Energy Modeling Forum Study #37
High Electrification Scenarios for North America
Study Description and Design

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EMF 37
High Electrification Scenarios for North America

- Rationale
  - The EMF 37 study is motivated by a desire to understand the potential role for electrification under economy-wide decarbonization pathways in important economic sectors—transportation, buildings, and industry.
  - Much of the deep decarbonization literature points to the decarbonization of the power sector followed by the electrification of the economy, but there is a lack of consensus on the ultimate potential for electrification, and rate at which it can be implemented given technical, behavioral, and economic limits – and competition from other promising emission mitigation options.
  - This study is being designed to explore the opportunities, limitations, trade-offs, and robustness of results associated with high electrification in North America.

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High Electrification Scenarios for North America

Major Motivating Questions for EMF 37

- To what extent can the transportation, buildings, and industrial sectors be electrified? How might technological and behavioral change and decarbonization efforts alter the extent of electrification?
  - Beyond decarbonization efforts, what are the key drivers of electrification in the transportation, buildings, and industrial sectors?
  - How might the availability of other low-carbon fuel sources (e.g., biofuels or fossil-derived hydrogen with CCS) compete with electricity to moderate the extent of electrification?
- What are the implications of high electrification scenarios on the energy system and economic and environmental outcomes in North America in reference projections and across a range of decarbonization scenarios?
- How does technological change in the power sector shape electrification pathways?

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High Electrification Scenarios for North America

- Importantly, the study is designed to engage all energy and economy-wide models as well as sectoral and technology experts forming study groups focused on transportation, industry, buildings and carbon management.

- The study description and design document covers the following areas:
  - Study Structure and Process i.e., types of models and rounds of the study
  - Overview of the Scenarios i.e., scenario matrices and illustrative sensitivity examples
  - Scenario Details and Discussion i.e., detailed specifications
  - Reporting and Submissions i.e., reporting template development and submission process

Study Structure & Process

Initial EMF 37 Study Groups

National Modelers
Full energy sector models

Electric sector only models

-See list on next slide

Steering Committee
- John Weyant (Stanford)
- Allen Fawcett (EPA)
- Jim McFarland (EPA)
- Trieu Mai (NREL)
- Geoff Blanford (EPRI)

Transportation Study Group
- Sharyn Lie (EPA)
- Kara Podkaminer (DOE-EERE)
- John Maples (EIA)
- Mary Zimmerman (DOT)
- Matteo Muratori (NREL)
- Lew Fulton (UC Davis)
- Noell Chisostomo (CEC)
- Geoff Morrison (Cadmus Group)

Carbon Management Study Group
- Jared Daniels(DOE-FE)
- Jae Edmonds (JGCRI)
- Stephanie Waldhoff (JGCRI)
- Francis Wood (On Location)
- Christopher Nichols (NETL)
- Nadeja Victor (NETL)

Buildings Study Group
- Kevin Jarzomski (EIA)
- Mike Henchen (RMI)
- Elaine Hale (NREL)
- Joe Bryson (EPA)
- Jared Langevin (LBNL)
- Pierre Delforge (NRDC)

Industry Study Group
- Betsy Dutrow (EPA)
- Ernst Worrell (Utrecht University)
- Gale Boyd (Duke University)
- Chris Bataille (IDDRI)
- Wolfgang Eichhammer (FISIR, DEU)
- Kelly Perl (EIA)
- Eric Masanet (UCSB)

