Energy Futures Dashboard:
User's Mid Atlantic Scenario Summary for 2050

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Introduction

This report summarizes your user scenario as modeled via the Futures Dashboard (EFD) composed as part of the Energy Infrastructure of the Future (EIoF) study organized by the Energy Institute of The University of Texas at Austin.

The Energy Infrastructure of the Future (EIoF) study seeks to provide a comprehensive understanding of the state of energy infrastructure in the United States throughout all stages, from fuel extraction to end use consumption. For the purposes of this study, the country is divided into geographic regions established by the EIoF project (see Figure 1). The regional definitions enable us to investigate broad geographical differences in energy infrastructure quantities, costs, regulations, and customers that can be compared to trends for the continental United States. In total, there are 13 regions comprised of one or more states.

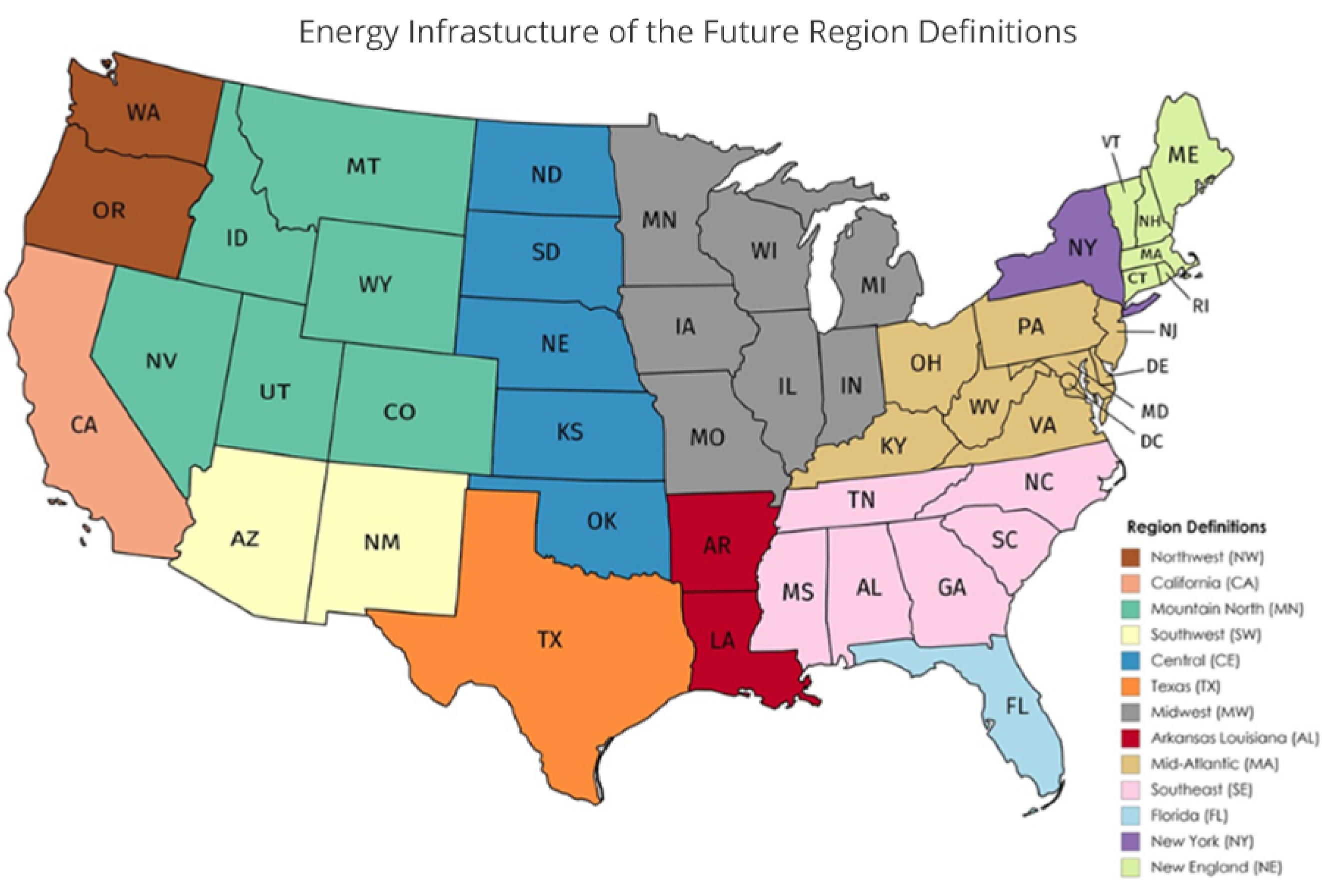

Figure 1. Regional definitions used for analysis in the Energy Infrastructure of the Future (EIoF) study.

User Input Settings: Mid Atlantic

Electricity(selected percentage by fuel and technology)

Fossil Fuels			Renewable						Nuclear
Coal	**Natural Gas**	**Petroleum**	**Hydro**	**Wind**	**Solar PV**	**Solar CSP**	**Biomass**	**Geothermal**	**Nuclear**
0%	35%	0%	1%	3%	2%	0%	0%	0%	59%

Light-duty vehicles (selected fuel percentages):

Liquid Fuels (petroleum + biofuel blend)	Electricity (electric vehicles)
65%	35%

Home Heating (selected fuel percentages):

Natural Gas	Electricity (electric vehicles)	Other (petroleum, biomas)
50%	12%	38%

Primary Energy Consumption: Historical and Future

Regional historical 2016 (extrapolated to 2020) energy consumption calculations are informed by Energy Data System historical data. The future 2050 energy consumption calculations are informed by the reference scenario of the Annual Energy Outlook (2019) of the Energy Information Administration . See the documentation for the Energy Futures Dashboard on the Energy Infrastructure of the Future webpage.

