Historical overview of the EPAUS9r TIMES model and its application in analyzing energy system decarbonization

Carol Lenox
US EPA
IEA-ETSAP workshop

December 1. 2022

Disclaimer

- The views expressed in this presentation are those of the author and do not necessarily reflect the views or policies of the US EPA.
- All results provided here are from an ongoing research study. Do not cite or redistribute for other purposes.

Geographic scope of EPA ORD models & select applications

COMET-NYC

Energy system optimization model

Evaluation of NYC transportation policies

EPAUS9r-TIMES

Energy system optimization models

Starter model for developing countries

Scenarios for exploring deep decarbonization
Assessment of hydrogen use in transportation

GCAM-USA

Human-Earth Systems simulation model

Air pollutant emission impacts of alternative CO2 mitigation pathways

State and regional EV emission impacts

State-level NOx reduction potential of EE/RE

ORD Energy Modeling Tool Overview: EPAUS9r-TIMES

2002	Began to build MARKAL U.S. national model
2005	Completed **national model**
2008	First publicly released version of **national model and 9 region model**
2010	Released updated national and regional models
2012	Released updated national and regional models
2014	Released updated **regional model only**
2016	Released **first TIMES version** (9rT) of regional model
2018	Released updated version of 9rT model
2020	Released updated version of 9rT model

Time Horizon: 2010 – 2055, 1, 3, and 5-year increments

Spatial Resolution: 9 US Census Divisions

Sectors: Resource supply, EGUs, transportation, buildings, industrial

Main data source: DOE's Annual Energy Outlook (AEO)

Pollutants: GHG and criteria air pollutants

Availability: Developed and housed at EPA/ORD, publicly available

In-house staffing: 9 FTEs in 2002, 1 ½ FTEs in 2022, over the years there have been 20 post-doc/post-masters contractors and over 25 student contractors

EPAUS9r Database User Community

The EPAUS9r database has been utilized by a wide range of external parties. These users represent more than 50 organizations, including:

- DOE's National Energy Technology Laboratory (NETL)
- Northeast States for Coordinated Air Use Management (NESCAUM)
- Open Energy Outlook (an international team of energy system researchers)
- Carnegie Melon University
- University of Colorado at Boulder
- Johns Hopkins
- University Texas El Paso

TIMES Modeling – EPAUS9rT database

Published Papers:

- Since 2010, **over 55 peer-reviewed papers** (> 30 in-house) have been published using our MARKAL/TIMES modeling framework

Example Peer Reviewed Papers

- Browning, Morgan S. and Carol S. Lenox (2020). Contribution of offshore wind to the power grid: U.S. air quality implications. *Applied Energy*, vol. 276
- Brown, K. and D.H. Loughlin (2019). Assessment of a hybrid solar thermal – gas turbine technology. Clean Energy and Environmental Policy., pp. 1-14. doi: 10.1007/s10098-018-1659-3.
- Brown, Kristen E., Hottle, Troy A., Bandyopadhyay, Rubenka, Babaee, Samaneh, Dodder, Rebecca S., Kaplan P. Ozge, Lenox, Carol S., and Daniel H. Loughlin (2018). Evolution of the United States Energy System and Related Emissions under Varying Social and Technological Development Paradigms: Plausible Scenarios for Use in Robust Decision Making. Environmental Science and Technology, doi: 10.1021/acs.est.8b00575
- Lenox, C.S. and D.H. Loughlin. (2017). Effects of recent energy system changes on CO_2 projections for the United States. *Clean Technologies and Environmental Policy*, doi: 10.1007/s10098-017-1417-y.
- Loughlin, D.H., Macpherson, A.J., Kaufman, K.R., and B.N. Keaveny (2017). Marginal abatement cost curves for NOx that incorporate control measures, renewable energy, energy efficiency and fuel switching. *Journal of the Air and Waste Management Assoc*., 67(10), 1115-1125. doi: 10.1080/10962247.2017.1342715.
- Babaee, S. and D.H. Loughlin (2017). Exploring the role of natural gas power plants with carbon capture and storage as a bridge to a low-carbon future. Clean Technologies and Environmental Policy, doi: 10.1007/s10098-017-1479-x.
- Lenox, C.S. and P.O. Kaplan. Role of natural gas in meeting an electric sector emissions reduction strategy and effects on greenhouse gas emissions. Energy Economics, doi: 10.1016/j.eneco.2016.06.009.

