intensity declines by 5%.  jet fuel consumption grows more than any other transportation fuel during the projection period, rising 35% from 2018 to 2050  Motor gasoline and distillate fuel oil’s combined share of total transportation energy consumption decreases from 84% in 2018 to 74% in 2050 as the use of alternative fuels increases  Light-duty vehicle miles traveled increase by 20% in the Reference case, growing from 2.9 trillion miles in 2018 to 3.5 trillion miles in 2050 as a result of rising incomes and growing population  Air travel grows 77% from 990 billion revenue passenger miles to 1,753 billion revenue passenger miles between 2018 and 2050 in the Reference case because of increased demand for global connectivity and rising personal incomes. Bus and passenger rail travel increase 11% and 31%, respectively  Energy use per passenger-mile of travel in light-duty vehicles declines nearly 40% between 2018 and 2050 as newer, more fuel-efficient vehicles enter the market, including both more efficient conventional gasoline vehicles and highly efficient alternatives such as battery electric vehicles. Light-duty vehicle energy efficiencies are affected by current federal fuel economy and greenhouse gas emission standards  The fuel economy of light-duty vehicles in use from 2018 to 2050 increases by 60% for cars and by 60% for light trucks in the Reference case. Across all light-duty vehicles, fuel efficiency improves by 65% from 2018 to 2050 as newer, more fuel-efficient vehicles enter the market, including a higher share of cars, which are more efficient than light trucks  The combined share of sales attributable to gasoline and flex-fuel vehicles (which use gasoline blended with up to 85% ethanol) declines from 93% in 2018 to 75% in 2050 because of the growth in battery electric vehicle (BEV), plug-in hybrid electric vehicle (PHEV), and hybrid electric vehicle sales | The Low Oil Price case, with the U.S. crude oil benchmark West Texas Intermediate (WTI, Cushing, Oklahoma) price at $58 per barrel or lower, is the only case in which natural gas production from oil formations is lower in 2050 than at current levels2 |  |  |  |  | Case focuses on the impact of carbon policy.   Carbon policy is modeled as a carbon tax of US  $35/tonne starting 2022 and increasing at 5%  per year until the last model year   All other countries outside of North America  also impose the same carbon tax Two sub-cases are defined:  7.1 Case 1 models the carbon policy adopted in all three countries (US, Canada, Mexico).  7.2 Second case models the carbon policy adopted in only Canada and Mexico but not in the US |

MDG (Mill2ennium Development Goals) (): 1) Eradication of extreme poverty and hunger; 2) universal primary education; 3) gender equality and empower women; 4) reduce child mortality; 5) improve maternal health; 6) Combat HIW/AIDs, malaria and others; 7) Ensure Environmental Sustainability; 8)Global partnership for development