EMF 37 Energy Systems Models

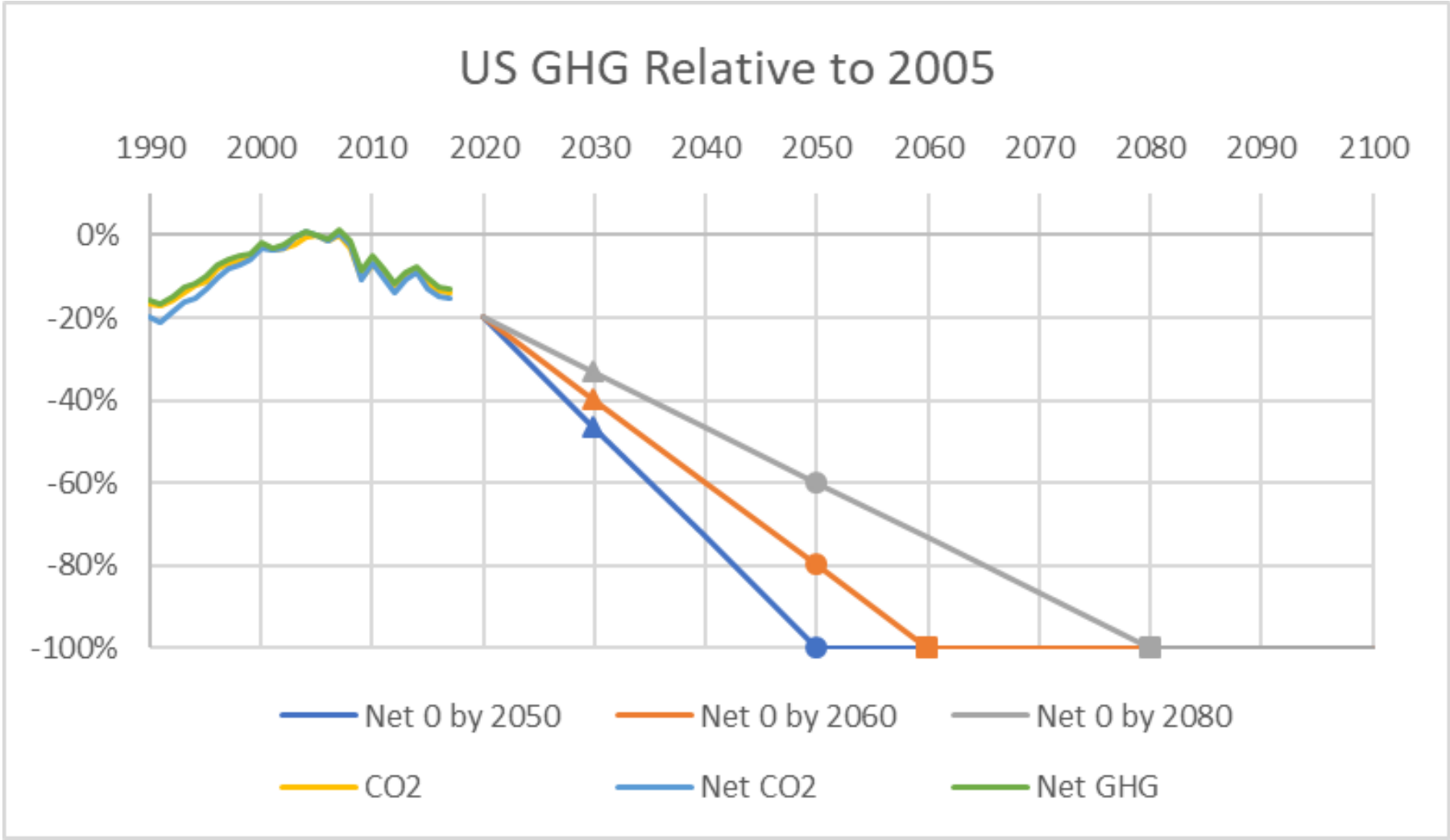
Model (s)	Name	Organization	All Energy, Electricity Only, CGE
Alt. NEMS versions	Frances Wood, Sharon Showalter	OnLocation	All Energy
ARTIMAS	Jared Woollacott	RTI	All Energy & CGE
CER	Matthew Hansen	Canadian Energy Regulator	All Energy
CIMS	Mark Jaccard	Simon Fraser University	
DIEM	Martin Ross	Duke	All Energy & CGE
E4ST	Dan Shawhan	RFF	Electricity only
EC-MSMR/GCAM-EC	Nick Macaluso	E&CC Canada	All Energy
Energy 2020	Jeff Amlin	Systematic Solutions	
Energy Policy Simulator	Robbie Orvis	Energy Innovations	All Energy
FACETS	Evelyn Wright	Sustainable Energy Economics	
FARM	Ron Sands	USDA-ERS	All Energy CGE
GCAM	Jae Edmonds	JGCRI	All Energy
G-Cubed	W. McKibbin, P. Wilcoxen, A. Morris	ANU/Syracuse/Brookings	All Energy CGE
GENeSYSMOD	Alejandro Sarmiento	DIW Berlin	
GH-E3	Mark Hafstead	Stanford/RFF	Alll Energy CGE
GLIMPSE/GCAM-USA	Dan Loughlin	EPA-ORD	All Energy
HAIKU	Karen Palmer	RFF	Electricity Only
IGEM	Dick Goettle	DJA	All Energy CGE
IPM	Imran Lalani	EPA-CAMD	
TIMES-EPAUS9rT	Carol Lenox	EPA-ORD	All Energy
MUSE	Sara Giarola	Imperial College London	All Energy
NANGAM	Sauleh Siddiqui, Charalampos Avraam	American University	
NATEM	Olivier Bahn, Kathleen Vaillencourt Kathleen Vaillencourt	HEC Montreal, ESMIA ESMIA	All Energy
NETL-MARKAL	Christopher Nichols,Nadejda Victor	NETL	All Energy
NewERA	Sugandha Tuladhar	NERA	All Energy & CGE
Pathways	Amber Mahone, Sharad Bharadwaj	EThree	All Energy
ReEDS	Trieu Mai	NREL	Electricity only
REGEN	Geoff Blanford	EPRI	All Energy
SAGE	A. Marten, D.Schreiber, A.Wolverton	EPA-NCEE	
MC + TIMES-UCL	Giovanni Hernandez	Independent Energy Consultant	Both
Tamoa	Joe Decarolis	NCSU	
TIMES-UCL	Baltazar Solano	UCL	All Energy
urbs-MX	Anahi Molar-Cruz	Technical University of Munich	
USREP-ReEDS	Mei Yuan, Max Brown, Stuart Cohen	MIT/NREL	All Energy CGE & Electricty Sector
USREP-EleMod	Mei Yuan, Karen Tapia-Ahumada	MIT	All Energy CGE & Electricty Sector