Application

Some initial results from the EMF37:
Deep Decarbonization and High Electrification
Scenarios for North America

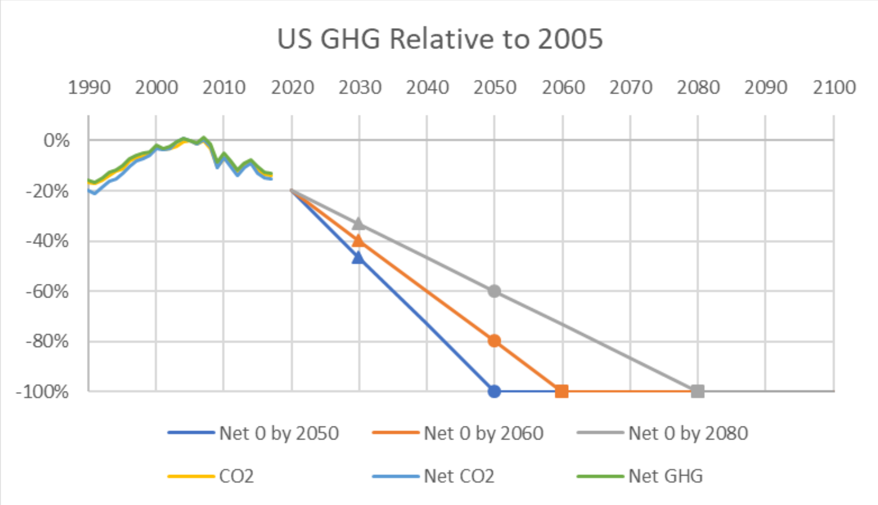
Energy Modeling Forum (EMF) 37

Deep Decarbonization and High Electrification Scenarios for North America

Participating Models		
	Submissions	
Model	Scenarios	Variables
ADAGE	6	374
AnyMOD	19	19
CTUS-NEMS	3	264
EC-MSMR	6	175
EPAUS9rTIMES	16	210
EPS	7	493
FARM	8	250
GCAM	16	501
GCAM-USA	14	372
gTech	12	188
MARKAL-NETL	18	329
NATEM	8	512
TEMPO	6	121
USREP-ReEDS	10	338
Scout	3	54

Motivating Questions of the Study:

- What roles do the transportation, buildings, and industry sectors play in reaching economy-wide net-zero emissions goals?
  - How do differing pathways for technology, behavioral change, and complimentary policies impact sectoral pathways in deep decarbonization scenarios?
  - How do carbon management technologies (CDR, BECCS, DAC, H2, etc.) impact net-zero scenarios?
- To what extent can the transportation, buildings, and industrial sectors be electrified, particularly in the context of policies to achieve deep decarbonization and "net-zero" emissions? How might technological and behavioral change, decarbonization efforts alter the extent of electrification?