EIA did not include the effects of the existing 45Q federal tax credits for carbon capture and sequestration in AEO2019 because the credits, although recently doubled, still do not appear large enough to encourage substantial market penetration of carbon capture in the scenarios modeled 2.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Scenario name** | **Description** | **Degrees of warming or forcing** | **Base carbon tax** | **Timeframe** | **Carbon tax escalation rate** | **With & Without BECCS** | **GCAM** | **GCAM-USA** | **Ref** |
| SSP1 | Sustainability   * Good progress towards sustainable development * Stabilizing population – 6.9 billion (2100) * Decreasing income inequality ($46,306) * Early MDG achievement * Low resource intensity and fossil fuel dependency; High renewables preference * Strong int’l governance and local institutions * Well managed urbanization * Environmentalism   Technical change on extraction cost (% per year): Coal - 0.5%, Gas - 0.5%, Conv. oil - 0.5%, Unconv. Oil - 0%.  Cost Adder in 2100 ($/GJ): Coal - $1.37, Gas - $0.14, Conv. oil - $0.20, Unconv. Oil - $0.21. |  |  |  |  |  |  |  | 3 |
| SSP2 | Middle of the Road   * Current trends continue * Moderate population growth * Slowly converging incomes between industrialized and developing countries * Delayed MDG achievement * Reductions in resource and energy intensity at historic rates * Environmental degradation   Technical change on extraction cost (% per year): Coal - 0.5%, Gas - 0.5%, Conv. oil - 0.5%, Unconv. Oil – 0.5%.  Cost Adder in 2100 ($/GJ): Coal - $0.27, Gas - $0.14, Conv. oil - $0.20, Unconv. Oil - $0.21. |  |  |  |  |  |  |  | 3 |
| SSP3 | Fragmentation   * Rapid population growth * Slow economic growth * Failing to achieve MDG * High resource intensity and fossil fuel dependency * Low investments in technology development and education * Unplanned settlements * Weak int’l governance and local institutions   Technical change on extraction cost (% per year): Coal – 1.0%, Gas - 0.5%, Conv. oil - 0.5%, Unconv. Oil – 0.5%.  Cost Adder in 2100 ($/GJ): Coal - $0.0, Gas - $0.14, Conv. oil - $0.20, Unconv. Oil - $0.21. |  |  |  |  |  |  |  | 3 |
| SSP4 | Inequality   * Increasing inequality within and across countries * Effective governance controlled by a small number of rich global elites * Most of populations with limited access to higher education and basic services * Energy tech R&D made by global energy corporations * Low social cohesion   Technical change on extraction cost (% per year): Coal – 0.5%, Gas - 1%, Conv. oil - 1%, Unconv. Oil – 2%.  Cost Adder in 2100 ($/GJ): Coal - $0.27, Gas - $0.71, Conv. oil - $0.98, Unconv. Oil - $1.06. |  |  |  |  |  |  |  | 3 |
| SSP5 | Conventional Development   * Rapid economic development * Stabilizing population * Consumerism * High fossil fuel dependency * Eradication of extreme poverty and universal access to education and basic services * Highly engineered infrastructure and ecosystems   Technical change on extraction cost (% per year): Coal – 2%, Gas - 2%, Conv. oil - 2%, Unconv. Oil – n/a.  Cost Adder in 2100 ($/GJ): Coal - $0, Gas - $0, Conv. oil - $0, Unconv. Oil - $0. |  |  |  |  |  |  |  | 3 |
| Base EMF 32 scenario | CO2 emissions from fossil fuels without climate policy |  | no | 2010-2050 | no | no |  |  | 4 |
| 25$ with 1% | To compare with base EMF 32 scenario. Cover three types of carbon tax revenue recycling: lump sum to consumers, reduction in labor tax rates, and reduction in capital tax rate |  | 25$/tCO2 | 2020- end of the simulation | 1%/ year | n/a |  |  | 4 |
| 25$ with 5% | To compare with base EMF 32 scenario. Cover three types of carbon tax revenue recycling: lump sum to consumers, reduction in labor tax rates, and reduction in capital tax rate |  | 25$/tCO2 | 2020- end of the simulation | 5%/ year | n/a |  |  | 4 |
| 50$ with 1% | To compare with base EMF 32 scenario. Cover three types of carbon tax revenue recycling: lump sum to consumers, reduction in labor tax rates, and reduction in capital tax rate |  | 50$/tCO2 | 2020- end of the simulation | 1%/ year | n/a |  |  |  |
| 50$ with 5% | To compare with base EMF 32 scenario. Cover three types of carbon tax revenue recycling: lump sum to consumers, reduction in labor tax rates, and reduction in capital tax rate. Scenario provides the maximum (up to 48%) emissions reductions below 2005 level compare to other exogenous EMF 32 scenarios. |  | 50$/ tCO2 | 2020- end of the simulation | 5%/ year | n/a |  |  | 4 |
| 76% reduction (no BECCS) | To compare with base EMF 32 scenario. 76% reduction of CO2 emissions from 2005 level. Deep de-carbonization scenario |  |  | 2020-2050 |  | CCS is available for fossil fuels but not for bio-electricity |  |  | 4 |
| 76% reduction with BECCS | To compare with base EMF 32 scenario .76% reduction of CO2 emissions from 2005 level. Deep de-carbonization scenario |  |  | 2020-2050 |  | CCS is available for all electricity generation technologies, including bio-electricity |  |  | 4 |
| EMF 34, Carbon Policy | Case focuses on the impact of carbon policy as a carbon tax | n/a | 35$/ tonne | 2022 – end of the simulation | 5% / year | n/a |  |  | 5 |
| 450 Scenario | Carbon tax for power and industry sector in the US and Canada | n/a | 2020 – 20$/tCO2;  2030 – 100$/tCO2;  2040 – 140$/tCO2 for $2014 | 2020-2040 | n/a | n/a |  |  |  |
|  |  |  |  |  |  |  |  |  |  |