Round	Month	Meeting Focus	Objectives
kick-off	29-Oct-20	overview and process	
beta round	11-Dec-20	economy-wide initial scenarios	Present initial beta round results from subset of econmy-wide models. Discussion of results with
	8-Jan-21	carbon management	Beta round results from study group models. Questionaire Discussion. Discuss data study group can use from economy-wide models. Discuss data study group can provide to economy-wide models. Round 1 scenario specification discussion.
	12-Feb-21	transportation	
	12-Mar-21	buildings	
	9-Apr-21	industry	
	14-May-21	economy-wide beta round scenarios	economy-wide models. Plan for data exchanges between subgroups and economy-wide models.
	June-July 2021		finalize round 1 scenarios, data template, data hand-off, model improvements, round 1 data submission due before first round 1 meeting
round 1	~ September	carbon management round 1 scenarios	
	2	transportation round 1 scenarios	
	3	buildings round 1 scenarios	
	4	industry round 1 scenarios	
	5	power round 1 scenarios	
	6	economy-wide round 1 scenarios (+ sensitivities)	
round 2	7	carbon management round 2 scenarios	
	8	transportation round 2 scenarios	
	9	buildings round 2 scenarios	
	10	industry round 2 scenarios	
	11	power round 2 scenarios	
	12	economy-wide final scenarios + sensitivities	
final	13	carbon management final scenarios	
	14	transportation final scenarios	
	15	buildings final scenarios	
	16	power final scenarios	
		Paper drafts	

- For this study we are proceeding with a beta round
  - work out reporting issues (e.g., consistency with units and variable definitions).
  - allow us to begin the dialogue between the modeling teams and the study groups to help flesh out the design of the scenarios for subsequent rounds
  - determine how best to pass data between economy-wide and sectoral models
- Subsequent rounds will add scenarios developed during the beta round in consultation with the study groups.
- The anticipated study schedule includes roughly monthly virtual meetings that are intended to be shorter and more frequent than the in-person meetings in a traditional EMF study.
- The meetings are organized by round and allow for a rotating focus between the overall results from the economy-wide models and focused meetings for the study groups.