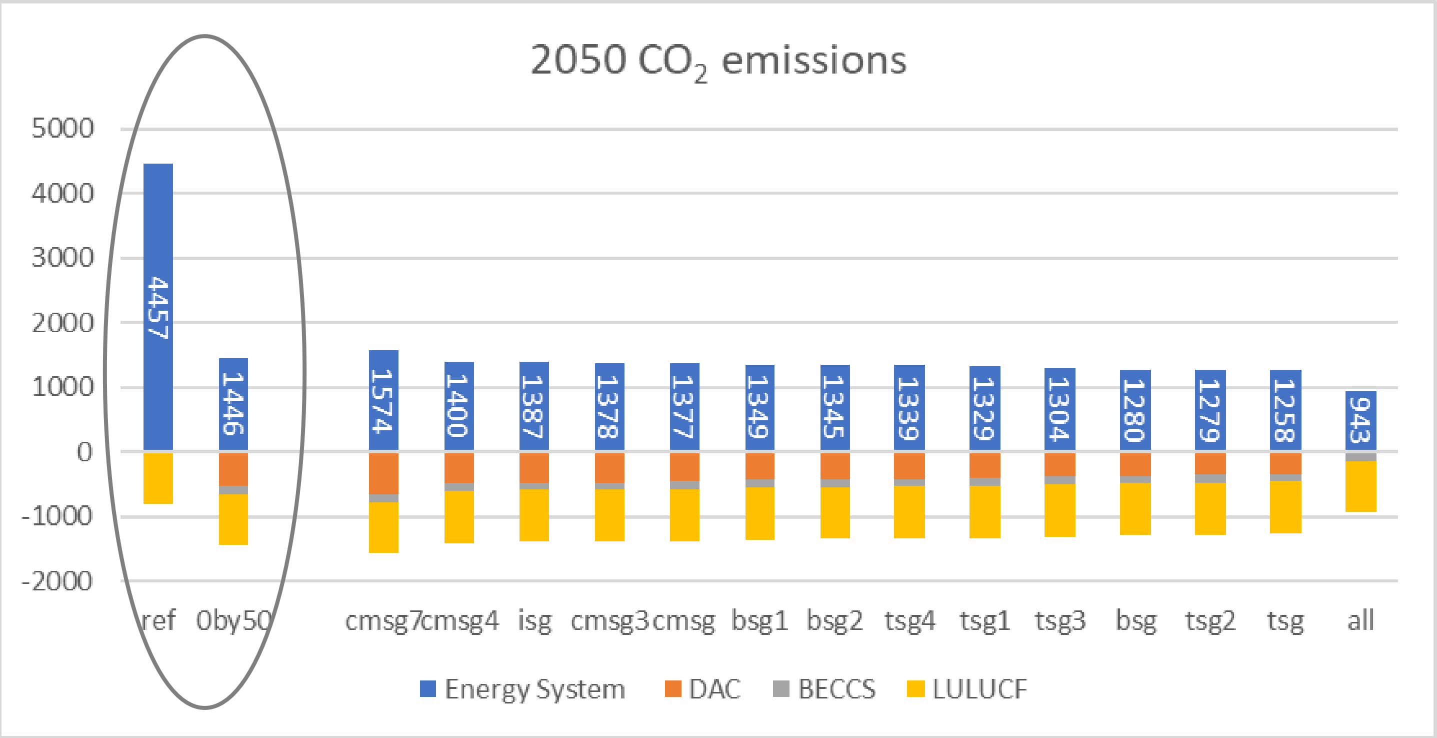


Illustrative decarbonization pathways for the US, from the EMF37 study design

26 possible scenarios, 1690 requested variables per scenario

EPAUS9rT EMF Scenario Implementation

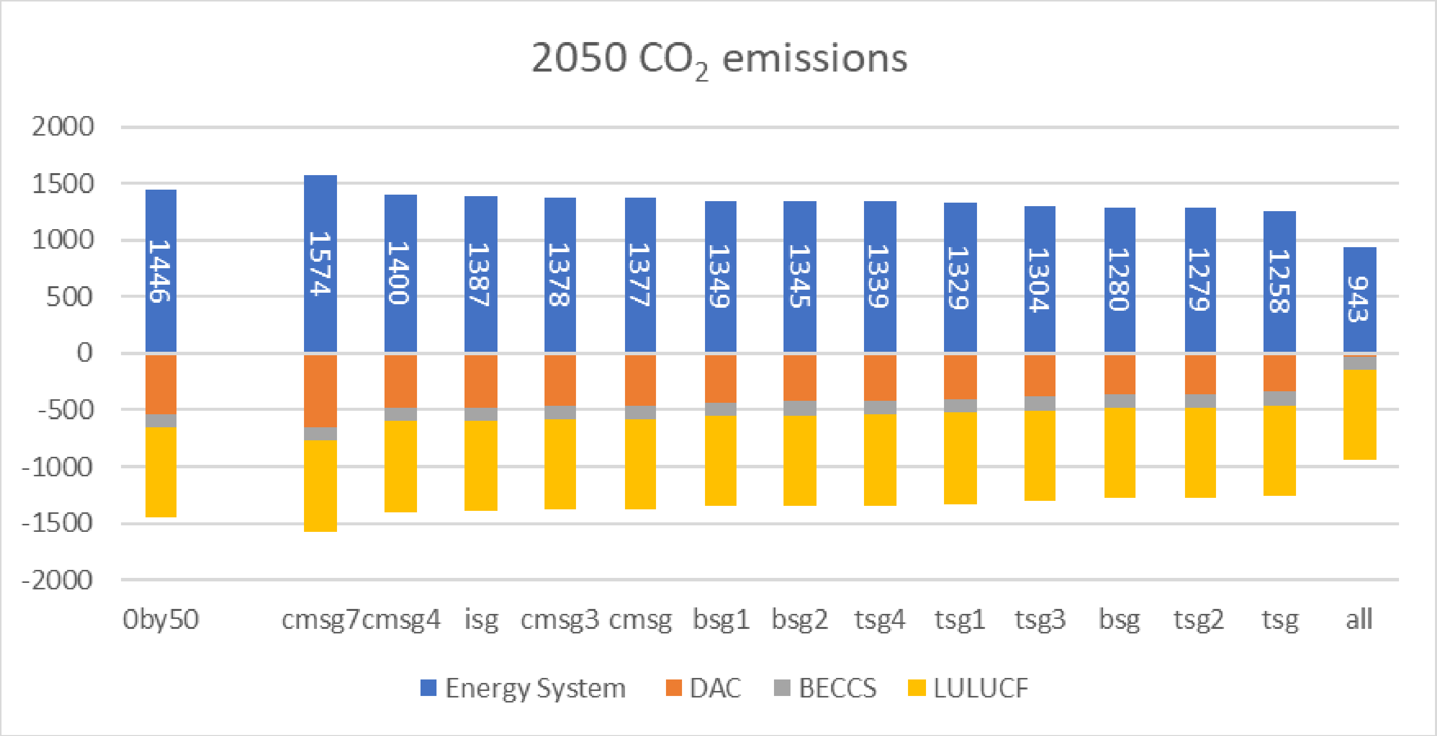
0by50	Netzero CO_2 emissions by 2050	Emissions reduction trajectory to netzero CO_2 by 2050, including land use management strategies that sequester carbon
All the following scenarios include the netzero emissions constraint		
bsg1	Aggressive electrification	No new capacity of non-electric powered technologies after 2030. Fuel constraints relaxed to allow for increased electrification.
bsg2	Accelerated deployment	Demand adjustments to reflect user conservation measures and increased electrification
bsg	Aggressive energy efficiency	All bsg improvements above plus allowing only the highest effieciency technologies to be purchased after 2030.
tsg1	Advanced transportation technology	Implemented cost improvements for H2 and electric powered vehicles in light-duty and heavy-duty vehicles
tsg2	Adv technology and policy	Combined the changes in tsg1 and tsg3
tsg3	Advanced Policy	Implemented no new purchases of gasoline or diesel vehicles starting in 2035
tsg4	Behavior change	Demand adjustments due to changes in transportation behavior
tsg		All tsg improvements above
cmsg1	No DAC or CCS	Infeasible run
cmsg3	Advanced H2	Technology cost and distribution cost assumptions in the EPAUS9r TIMES reflecting DOE earthshot and other goals
cmsg4	Advance DAC	Implemented cost and efficiency improvements
cmsg7	No H2	No hydrogen allowed
cmsg		All cmsg improvements added
isg		Demand reductions, and efficiency improvements, and increased electrification
all		Includes all system improvements modeled in each of the sector scenarios