The Mid Atlantic historical and future values for energy consumption are shown in Table 1 and represented within the Sankey diagrams for 2050 (Figure 2) and 2016 (Figure 3).

Table 1. Summary of Mid Atlantic historical (2016) and future (2050) primary energy consumption by resource as partially informed by the user's choice.

Primary Energy Source	2016	2050
Petroleum	5.58 (34.7%)	4.54 (24.5%)
Coal	3.46 (21.5%)	0.37 (2.0%)
Natural Gas	4.56 (28.3%)	6.50 (35.0%)
Nuclear	1.82 (11.3%)	6.26 (33.7%)
Hydro	0.10 (0.6%)	0.08 (0.4%)
Wind	0.06 (0.4%)	0.24 (1.3%)
Solar	0.04 (0.2%)	0.19 (1.0%)
Biomass	0.47 (2.9%)	0.37 (2.0%)
Geothermal	0.01 (0.1%)	0.01 (0.1%)
Total	**16.11 (100.0%)**	**18.56 (100.0%)**

Electricity Generation and Consumption: Historical and Future

The EFD solves for the power plant and storage capacity to meet the user's 2050 desired future electricity mix using two different approaches, both of which pose relatively simplistic and "extreme" assumptions that allow the user to explore solution boundaries at high mixes of renewable electricity:

- **"Without Storage":** Wind, solar PV, and solar CSP are assumed to be curtailed (generation is reduced below what is possible) for any given hour in which their combined electricity generation is more than the assumed total electricity demand for that hour.
- **"With Storage":** If the combined electricity generation of wind, solar PV, and solar CSP is more than the assumed total electricity demand for any hour, then the EFD assumes that electricity is stored in batteries (lithium-ion batteries are assumed for costs). Then, for all hours in which wind and solar generation are less than total electricity demand, the electricity stored in the batteries is discharged to the grid starting from the hours of highest to lowest net load (net load = electricity demand – (wind generation + solar PV generation + solar CSP generation).

Table 2. Electricity generation for the Mid Atlantic region (values in terawatt-hours, TWh, with the percentage of the total in parentheses).