Overview of Scenarios

EMF 37 - Illustrative decarbonization pathways for the US



EMF 37 - Core scenario matrix: decarbonization and electrification scenarios

		No Target	Net 0 by 2050	Net 0 by 2060	Net 0 by 2080	Net 0 GHG by 2050
% Below 2005 in year	*2030*	*Endog.*	*-47%*	*-40%*	*-33%*	*-47%*
	2050	*Endog.*	*-100%*	*-80%*	*-60%*	*-100%*
Reference Electrification Scenarios		***NT.Ref***	***0by50.Ref***	***0by60.Ref***	***0by80.Ref***	***0GHGby50.Ref***
Advanced Electrification Scenarios	All	***NT.All-a***	***0by50.All-a***	***0by60.All***	***0by80.All***	***0GHG0by50.All***
	Transportation	***NT.Trans-a***	***0by50.Trans-a***			
	Buildings	***NT.Bldg-a***	***0by50.Bldg-a***			
	Industry	***NT.Ind-a***	***0by50.Ind-a***			

- The Beta round only includes the two scenarios highlighted in yellow.
  - *Note that if your model is not ready to solve the 0by50.Ref scenario for the beta round, you can instead submit the 0by60.Ref or 0by80.Ref scenario.*
- This round will allow us to both work out data reporting issues, and to begin the dialogue with the study groups about how to specify the advanced electrification and other sensitivity scenarios.

EMF 37 - Expanded scenario matrix for sectoral study groups

		No Target	Net 0 by 2050	Net 0 by 2060	Net 0 by 2080
% Below 2005 in year	*2030*	*Endog.*	*-47%*	*-40%*	*-33%*
	2050	*Endog.*	*-100%*	*-80%*	*-60%*
Reference Electrification Scenarios		***NT.Ref***	***0by50.Ref***	***0by60.Ref***	***0by80.Ref***
Advanced Electrification Scenarios	All	***NT.All-a***	***0by50.All-a***	***0by60.All***	***0by80.All***
	Transportation (a)	***NT.Trans-a***	***0by50.Trans-a***		
	Trans. (b)	*NT.Trans-b*	*0by50.Trans-b*		
	Trans. (c)	*NT.Trans-c*	*0by50.Trans-c*		
	Trans. (d)	*NT.Trans-d*	*0by50.Trans-d*		
	Buildings (a)	***NT.Bldg-a***	***0by50.Bldg-a***		
	Buildings (b)	*NT.Bldg-b*	*0by50.Bldg-b*		
	Buildings (c)	*NT.Bldg-c*	*0by50.Bldg-c*		
	Industry (a)	***NT.Ind-a***	***0by50.Ind-a***		
	Industry (b)	*NT.Ind-b*	*0by50.Ind-b*		
	Industry (c)	*NT.Ind-c*	*0by50.Ind-c*		

EMF 37 - Sector-specific scenarios *(Illustrative)*

Transportation

- Basic/rapid EV adoption (there are a host of market- and policy-based drivers embedded here, any of them could be tested)
- Slow/fast EV charging profile evolution (from L1-dominated home charging to higher level public charging)
- Basic/rapid expansion of managed charging
- Basic/rapid reductions in battery costs
- Autonomous vehicles
- Significant mode shifting and micro-mobility
- Role of off-road vehicles and construction equipment
- Basic/rapid reduction in battery costs
- Complementary policies targeted at EV adoption

Buildings

- Basic/rapid end-use heating/cooling (water and space)
- Basic/rapid expansion of controllable load
- Mild/significant impacts attributable to climate change
- Complementary policies such as building codes

Industry

- High/low technology availability and/or cost for electrification
- Slow/fast adoption of new process technologies
- High/low degree of electrification
- CCS on process technologies
- Structural change (e.g., offshoring, 3-D printing)

EMF 37 - Alternate dimensions scenario matrix (Illustrative)