- In the reference net-zero by 2050 scenario, energy system emissions are reduced 68% via a combination of electrification, efficiency improvements, and fuel-switching.
- The remaining CO_2 emissions reductions come through carbon capture and land-use changes

2050 CO_2 Emissions (Mt)

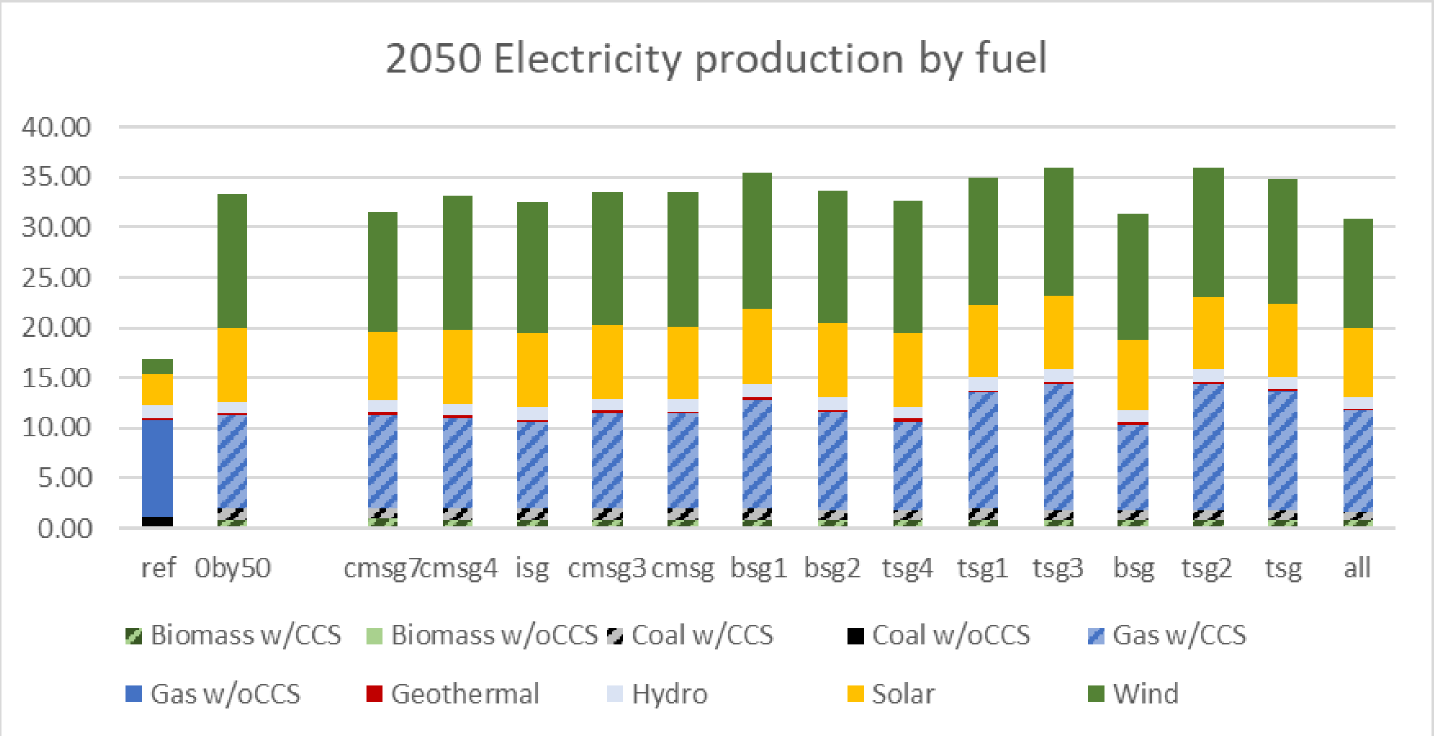
0by50	Netzero CO_2 emissions by 2050	Emissions reduction trajectory to netzero CO_2 by 2050, including land use management strategies that sequester carbon
All the following scenarios include the netzero emissions constraint		
bsg1	Aggressive electrification	No new capacity of non-electric powered technologies after 2030. Fuel constraints relaxed to allow for increased electrification.
bsg2	Accelerated deployment	Demand adjustments to reflect user conservation measures and increased electrification
bsg	Aggressive energy efficiency	All bsg improvements above plus allowing only the highest effieciency technologies to be purchased after 2030.
tsg1	Advanced transportation technology	Implemented cost improvements for H2 and electric powered vehicles in light-duty and heavy-duty vehicles
tsg2	Adv technology and policy	Combined the changes in tsg1 and tsg3
tsg3	Advanced Policy	Implemented no new purchases of gasoline or diesel vehicles starting in 2035
tsg4	Behavior change	Demand adjustments due to changes in transportation behavior
tsg		All tsg improvements above
cmsg1	No DAC or CCS	Infeasible run
cmsg3	Advanced H2	Technology cost and distribution cost assumptions in the EPAUS9r TIMES reflecting DOE earthshot and other goals
cmsg4	Advance DAC	Implemented cost and efficiency improvements
cmsg7	No H2	No hydrogen allowed
cmsg		All cmsg improvements added
isg		Demand reductions, and efficiency improvements, and increased electrification
all		Includes all system improvements modeled in each of the sector scenarios