	Total	Fossil Fuels			Renewable						Nuclear
		Coal	Natural Gas	Petroleum	Hydro	Wind	Solar PV	Solar CSP	Biomass	Geothermal	Nuclear
2016	696.30 (100.0%)	293.90 (42.2%)	204.39 (29.4%)	1.54 (0.2%)	10.36 (1.5%)	6.65 (1.0%)	1.09 (0.2%)	0 (0%)	4.25 (0.6%)	0.00 (0.0%)	174.12 (25.0%)
2050 (user choice)	100%	0%	35%	0%	1%	3%	2%	0%	0%	0%	59%
2050 (website calculation w/ storage)	1095.58 (100%)	0.00 (0%)	384.20 (35%)	0.00 (0%)	10.21 (1%)	32.87 (3%)	21.91 (2%)	0.00 (0%)	0.00 (0%)	0.00 (0)%	646.39 (59%)

2050 (website calculation no storage)	1095.58 (100%)	0.00 (0%)	384.20 (35%)	0.00 (0%)	10.21 (1%)	32.87 (3%)	21.91 (2%)	0.00 (0%)	0.00 (0%)	0.00 (0)%	646.39 (59%)
Did dashboard calculation meet user's 2050 criteria (w/ storage)?		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Did dashboard calculation meet user's 2050 criteria (without storage)?		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 3. Electricity generation capacity for the Mid Atlantic region (values in megawatts, MW)

	Total	**Fossil Fuels**			**Renewable**						**Nuclear**
		Coal	Natural Gas	Petroleum	Hydro	Wind	Solar PV	Solar CSP	Biomass	Geothermal	Nuclear
2016	181,487.1	69,237.4	71,959.6	7,746.9	3,828	2,794.6	1,102.2	0	2,404.8	0	22,413.6
2050 (website calculation w/ storage)	229,359	0	126,095	0	2,234	10,340	13,018	0	0	0	77,673
2050 (website calculation no storage)	230,721	0	127,456	0	2,234	10,340	13,018	0	0	0	77,673

Electricity Generation and Storage Capacity in 2050

The EFD calculates how much power plant capacity of each type is required to meet the user's desired mix of electricity and serve the total hourly electricity demand in 2050. Based on historical data and this 2050 requirement, the EFD calculates the required generation capacity from 2020 to 2050 by linearly increasing or decreasing the capacity from 2020 to reach the 2050 requirement.

Table 4 summarizes the total electricity generation and total capacity of power plants and battery storage (for the "with storage" scenario) calculated to meet the user's input requirements. Table 4 also summarizes land use for power plants (currently only wind, solar PV, and CSP) in two ways. The "direct area" relates to the land area with directly covered by power plant infrastructure, roads, and facilities. The "total area" relates to all area that is encompassed within a power plant project site, including land between infrastructures (e.g., land between wind turbines).

Table 4. Summary of required power plant capacity (MW) and land use to meet total electricity generation (TWh) in 2050.

	Without Electricity Storage	**With Electricity Storage**
Net Generation	1,095 TWh	1,095 MW
Power Plant Capacity	230,721 MW	229,359 MW
Storage Cap. (Power)	N/A	1,416 MW
Storage Cap. (Energy)	N/A	0.0 TWh
Land Use, direct area (1000s acres)	71	71
Land Use, direct area (% of accessed regions)	0.0%	0.0%
Land Use, total area (1000s acres)	581	581
Land Use, total area (% of accessed regions)	0.1%	0.1%

Carbon Dioxide (CO_2) Emissions from Energy

The EFD estimates carbon dioxide (CO_2) emissions from fossil fuel combustion and the equivalent CO_2 emissions from the life cycle of manufacturing and constructing power plants. Data from 2000-2019 are calculated using the same methods that project future emissions, and thus they are not directly from government data sets. The greenhouse gas emissions associated with power plant life cycle are as used in a previous Energy Institute study as documented by [Rhodes et al. (2017)] in Energy Policy: "A geographically resolved method to estimate levelized power plant costs with environmental externalities." Because the EFD limits user inputs to change only a subset of the energy system, the user does not have the options to reduce CO_2 emissions to 0 by 2050 for the entire energy system.