**45Q Carbon Capture Tax Credit (**[**https://uscode.house.gov/view.xhtml?req=(title:26%20section:45Q%20edition:prelim)**](https://uscode.house.gov/view.xhtml?req=(title:26%20section:45Q%20edition:prelim))**)**

**(**<https://www.betterenergy.org/blog/primer-section-45q-tax-credit-for-carbon-capture-projects/>**)**

§45Q. Credit for carbon oxide sequestration – if we modify BSM only bcz for now we don’t have BECCS option

(a) General rule

For purposes of section 38, the carbon oxide sequestration credit for any taxable year is an amount equal to the sum of-

(1) $20 per metric ton of qualified carbon oxide which is-

(A) captured by the taxpayer using carbon capture equipment which is originally placed in service at a qualified facility before the date of the enactment of the Bipartisan Budget Act of 2018, and

(B) disposed of by the taxpayer in secure geological storage and not used by the taxpayer as described in paragraph (2)(B),

(2) $10 per metric ton of qualified carbon oxide which is-

(A) captured by the taxpayer using carbon capture equipment which is originally placed in service at a qualified facility before the date of the enactment of the Bipartisan Budget Act of 2018, and

(B)(i) used by the taxpayer as a tertiary injectant in a qualified enhanced oil or natural gas recovery project and disposed of by the taxpayer in secure geological storage, or

(ii) utilized by the taxpayer in a manner described in subsection (f)(5),

(3) the applicable dollar amount (as determined under subsection (b)(1)) per metric ton of qualified carbon oxide which is-

(A) captured by the taxpayer using carbon capture equipment which is originally placed in service at a qualified facility on or after the date of the enactment of the Bipartisan Budget Act of 2018, during the 12-year period beginning on the date the equipment was originally placed in service, and

(B) disposed of by the taxpayer in secure geological storage and not used by the taxpayer as described in paragraph (4)(B), and

(4) the applicable dollar amount (as determined under subsection (b)(1)) per metric ton of qualified carbon oxide which is-

(A) captured by the taxpayer using carbon capture equipment which is originally placed in service at a qualified facility on or after the date of the enactment of the Bipartisan Budget Act of 2018, during the 12-year period beginning on the date the equipment was originally placed in service, and

(B)(i) used by the taxpayer as a tertiary injectant in a qualified enhanced oil or natural gas recovery project and disposed of by the taxpayer in secure geological storage, or

(ii) utilized by the taxpayer in a manner described in subsection (f)(5).

(b) Applicable dollar amount; additional equipment; election

(1) Applicable dollar amount

(A) In general

The applicable dollar amount shall be an amount equal to-

(i) for any taxable year beginning in a calendar year after 2016 and before 2027-

(I) for purposes of paragraph (3) of subsection (a), the dollar amount established by linear interpolation between $22.66 and $50 for each calendar year during such period, and

(II) for purposes of paragraph (4) of such subsection, the dollar amount established by linear interpolation between $12.83 and $35 for each calendar year during such period, and

(ii) for any taxable year beginning in a calendar year after 2026-

(I) for purposes of paragraph (3) of subsection (a), an amount equal to the product of $50 and the inflation adjustment factor for such calendar year determined under section 43(b)(3)(B) for such calendar year, determined by substituting "2025" for "1990", and

(II) for purposes of paragraph (4) of such subsection, an amount equal to the product of $35 and the inflation adjustment factor for such calendar year determined under section 43(b)(3)(B) for such calendar year, determined by substituting "2025" for "1990".