- Across the sector scenarios, the energy system CO_2 emissions reductions range from 65% to 79%, with the highest reduction coming from the scenario in which all system improvements were available to the model.
- The scenario in which no hydrogen fuel was allowed in the transportation sector had the least reduction in energy system emissions and required the highest level of DAC to achieve net-zero.

2050 Electricity production by fuel (EJ)

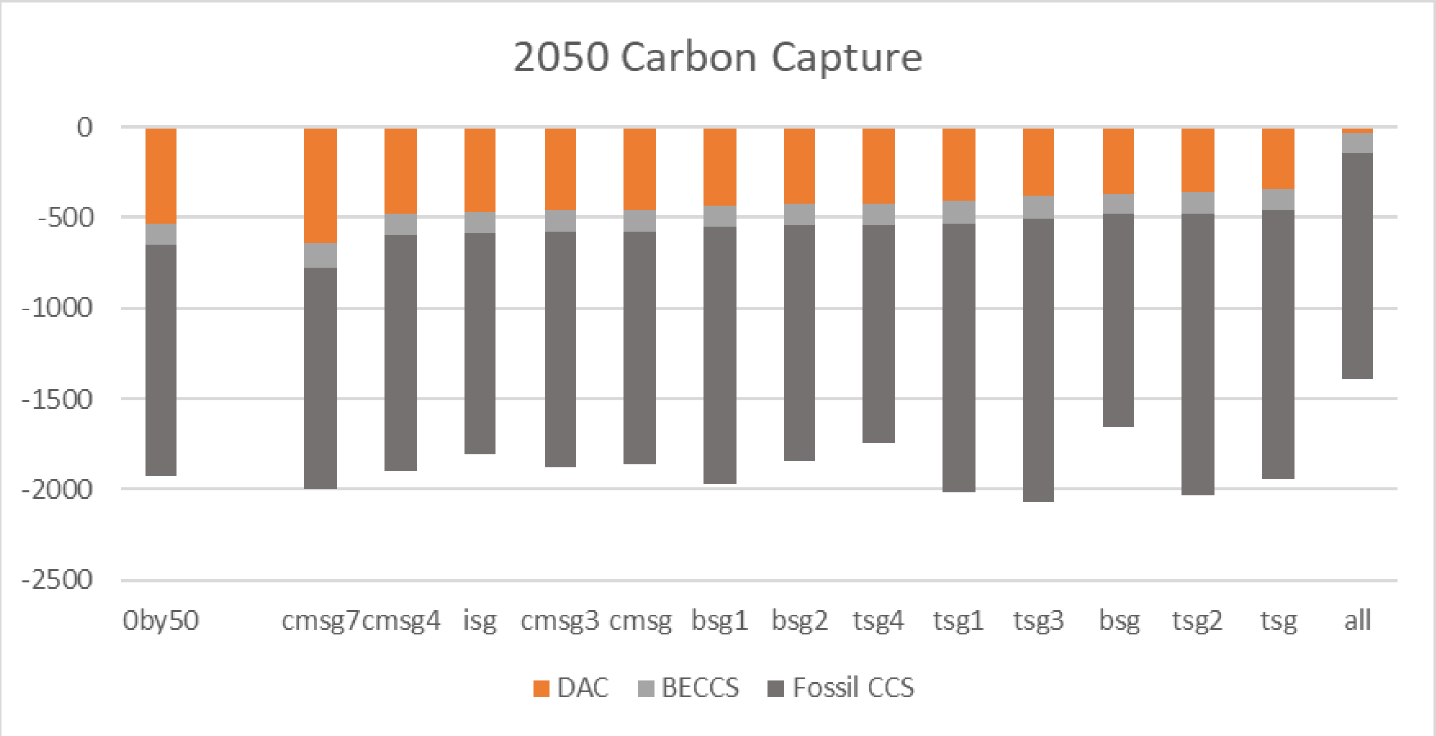
0by50	Netzero CO_2 emissions by 2050	Emissions reduction trajectory to netzero CO_2 by 2050, including land use management strategies that sequester carbon
All the following scenarios include the netzero emissions constraint		
bsg1	Aggressive electrification	No new capacity of non-electric powered technologies after 2030. Fuel constraints relaxed to allow for increased electrification.
bsg2	Accelerated deployment	Demand adjustments to reflect user conservation measures and increased electrification
bsg	Aggressive energy efficiency	All bsg improvements above plus allowing only the highest effieciency technologies to be purchased after 2030.
tsg1	Advanced transportation technology	Implemented cost improvements for H2 and electric powered vehicles in light-duty and heavy-duty vehicles
tsg2	Adv technology and policy	Combined the changes in tsg1 and tsg3
tsg3	Advanced Policy	Implemented no new purchases of gasoline or diesel vehicles starting in 2035
tsg4	Behavior change	Demand adjustments due to changes in transportation behavior
tsg		All tsg improvements above
cmsg1	No DAC or CCS	Infeasible run
cmsg3	Advanced H2	Technology cost and distribution cost assumptions in the EPAUS9r TIMES reflecting DOE earthshot and other goals
cmsg4	Advance DAC	Implemented cost and efficiency improvements
cmsg7	No H2	No hydrogen allowed
cmsg		All cmsg improvements added
isg		Demand reductions, and efficiency improvements, and increased electrification
all		Includes all system improvements modeled in each of the sector scenarios