Example Alternate Dimensions							Degree of Electrification			No Target	Net 0 by 2050	Net 0 by 2060	Net 0 by 2080
		Carbon		Low Carb.		Comp.				*Endog.*	*-47%*	*-40%*	*-33%*
EE	*Behavior*	*Mgmt.*	*Power*	*Fuels*	*H_2*	*Policies*	*Trans.*	*Buildings*	*Industry*	*Endog.*	*-100%*	*-80%*	*-60%*
Case a	Case a	Case a	Case a	Case a	Case a	Case a	Ref	Ref	Ref	***NT.Ref***	***0by50.Ref***	***0by60.Ref***	***0by80.Ref***
Case a	Case a	Case a	Case a	Case a	Case a	Case a	**Adv**	**Adv**	**Adv**	***NT.All-a***	***0by50.All-a***	***0by60.All***	***0by80.All***
Case a	Case a	Case a	Case a	Case a	Case a	Case a	**Adv**	Ref	Ref	***NT.Trans-a***	***0by50.Trans-a***		
Case a	Case a	Case a	Case a	Case a	Case a	Case a	Ref	**Adv**	Ref	***NT.Bldg-a***	***0by50.Bldg-a***		
Case a	Case a	Case a	Case a	Case a	Case a	Case a	Ref	Ref	**Adv**	***NT.Ind-a***	***0by50.Ind-a***		
Case b	Case a	Case a	Case a	Case a	Case a	Case a	**Adv**	**Adv**	**Adv**	*NT.All-a.EE-b*	*0by50.All-a.EE-b*		
Case a	**Case b**	Case a	Case a	Case a	Case a	Case a	**Adv**	**Adv**	**Adv**	*NT.All-a.Bhv-b*	*0by50.All-a.Bhv-b*		
Case a	Case a	**Case b**	Case a	Case a	Case a	Case a	**Adv**	**Adv**	**Adv**	*NT.All-a.CDR-b*	*0by50.All-a.CDR-b*		
Case a	Case a	Case a	**Case b**	Case a	Case a	Case a	**Adv**	**Adv**	**Adv**	*NT.All-a.Pwr-b*	*0by50.All-a.Pwr-b*		
Case a	Case a	Case a	Case a	**Case b**	Case a	Case a	**Adv**	**Adv**	**Adv**	*NT.All-a.LCF-b*	*0by50.All-a.LCF-b*		
Case a	Case a	Case a	Case a	Case a	**Case b**	Case a	**Adv**	**Adv**	**Adv**	*NT.All-a.H2-b*	*0by50.All-a.H2-b*		
Case a	Case a	Case a	Case a	Case a	Case a	**Case b**	Adv	Adv	Adv	*NT.All-a.CmPl-b*	*0by50.All-a.CmPl-b*		
Case b	**Case b**	**Case b**	**Case b**	**Case b**	**Case b**	**Case b**	**Adv**	**Adv**	**Adv**	*NT.All-a.AllAlts-b*	*0by50.All-a.AllAlts-b*		

EMF 37 - Alternate dimensions scenario matrix (CMSG)

CMSG Scenarios			Degree of Electrification			No Target	Net 0 by 2050	Net 0 by 2060	Net 0 by 2080
	H2 Prod.					*Endog.*	*-47%*	*-40%*	*-33%*
CCS	*& Use*	*DAC*	*Trans.*	*Buildings*	*Industry*	*Endog.*	*-100%*	*-80%*	*-60%*
Ref	Ref	Ref	Ref	Ref	Ref	*NT.Ref*	*0by50.Ref*	*0by60.Ref*	*0by80.Ref*
Ref	Ref	Ref	**Adv**	**Adv**	**Adv**	*NT.All-a*	*0by50.All-a*	*0by60.All*	*0by80.All*
Ref	Ref	Ref	**Adv**	Ref	Ref	*NT.Trans-a*	*0by50.Trans-a*		
Ref	Ref	Ref	Ref	**Adv**	Ref	*NT.Bldg-a*	*0by50.Bldg-a*		
Ref	Ref	Ref	Ref	Ref	**Adv**	*NT.Ind-a*	*0by50.Ind-a*		
None	Ref	None	Ref?	Ref?	Ref?		***CMSG-01-2050***	***CMSG-01-2060***	***CMSG-01-2080***
Adv	Ref	Ref	Ref?	Ref?	Ref?		***CMSG-02-2050***	***CMSG-02-2060***	***CMSG-02-2080***
Ref	Adv	Ref	Ref?	Ref?	Ref?		***CMSG-03-2050***	***CMSG-03-2060***	***CMSG-03-2080***
Ref	Ref	Adv	Ref?	Ref?	Ref?		***CMSG-04-2050***	***CMSG-04-2060***	***CMSG-04-2080***
Adv	Adv	Adv	Ref?	Ref?	Ref?	***CMSG-03-BAU***	***CMSG-05-2050***	***CMSG-05-2060***	***CMSG-05-2080***