(B) Rounding

The applicable dollar amount determined under subparagraph (A) shall be rounded to the nearest cent.

(2) Installation of additional carbon capture equipment on existing qualified facility

In the case of a qualified facility placed in service before the date of the enactment of the Bipartisan Budget Act of 2018, for which additional carbon capture equipment is placed in service on or after the date of the enactment of such Act, the amount of qualified carbon oxide which is captured by the taxpayer shall be equal to-

(A) for purposes of paragraphs (1)(A) and (2)(A) of subsection (a), the lesser of-

(i) the total amount of qualified carbon oxide captured at such facility for the taxable year, or

(ii) the total amount of the carbon dioxide capture capacity of the carbon capture equipment in service at such facility on the day before the date of the enactment of the Bipartisan Budget Act of 2018, and

(B) for purposes of paragraphs (3)(A) and (4)(A) of such subsection, an amount (not less than zero) equal to the excess of-

(i) the amount described in clause (i) of subparagraph (A), over

(ii) the amount described in clause (ii) of such subparagraph.

(3) Election

For purposes of determining the carbon oxide sequestration credit under this section, a taxpayer may elect to have the dollar amounts applicable under paragraph (1) or (2) of subsection (a) apply in lieu of the dollar amounts applicable under paragraph (3) or (4) of such subsection for each metric ton of qualified carbon oxide which is captured by the taxpayer using carbon capture equipment which is originally placed in service at a qualified facility on or after the date of the enactment of the Bipartisan Budget Act of 2018.

(c) Qualified carbon oxide

For purposes of this section-

(1) In general

The term "qualified carbon oxide" means-

(A) any carbon dioxide which-

(i) is captured from an industrial source by carbon capture equipment which is originally placed in service before the date of the enactment of the Bipartisan Budget Act of 2018,

(ii) would otherwise be released into the atmosphere as industrial emission of greenhouse gas or lead to such release, and

(iii) is measured at the source of capture and verified at the point of disposal, injection, or utilization,

(B) any carbon dioxide or other carbon oxide which-

(i) is captured from an industrial source by carbon capture equipment which is originally placed in service on or after the date of the enactment of the Bipartisan Budget Act of 2018,

(ii) would otherwise be released into the atmosphere as industrial emission of greenhouse gas or lead to such release, and

(iii) is measured at the source of capture and verified at the point of disposal, injection, or utilization, or

(C) in the case of a direct air capture facility, any carbon dioxide which-

(i) is captured directly from the ambient air, and

(ii) is measured at the source of capture and verified at the point of disposal, injection, or utilization.

(2) Recycled carbon oxide

The term "qualified carbon oxide" includes the initial deposit of captured carbon oxide used as a tertiary injectant. Such term does not include carbon oxide that is recaptured, recycled, and re-injected as part of the enhanced oil and natural gas recovery process.

(d) Qualified facility

For purposes of this section, the term "qualified facility" means any industrial facility or direct air capture facility-

(1) the construction of which begins before January 1, 2024, and-

(A) construction of carbon capture equipment begins before such date, or

(B) the original planning and design for such facility includes installation of carbon capture equipment, and

(2) which captures-

(A) in the case of a facility which emits not more than 500,000 metric tons of carbon oxide into the atmosphere during the taxable year, not less than 25,000 metric tons of qualified carbon oxide during the taxable year which is utilized in a manner described in subsection (f)(5),

(B) in the case of an electricity generating facility which is not described in subparagraph (A), not less than 500,000 metric tons of qualified carbon oxide during the taxable year, or

(C) in the case of a direct air capture facility or any facility not described in subparagraph (A) or (B), not less than 100,000 metric tons of qualified carbon oxide during the taxable year.

(e) Definitions

For purposes of this section-

(1) Direct air capture facility

(A) In general

Subject to subparagraph (B), the term "direct air capture facility" means any facility which uses carbon capture equipment to capture carbon dioxide directly from the ambient air.