- Electricity production increased 83% to 113% across all scenarios.
- Electric sector CO_2 emissions reduced ~85% in all scenarios.
- In all scenarios, electricity production technologies from coal, natural gas, and biomass implemented carbon capture technologies to minimize emissions. The model preferred this, along with increases in wind and solar, over implementing a large amount of BECCs.

2050 Carbon Capture (Mt)

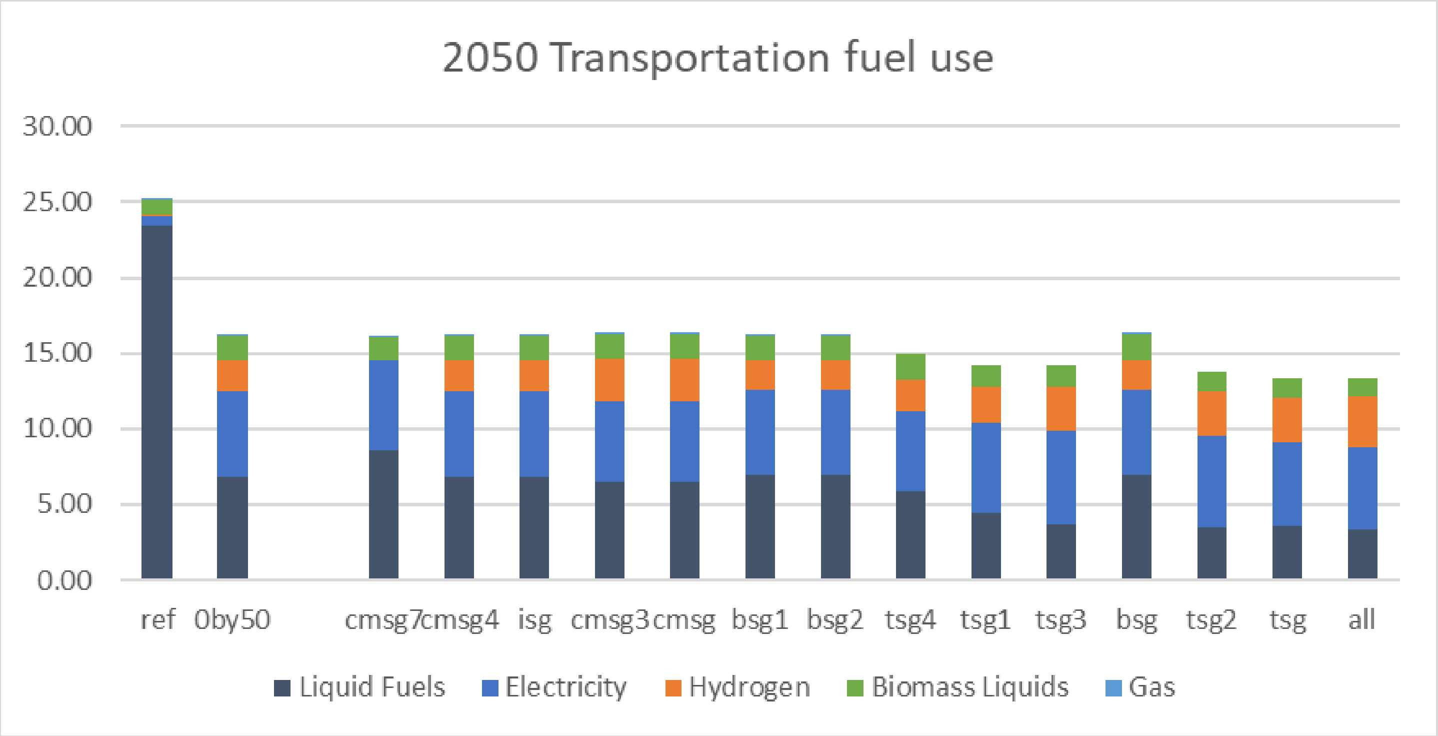
0by50	Netzero CO_2 emissions by 2050	Emissions reduction trajectory to netzero CO_2 by 2050, including land use management strategies that sequester carbon
All the following scenarios include the netzero emissions constraint		
bsg1	Aggressive electrification	No new capacity of non-electric powered technologies after 2030. Fuel constraints relaxed to allow for increased electrification.
bsg2	Accelerated deployment	Demand adjustments to reflect user conservation measures and increased electrification
bsg	Aggressive energy efficiency	All bsg improvements above plus allowing only the highest effieciency technologies to be purchased after 2030.
tsg1	Advanced transportation technology	Implemented cost improvements for H2 and electric powered vehicles in light-duty and heavy-duty vehicles
tsg2	Adv technology and policy	Combined the changes in tsg1 and tsg3
tsg3	Advanced Policy	Implemented no new purchases of gasoline or diesel vehicles starting in 2035
tsg4	Behavior change	Demand adjustments due to changes in transportation behavior
tsg		All tsg improvements above
cmsg1	No DAC or CCS	Infeasible run
cmsg3	Advanced H2	Technology cost and distribution cost assumptions in the EPAUS9r TIMES reflecting DOE earthshot and other goals
cmsg4	Advance DAC	Implemented cost and efficiency improvements
cmsg7	No H2	No hydrogen allowed
cmsg		All cmsg improvements added
isg		Demand reductions, and efficiency improvements, and increased electrification
all		Includes all system improvements modeled in each of the sector scenarios