EMF 37 - Alternate dimension descriptions *(Illustrative)*

Dimension	Description
Energy Efficiency	Low cost, high potential for efficiency
Carbon Management / Carbon Dioxide Removal	Availability and cost of CDR technologies such as biomass energy with CCS and direct air capture
Behavioral Change	Significant behavioral changes such as work from home and personal mobility
Power Sector	Lower cost renewables/CCS/nuclear/SMR
Low Carbon Fuels	Low cost biofuels
H2	Low cost hydrogen
Complementary Policies	Expansion of state policies; layered federal policies (e.g., CES)

SB100: Pathways to Success

A collaborative study by EDF, CATF, E3, Stanford & Princeton

Jane Long,
Environmental Defense Fund

Stanford University Energy Forum 5-10-21

Main question

How can California affordably and reliably decarbonize its electricity sector by 2045?

Project design

- Use three electricity system optimization models.
- Identify strategies that meet demand for electricity while eliminating CO_2 emissions.
- Run models with and without clean firm power – power that is available on demand for as long as needed.
- Evaluate cost, build out, land use, storage and transmission implications.

Key messages about renewable energy

- Renewable energy has become inexpensive. Price is no longer a constraint.
- Major constraints will be seasonal variability, land use and transmission issues.

Key messages about energy storage

- We project the need for storage will be 25- 110 GW providing 100 – 800 GWh energy.
- The largest battery facility in the world is being built in CA at 0.4 GW / 1.6 GWh.
- Will all energy storage come from batteries?

Key messages about clean firm power

- California can reach SB100 goals without increases to wholesale electricity rates ***if*** it has at least 30 GW of clean firm power.
- The type of clean firm power doesn't change the cost much.
- The higher cost/MW for clean firm power is not that important, the system cost is the key factor.
- If California needs clean firm power, then most regions likely need clean firm power.

What to do

- Plan for clean firm power now, including *cost recovery*.
- Plan for realistic land use and transmission limitations.
- Develop realistic assumptions for future battery capacity.
- Plan for storage beyond batteries

Scenario Details & Specification

Scenario Details and Discussion
Reference Scenario

- The reference scenario assumes no new federal climate policy.
- To the extent practicable, modelers should include existing federal incentives for energy technologies as well as state policies (e.g., RPS, RGGI, AB32).
- In light of the rapidly changing economic circumstances, for the **beta** and first rounds, models should use their existing reference scenario.
- Future rounds may encourage baseline calibration to a forthcoming EIA Annual Energy Outlook scenario (e.g., AEO 2021).

Scenario Details and Discussion
Decarbonization Dimension

Net Zero Pathways

- The decarbonization pathways are defined as linear reductions from 2020 to Net Zero emissions by 2050, 2060, or 2080. The targets are specified as CO_2-only and include the following source categories: fossil fuel combustion, non-energy use fossil fuels, and industrial process emissions. Non-CO_2 GHG emissions are not included.
- Because not all the EMF 37 models include land and forest carbon sinks, in this study the Net Zero annual emissions targets are converted into gross CO_2 emission targets. Converting the net emissions goals to goals framed as a reduction in gross fossil carbon emissions requires consideration of the full array of U.S. GHG sources and sinks.
- For models that do not endogenously estimate LULUCF, we will assume a constant sink of 800 $MtCO_2$ per year. This assumption provides 800 Mt CO_2 per year head room for models to reach the Net Zero targets and translates into a maximum reduction of combustion and non-combustion CO_2 emissions of 87% in the final year (e.g., 2050, 2060, or 2080) as shown in Table 7.
- A more detailed sectoral breakdown of the US GHG Inventory is presented in Table 8. Note that emissions from biomass consumption (e.g., wood, ethanol and biodiesel) are embedded with the LULUCF category.
- While the emissions pathways are specified as CO2 only, models should assume that the resulting carbon price or shadow price on carbon should also be applied to non-CO2 greenhouse gases. In addition, we include a net-zero GHG by 2050 sensitivity scenario to shed additional light on the differences between net-zero CO2 and net-zero GHG targets.