(B) Exception

The term "direct air capture facility" shall not include any facility which captures carbon dioxide-

(i) which is deliberately released from naturally occurring subsurface springs, or

(ii) using natural photosynthesis.

(2) Qualified enhanced oil or natural gas recovery project

The term "qualified enhanced oil or natural gas recovery project" has the meaning given the term "qualified enhanced oil recovery project" by section 43(c)(2), by substituting "crude oil or natural gas" for "crude oil" in subparagraph (A)(i) thereof.

(3) Tertiary injectant

The term "tertiary injectant" has the same meaning as when used within section 193(b)(1).

(f) Special rules

(1) Only qualified carbon oxide captured and disposed of or used within the united states taken into account

The credit under this section shall apply only with respect to qualified carbon oxide the capture and disposal, use, or utilization of which is within-

(A) the United States (within the meaning of section 638(1)), or

(B) a possession of the United States (within the meaning of section 638(2)).

(2) Secure geological storage

The Secretary, in consultation with the Administrator of the Environmental Protection Agency, the Secretary of Energy, and the Secretary of the Interior, shall establish regulations for determining adequate security measures for the geological storage of qualified carbon oxide under subsection (a) such that the qualified carbon oxide does not escape into the atmosphere. Such term shall include storage at deep saline formations, oil and gas reservoirs, and unminable coal seams under such conditions as the Secretary may determine under such regulations.

(3) Credit attributable to taxpayer

(A) In general

Except as provided in subparagraph (B) or in any regulations prescribed by the Secretary, any credit under this section shall be attributable to-

(i) in the case of qualified carbon oxide captured using carbon capture equipment which is originally placed in service at a qualified facility before the date of the enactment of the Bipartisan Budget Act of 2018, the person that captures and physically or contractually ensures the disposal, utilization, or use as a tertiary injectant of such qualified carbon oxide, and

(ii) in the case of qualified carbon oxide captured using carbon capture equipment which is originally placed in service at a qualified facility on or after the date of the enactment of the Bipartisan Budget Act of 2018, the person that owns the carbon capture equipment and physically or contractually ensures the capture and disposal, utilization, or use as a tertiary injectant of such qualified carbon oxide.

(B) Election

If the person described in subparagraph (A) makes an election under this subparagraph in such time and manner as the Secretary may prescribe by regulations, the credit under this section-

(i) shall be allowable to the person that disposes of the qualified carbon oxide, utilizes the qualified carbon oxide, or uses the qualified carbon oxide as a tertiary injectant, and

(ii) shall not be allowable to the person described in subparagraph (A).

(4) Recapture

The Secretary shall, by regulations, provide for recapturing the benefit of any credit allowable under subsection (a) with respect to any qualified carbon oxide which ceases to be captured, disposed of, or used as a tertiary injectant in a manner consistent with the requirements of this section.

(5) Utilization of qualified carbon oxide

(A) In general

For purposes of this section, utilization of qualified carbon oxide means-

(i) the fixation of such qualified carbon oxide through photosynthesis or chemosynthesis, such as through the growing of algae or bacteria,

(ii) the chemical conversion of such qualified carbon oxide to a material or chemical compound in which such qualified carbon oxide is securely stored, or

(iii) the use of such qualified carbon oxide for any other purpose for which a commercial market exists (with the exception of use as a tertiary injectant in a qualified enhanced oil or natural gas recovery project), as determined by the Secretary.

(B) Measurement

(i) In general

For purposes of determining the amount of qualified carbon oxide utilized by the taxpayer under paragraph (2)(B)(ii) or (4)(B)(ii) of subsection (a), such amount shall be equal to the metric tons of qualified carbon oxide which the taxpayer demonstrates, based upon an analysis of lifecycle greenhouse gas emissions and subject to such requirements as the Secretary, in consultation with the Secretary of Energy and the Administrator of the Environmental Protection Agency, determines appropriate, were-

(I) captured and permanently isolated from the atmosphere, or

(II) displaced from being emitted into the atmosphere,

through use of a process described in subparagraph (A).