Table 5. Estimates of CO^2emissions ($MtCO^2$/yr, million tonnes of CO^2
per year) from burning fossils and constructing power plants in the historical year 2016 and future year 2050 as affected by user inputs. Because the EFD limits user inputs to change only a subset of the energy system, the user does not have the options to reduce CO
^{2}emissions to 0 by 2050 for the entire energy system.

Fossil Fuel & Infrastructure	**2016**	**2050 (w/o Electricity Storage)**	**2050 (w/ Electricity Storage)**
Coal (all sectors)	330.7	34.9	34.9
Petroleum (all sectors)	359.1	233.0	233.0
Natural Gas (all sectors)	242.6	322.4	322.4
Power Plant life cycle	1.2	2.6	2.6

Estimated Cost of Service for Electricity in 2050

The EFD estimates the cost of electricity to a residential customer in three ways, and each calculation uses the same 2050 costs, in units of $2017, divided by a different divisor as displayed in Table 6. The first cost estimate is the cost per kilowatt-hour (¢/kWh), or the unit price of electricity. This cost mimics the method applied for establishing the "cost of service" for regulated vertically integrated electric utilities. This electricity. This cost mimics the method applied for establishing the "cost of service" for regulated vertically integrated electric utilities. This cost is the sum of costs for power plants and the transmission and distribution grid, decomposed into two parts for both: (1) the fixed cost of capital expenditures (= capital depreciation + interest on debt + annual capital spending on existing nuclear plant upgrades), and (2) the fixed and variable cost of operating and maintenance expenditures, including power plant fuel costs. The second cost estimate is the annual 2050 cost per person (fixed and variable costs divided by population). The third cost estimate is the annual 2050 cost per customer (fixed and variable costs divided by number of customers). Here, a "customer" is the same as the number of meters or accounts with electricity providers. In most regions of the U.S. there are 2-2.5 persons per electricity customer account.

Table 6. Summary of 2050 electricity cost, similar to a "cost of service" calculation for a regulated electric utility.

	Without Electricity Storage	**With Electricity Storage**
Total Cost	¢10.2/kWh	¢10.2/kWh
Fixed (Capital) Cost	¢6.4/kWh	¢6.4/kWh
Var. (Operating) Cost	¢3.9/kWh	¢3.9/kWh
Total Cost Per Customer	$1812.2/year	$1812.7/year
Total Cost Per Person	$1835.4/year	$1835.9/year

Major Assumptions that inform Interpretation of Results

There will be changes to consumer behavior and energy demand between today and 2050. These changes will be affected by new technologies and economic factors, but the EFD does not allow the user to explore the vast majority of these factors.

The EFD allows users to interact with only a small subset of variables that are important when considering the viability and options for our future energy system. This subset is limited to enable users to gain rapid feedback (in 1-2 minutes of computation rather than hours or days) while still enabling investigation and communication of many important insights into the constraints and possibilities for a future U.S. energy supply.

The EFD, for example, does not allow users to explore concepts such as demand response, energy efficiency, and energy conservation. Thus, the EFD does not allow users to affect how electricity energy and power demand, at any given hour, day, or month might change depending on their choices for the year 2050. Also, the EFD does not have any internal algorithms to increase or decrease end-use energy demand based upon user choices.

Assumptions for 2050 Energy Consumption Levels

The EFD uses estimates for "present" energy consumption based on data from years 2016-2019 (depending on the data source used) that are extrapolated to represent data for the year 2020. Given the user's choices, energy consumption and resource values are set for the year 2050. Data for years 2021-2049 are linear interpolations between 2020 and 2050

The following 2050 quantities of energy consumption are predetermined, and thus not affected by user inputs into the EFD, for the following fuel and sector combinations:

- Industrial
    - Primary energy
        - Coal
        - Natural Gas
        - Petroleum
        - Biomass
        - Geothermal
    - Electricity (as secondary energy)
- Commercial
    - Primary energy
        - Coal
        - Natural Gas
        - Petroleum
        - Biomass
        - Geothermal
    - Electricity (as secondary energy)
- Residential
    - Primary energy for all end uses that are not space heating (e.g., cooking, washing, water heating)
        - Coal
        - Natural Gas
        - Petroleum
        - Biomass
        - Geothermal
    - Electricity (as secondary energy) for all end uses that are not space heating (e.g., cooking, washing, water heating)