Scenario Details and Discussion
Decarbonization Dimension

- **US CO_2 emissions and LULUCF sink and assumptions (Mt CO_2)**

	Inventory		*Projections / Targets*
Gas/Source	**2005**	**2018**	**20-50/60/80**
CO2 (gross)	6,132	5,425	800
Fossil Fuel Combustion	5,741	5,032	
Non-Energy Use	140	135	
Industrial Process	252	258	
Land Use, Land-Use Change, and Forestry (Sink)	-815	-774	-800
Net CO2 Emissions (Sources and Sinks)	5,317	4,651	**0**

Scenario Details and Discussion
Decarbonization Dimension

INCLUDED SOURCES		
	Inventory	
Gas/Source	**2005**	**2018**
CO2 (gross)	6,132	5,425
Fossil Fuel Combustion	5,741	5,032
Transportation	1,856	1,821
Electric Power	2,400	1,753
Industrial	850	833
Residential	358	337
Commercial	227	247
U.S. Territories	50	41
Non-Energy Use of Fuels	140	135
Industrial Process	252	258
Iron and Steel Production & Metallurgical Coke Production	70	43
Cement Production	46	40
Petroleum Systems	12	37
Natural Gas Systems	25	35
Petrochemical Production	27	29
Other	70	74
Land Use, Land-Use Change, and Forestry[a] (Sink)	-815	-774
Net CO2 Emissions (Sources and Sinks)	5,317	4,651
EMBEDDED or EXCLUDED		
Wood Biomass, Ethanol, and Biodiesel Consumption (embedded in LULUCF sink) [a]	231	329
Non-CO_2 GHG (excluded)	1,260	1,252

- **Summary of US CO_2 emissions inventory in 2005 and 2018 (Mt CO_2e).**

Source: Excerpt from US EPA GHG Inventory Report, Table ES-2.

[a] Emissions from Wood Biomass, Ethanol, and Biodiesel Consumption are not included specifically in summing Energy sector totals. Net carbon fluxes from changes in biogenic carbon reservoirs are accounted for in the estimates for LULUCF.

Scenario Details and Discussion
Decarbonization Dimension

Net and Gross Percentage Reductions

		Net 0 by 2050	Net 0 by 2060	Net 0 by 2080
Net % Below 2005	2020	-20%	-20%	-20%
	2030	-47%	-40%	-33%
	2050	-100%	-80%	-60%
	2060		-100%	-73%
	2080			-100%
Gross % Below 2005	2020	-18%	-18%	-18%
	2030	-41%	-35%	-29%
	2050	-87%	-70%	-52%
	2060		-87%	-64%
	2080			-87%

Net and Gross MtCO2 Targets

		Net 0 by 2050	Net 0 by 2060	Net 0 by 2080
Net CO2 Target (MtCO2)	2020	4,254	4,254	4,254
	2030	2,818	3,190	3,562
	2050	0	1,063	2,127
	2060		0	1,418
	2080			0
Gross CO2 Target (MtCO2)	2020	5,054	5,054	5,054
	2030	3,636	3,990	4,345
	2050	800	1,863	2,927
	2060		800	2,218
	2080			800

Scenario Details and Discussion
Decarbonization Dimension

- *Banking and Borrowing:*
  - No banking or borrowing is allowed in meeting the reduction targets.
  - While allowing full flexibility with banking and borrowing may be more efficient, it would obscure some of the key issues we want to explore in this study.
    - First, we are interested in what the net-zero energy system and economy look like, and banking would allow models to avoid meeting that target.
      - Note that net-zero is inclusive of the land use sink.
      - We may also want to consider if the CMSG can develop supply curves for other negative emissions technologies that can be used by other models.
    - Second, we are also interested in the 2030 results along the path towards net-zero. With banking and borrowing, and carbon prices following a Hotelling path, the near-term results and the initial carbon price are driven by long-term technology assumptions.
  - For consideration:
    - Some modelers have expressed concern about slow start and abrupt end of a linear path to net-zero. While we don't want to allow banking that would result in emissions higher than net-zero in 2050 (or 2060, or 2080), there is no reason a model couldn't over-comply in the early years if that makes it easier for the model to reach net-zero in the target year.

Scenario Details and Discussion
Electrification Dimension

- ***Starting Point for Other Scenario Specifications***
  - While the details of the remaining scenario specifications will be worked out over the course of the beta round.
  - We provide the descriptions below as a starting point.
  - These are based on descriptions of related scenarios from previous EMF studies.