(ii) Lifecycle greenhouse gas emissions

For purposes of clause (i), the term "lifecycle greenhouse gas emissions" has the same meaning given such term under subparagraph (H) of section 211(o)(1) of the Clean Air Act (42 U.S.C. 7545(o)(1)), as in effect on the date of the enactment of the Bipartisan Budget Act of 2018, except that "product" shall be substituted for "fuel" each place it appears in such subparagraph.

(6) Election for applicable facilities

(A) In general

For purposes of this section, in the case of an applicable facility, for any taxable year in which such facility captures not less than 500,000 metric tons of qualified carbon oxide during the taxable year, the person described in paragraph (3)(A)(ii) may elect to have such facility, and any carbon capture equipment placed in service at such facility, deemed as having been placed in service on the date of the enactment of the Bipartisan Budget Act of 2018.

(B) Applicable facility

For purposes of this paragraph, the term "applicable facility" means a qualified facility-

(i) which was placed in service before the date of the enactment of the Bipartisan Budget Act of 2018, and

(ii) for which no taxpayer claimed a credit under this section in regards to such facility for any taxable year ending before the date of the enactment of such Act.

(7) Inflation adjustment

In the case of any taxable year beginning in a calendar year after 2009, there shall be substituted for each dollar amount contained in paragraphs (1) and (2) of subsection (a) an amount equal to the product of-

(A) such dollar amount, multiplied by

(B) the inflation adjustment factor for such calendar year determined under section 43(b)(3)(B) for such calendar year, determined by substituting "2008" for "1990".

(g) Application of section for certain carbon capture equipment

In the case of any carbon capture equipment placed in service before the date of the enactment of the Bipartisan Budget Act of 2018, the credit under this section shall apply with respect to qualified carbon oxide captured using such equipment before the end of the calendar year in which the Secretary, in consultation with the Administrator of the Environmental Protection Agency, certifies that, during the period beginning after October 3, 2008, a total of 75,000,000 metric tons of qualified carbon oxide have been taken into account in accordance with-

(1) subsection (a) of this section, as in effect on the day before the date of the enactment of the Bipartisan Budget Act of 2018, and

(2) paragraphs (1) and (2) of subsection (a) of this section.

(h) Regulations

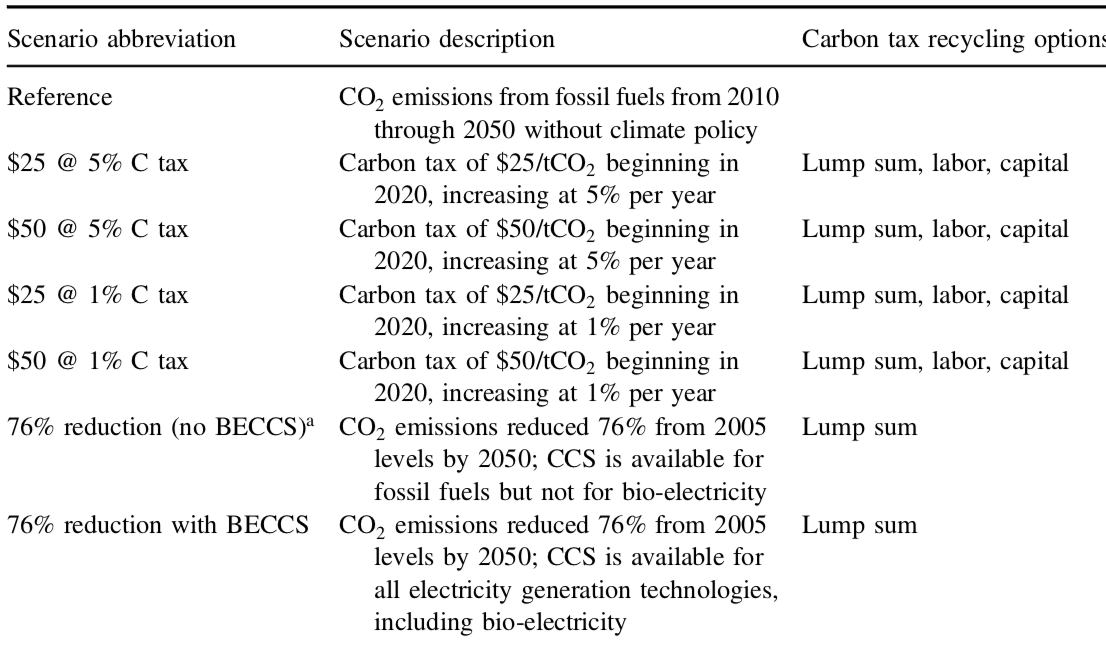
The Secretary may prescribe such regulations and other guidance as may be necessary or appropriate to carry out this section, including regulations or other guidance to-