- Across the models that reported all three the range of sequestered CO_2 is 1202-3268 mT.
- Carbon capture is highest in those runs with the highest amount of electrification OR in the case where no hydrogen is allowed in transportation
- Implementing all of the sector improvements leads to a 28% reduction in needed carbon capture over the reference 0by50 scenario

2050 Transportation Fuel Use (EJ)

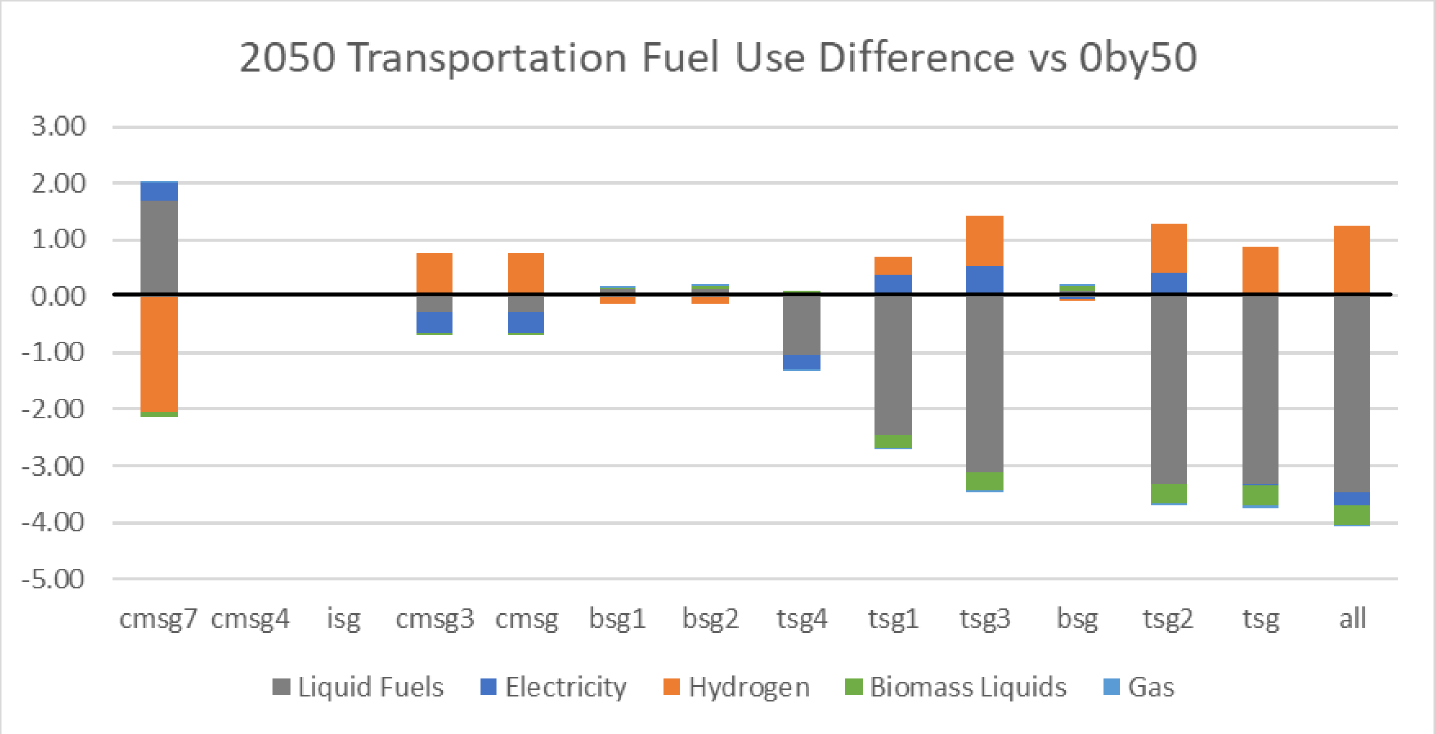
0by50	Netzero CO_2 emissions by 2050	Emissions reduction trajectory to netzero CO_2 by 2050, including land use management strategies that sequester carbon
All the following scenarios include the netzero emissions constraint		
bsg1	Aggressive electrification	No new capacity of non-electric powered technologies after 2030. Fuel constraints relaxed to allow for increased electrification.
bsg2	Accelerated deployment	Demand adjustments to reflect user conservation measures and increased electrification
bsg	Aggressive energy efficiency	All bsg improvements above plus allowing only the highest effieciency technologies to be purchased after 2030.
tsg1	Advanced transportation technology	Implemented cost improvements for H2 and electric powered vehicles in light-duty and heavy-duty vehicles
tsg2	Adv technology and policy	Combined the changes in tsg1 and tsg3
tsg3	Advanced Policy	Implemented no new purchases of gasoline or diesel vehicles starting in 2035
tsg4	Behavior change	Demand adjustments due to changes in transportation behavior
tsg		All tsg improvements above
cmsg1	No DAC or CCS	Infeasible run
cmsg3	Advanced H2	Technology cost and distribution cost assumptions in the EPAUS9r TIMES reflecting DOE earthshot and other goals
cmsg4	Advance DAC	Implemented cost and efficiency improvements
cmsg7	No H2	No hydrogen allowed
cmsg		All cmsg improvements added
isg		Demand reductions, and efficiency improvements, and increased electrification
all		Includes all system improvements modeled in each of the sector scenarios



- Transportation fuel use is reduced from 36% to 47%.
- Liquid fuels are primarily replaced by electricity, with smaller amounts of hydrogen and, in some cases, biofuels.

2050 Electricity production by fuel (EJ)

0by50	Netzero CO_2 emissions by 2050	Emissions reduction trajectory to netzero CO_2 by 2050, including land use management strategies that sequester carbon
	All the following scenarios include the netzero emissions constraint	
bsg1	Aggressive electrification	No new capacity of non-electric powered technologies after 2030. Fuel constraints relaxed to allow for increased electrification.
bsg2	Accelerated deployment	Demand adjustments to reflect user conservation measures and increased electrification
bsg	Aggressive energy efficiency	All bsg improvements above plus allowing only the highest effieciency technologies to be purchased after 2030.
tsg1	Advanced transportation technology	Implemented cost improvements for H2 and electric powered vehicles in light-duty and heavy-duty vehicles
tsg2	Adv technology and policy	Combined the changes in tsg1 and tsg3
tsg3	Advanced Policy	Implemented no new purchases of gasoline or diesel vehicles starting in 2035
tsg4	Behavior change	Demand adjustments due to changes in transportation behavior
tsg		All tsg improvements above
cmsg1	No DAC or CCS	Infeasible run
cmsg3	Advanced H2	Technology cost and distribution cost assumptions in the EPAUS9r TIMES reflecting DOE earthshot and other goals
cmsg4	Advance DAC	Implemented cost and efficiency improvements
cmsg7	No H2	No hydrogen allowed
cmsg		All cmsg improvements added
isg		Demand reductions, and efficiency improvements, and increased electrification
all		Includes all system improvements modeled in each of the sector scenarios



- When hydrogen is not available (cmsg7) there is a greater use of electricity and less of a decrease in liquid fuels.
- In all the transportation cases, biofuel use is reduced as greater amounts of hydrogen are available and more cost effective in the model.

Final Thoughts

EMF 37

- Final scenario results submitted November 25, 2022
- Scenarios with implementation of the IRA due in January 2023
- Overview, sector, and cross-sector papers will be released in 2023

EPAUS9rT

- We will be sunsetting the 9-region database over the coming months
- EPA ORD work with TIMES will continue with the COMET model