Scenario Details and Discussion
Electrification Dimension

Electrification Dimension

- Although the assumptions for electrification of transportation, buildings, and industry are still left to modeler's choice, we maintain the goal that differences between reference and advanced levels of electrification should be meaningful and lead to insights into the value of electrification as well as technology advancement at the end of this project.
- For the core scenarios, modelers are therefore requested to choose their assumptions for these sectors that the reference assumptions represent *evolutionary* (i.e., reference) improvements in technology and behavior and the optimistic assumptions represent *plausibly advanced* improvements.
- A comparison of the choice that modelers have made in this regard may well be one of the analyses that serves as an output of this process.
- Furthermore, sensitivity of technology uptake to these ranges of assumptions could be an important outcome of the study that might be informative to decision-makers.
- The specification of the reference and optimistic scenarios will be informed by the transportation, buildings, and industry study groups.

Scenario Details and Discussion
Electrification Dimension

Transportation Scenarios

- These scenarios should take an expansive view of the transportation sector to include personal and commercial vehicles, freight, public transit, and potentially aviation in the later years. As illustrated in Table 4, the scenarios may explore aspects of technology availability, cost, adoption rates, and the deployment of complementary infrastructure.

Buildings Scenarios

- These scenarios should explore the pace and scale at which end-use service demands such as heating and cooking may be met by electrification. The potential will likely differ across regions and commercial and residential properties.

Industry Scenarios

- The diversity of industrial processes makes this sector challenging to model. The scenarios may explore the rate and extent of electrification across a parsimonious disaggregation of the industrial sector (e.g., cement, iron and steel, chemicals, manufacturing, etc.).
- Some coordination across the buildings and industry scenarios may be beneficial for particular technology pathways to maintain consistency such as the adoption of heat pumps.

Scenario Details and Discussion
Alternate Dimensions

Alternate Dimensions

- The alternate dimensions capture sensitivities that effect all the electrifying sectors or have economywide effects.
- For example, although low carbon fuels such as green hydrogen or methane are frequently examined as alternatives to electric vehicles, the availability of low carbon fuels also has implications for the electrification of buildings and industry (e.g., low-emitting heat source).

Scenario Details and Discussion
Alternate Dimensions

Energy Efficiency

- This sensitivity explores the cost and potential for energy efficiency to meet service demands with less energy.

Carbon Dioxide Removal

- CO_2 removal technologies include biomass energy with CCS and direct air capture. CDR technologies may serve as a backstop source of emission reductions and may play a pivotal role in meeting net zero targets in a cost-effective manner. Sensitivities may explore the costs, pace of adoption, and scale of these technologies.

Behavioral Change

- Behavioral change encapsulates a broad range of potential sensitivities. Scoping meeting discussions centered around so-called Smart Growth scenarios that entail less sprawl, more urbanization and a greater degree of telework.

Power Sector

- Sensitivities within the power sector may also influence the extent of electrification and may include the cost and availability of generating technologies, grid integration, constraints on transmission expansion, storage technology development, inter-regional power flows (e.g., wind power from the Midwest to the Southeast), and co-production of power and fuels (e.g., H_2). Other sensitivities may include the interaction between variable renewable energy, demand reduction, and demand response.

Low Carbon Fuels

- The availability of low carbon fuels or energy carriers such as hydrogen produced from electrolysis or gasified biomass competes with electricity in all three electrifying sectors. These sensitivities explore the conditions under which low carbon fuels limit electrification.

Complementary Policies

- The scenario design layers stylized, economywide linear decarbonization scenarios on top of existing state and federal policies (e.g., RPS, AB32, CAFE standards). These sensitivities may explore the implications of tightening or loosening these complementary policies. This space was explored in greater depth in the Policy Scenarios portion of EMF 24.

Scenario Details and Discussion
Additional Assumptions

- **International Policy Outside of North America:**
  - The focus of this study is on high electrification scenarios for North America under different rates of decarbonization.
  - To minimize the trade effects in global models or models that represent international trade, assume that all regions face the same carbon price as found in North America.

- **Offsets:**
  - these scenarios assume no international or domestic offsets or tax credits of any kind.