(1) ensure proper allocation under subsection (a) for qualified carbon oxide captured by a taxpayer during the taxable year ending after the date of the enactment of the Bipartisan Budget Act of 2018, and

(2) determine whether a facility satisfies the requirements under subsection (d)(1) during such taxable year.

https://www.betterenergy.org/blog/primer-section-45q-tax-credit-for-carbon-capture-projects/

EMF 32 - U.S. CARBON TAX SCENARIOS AND BIOENERGY



The first scenario is a reference scenario of U.S. carbon dioxide (CO2) emissions from fossil fuel combustion from 2010 through 2050. All other scenarios will be compared to the reference in terms of emissions reductions and policy cost. The next four scenarios use an exogenous carbon price, starting in 2020, to cover variation in the initial carbon price and rate of increase over time. The starting price is either $25 or $50 per metric ton of CO2, with annual increases of 1% or 5%. Each of these four scenarios has variations to cover three types of carbon tax revenue recycling: lump sum to consumers, reduction in labor tax rates, and reduction in capital tax rates. The primary model output used to compare tax recycling options is consumer welfare, measured as equivalent variation.

Instead of an exogenous carbon price path, the next scenario specifies an exogenous time path of CO2 emissions, and the carbon price becomes endogenous. This is a deep de-carbonization scenario with emissions declining steadily after 2020 to reach a level 76% below 2005 emissions by 2050. In this scenario, we allow electricity generation from fossil fuels to use carbon dioxide capture and storage (CCS) if the carbon price is high enough to cover the cost of CCS. The option to use CCS limits the carbon tax and cost needed to meet an ambitious CO2 emissions target.

The final scenario, the modeler’s choice scenario, also has a 76% emissions reduction target, but allows CCS to be used with bio-electricity (BECCS) as well as with electricity generation using fossil fuels.

The possibility of bio-electricity com- bined with CCS creates a technology with the potential for negative CO2 emissions

It turns out that the option to recycle carbon tax revenue by reducing labor taxes or capital taxes can reduce the cost of CO2 mitigation in scenarios with an exogenous

carbon price path. However, with BECCS, revenues from a carbon policy reach a peak and then decline as a subsidy for sequestration offsets carbon tax revenues. The deep de-carbonization scenarios reduce CO2 emissions 76% by 2050, relative to 2005 CO2 emissions of 5,753 Tg CO2

CO2 emissions pathways for the reference and climate policy scenarios are dis- played in Fig. 1.1 The four exogenous-carbon-tax scenarios provide a wide range of emissions reductions by 2050, up to 48% below 2005 emissions in the scenario with a $50 tax in 2020 increasing at 5% per year.

CO2 prices for each scenario are shown in Fig. 2. Exogenous time series in Fig. 1 become endogenous in Fig. 2, and vice versa. The 76% emissions reduction pathway in Fig. 1 is exogenous, but the corresponding CO2 price paths in Fig. 2 are endoge- nous and vary by the presence or absence of BECCS.

We use the Future Agricultural Resources Model (FARM),

* .  GTAP-9 social accounting matrix (SAM) with 2011 base year.
* .  Energy accounting throughout the U.S. economy, from primary energy to final

energy consumption.

* .  Labor-leisure tradeoff in utility function.
* .  Calculation of equivalent variation for any policy scenario relative to the reference

scenario.

* .  Option to keep real government expenditure the same in the reference and policy scenarios.
* .  Option to tax final energy consumption based on carbon content of fuels.
* .  Options for recycling carbon tax revenue.
* .  Representation of specific electricity generation technologies, including bio-electricity

with and without CCS.

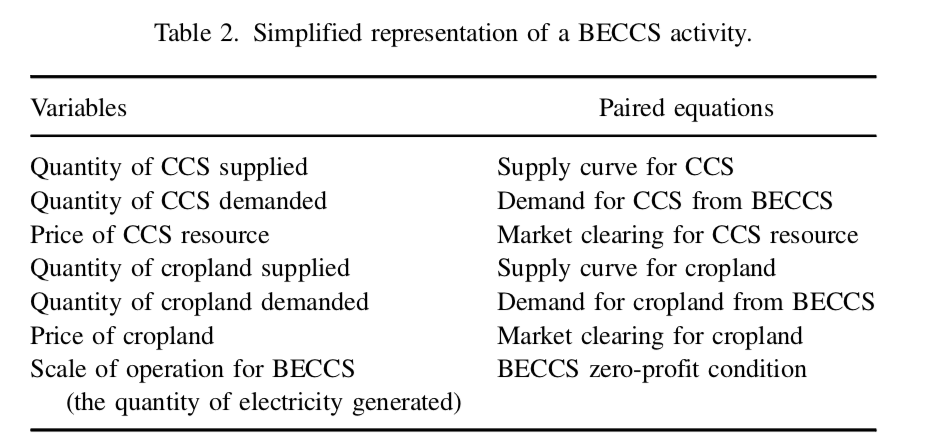
* .  Five-year time steps from 2011 to 2051, interpolated to five-year time steps from

2010 to 2050 for EMF reporting.

* .  Capital accumulation at each time step.
* .  Exogenous technical change over time.
* .  Land competition among forests, pasture, crops, and a dedicated energy crop

(switchgrass).

The economics of BECCS is complex relative to other CO2 mitigation technologies, with rents accruing to owners of agricultural land and owners of the carbon seques- tration resource. Further, a BECCS activity has joint products of electricity and carbon sequestration.



Each of the four fixed-carbon-tax scenarios was run with three types of tax revenue recycling: lump sum to a representative consumer; an equivalent reduction in direct taxes on labor; and an equivalent reduction on capital taxes

Equivalent variation is negative for all scenarios in Fig. 3, but a lower cost is achieved with labor tax recycling relative to lump sum recycling.4

The logic behind welfare improvements with capital-tax recycling is simple: in- vestment is a fixed fraction of total expenditure, and a reduced purchase price for capital goods allows more capital to be purchased each time step. Capital stock is fixed within each time step, and the increase in capital appears in the next time step. Therefore, the effect of a reduction in capital taxes does not appear until the second time step (2025). The capital stock continues to grow over time, relative to capital stock in the reference scenario.

For most scenarios in Fig. 5, tax revenue increases with the carbon tax. The one exception is the 76% reduction scenario with BECCS. In this case, carbon tax revenues peak and then decline as carbon sequestration increases through BECCS. The reason for the decline is that a subsidy must be paid to BECCS operators for each ton of carbon sequestered, at the prevailing carbon price. If the scale of BECCS becomes large relative to other mitigation technologies, then net CO2 emissions could become negative for the entire economy. In this case, the government pays a net subsidy instead of receiving tax revenue. The scale of BECCS is limited, however, by the amount of land needed to grow an energy crop (e.g., switchgrass) and competition with land used to grow crops. Carbon tax revenues, as a percent of gross domestic product (GDP), are shown in Table 3 for each scenario. Scenarios with a 1% per year increase in the carbon tax have a relatively constant ratio of revenue to GDP. Scenarios with a 5% per year increase in the carbon tax have an increasing ratio of revenue to GDP.

GCAM world – global conditions

GCAM USA – for result comparison

GCAM / GCAM USA – does produce result we need

By the end of Q2