- Transportation
    - Primary energy for all transportation that is not in light duty vehicles (e.g., aviation, rail, buses, freight and heavy-duty trucking)
        - Coal
        - Natural Gas
        - Biomass

Assumptions for Choosing 2050 Electricity Mix

The EFD does not include the full variety of known or existing technologies for future or increased electricity generation. Notable omissions of electricity technologies are:

- Carbon capture and storage (CCS) associated with electricity generation from fossil fuels or biomass
- Concentrating solar power (CSP) using parabolic troughs, because the EFD assumes all solar CSP uses a power tower design
- Advanced combustion cycles (e.g., natural gas power plants using the Allam cycle)

Notable restrictions and assumptions that affect the calculated use of electricity technologies are:

- Nuclear
    - Nuclear power capacity is assumed to operate at 100% capacity factor with no ramping capability. Thus, nuclear capacity is limited to the lowest hourly power demand assumed for 2050.
- Coal
    - There are no restrictions on the quantity of coal generation or power plant ramping rates.
- Natural Gas
    - Natural gas generation is calculated based on a combination of natural gas combined cycle (NGCC) or natural gas combustion turbines (NGCT).
    - There are no restrictions on the quantity of natural generation or power plant ramping rates of either natural gas combined cycle (NGCC) or natural gas combustion turbines (NGCT).
- Petroleum
    - There are no restrictions on the quantity of petroleum generation or power plant ramping rates.

The quantities of renewable energy resources (wind, solar PV, solar CSP, biomass, and geothermal) for each EIoF region are based on data within the Renewable Energy Laboratory (NREL) Regional Energy Deployment System (ReEDS) model. In addition, for each renewable electricity technology, the EFD assumes that some of a user's desired renewable electricity consumption within one region (e.g., California) can be generated in neighboring regions (e.g., Northwest, Mountain North, and Southwest) as follows:

- Geothermal
    - The EFD assumes no importation of geothermal electricity. If a user desires a future with geothermal electricity, 100% of that electricity is assumed to be generated within the geographic boundary of that region.
- Biomass
    - The EFD assumes no importation of biomass electricity. If a user desires a future with biomass electricity, 100% of that electricity is assumed to be generated within the geographic boundary of that region.
- Solar photovoltaics (PV)
    - The EFD assumes no importation of solar photovoltaic electricity. If a user desires a future with solar PV electricity, 100% of that electricity is assumed to be generated within the geographic boundary of that region.
- Wind
    - The EFD assumes that some percentage of wind generation for consumption in the user's chosen EIoF region can come from neighboring EIoF regions. These percentages are fixed as shown in Figure 6.

TO

FROM		NW Northwest	CA California	MN Mountain North	SW Southwest	CE Central	TX Texas	MW Midwest	AL Arkansas-Louisiana	MA Mid-Atlantic	SE Southeast	FL Florida	NY New York	NE New England
NW	Northwest	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CA	California	25%	80%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
MN	Mountain North	25%	10%	100%	0%	20%	0%	0%	0%	0%	0%	0%	0%	0%
SW	Southwest	0%	10%	0%	100%	20%	0%	0%	0%	0%	0%	0%	0%	0%
CE	Central	0%	0%	0%	0%	60%	0%	50%	30%	0%	0%	0%	0%	0%
TX	Texas	0%	0%	0%	0%	0%	100%	0%	30%	0%	0%	0%	0%	0%
MW	Midwest	0%	0%	0%	0%	0%	0%	30%	0%	30%	0%	0%	0%	0%
AL	Arkansas-Louisiana	0%	0%	0%	0%	0%	0%	20%	40%	0%	0%	0%	0%	0%
MA	Mid-Atlantic	0%	0%	0%	0%	0%	0%	0%	0%	10%	0%	0%	0%	0%
SE	Southeast	0%	0%	0%	0%	0%	0%	0%	0%	60%	100%	0%	0%	0%
FL	Florida	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%
NY	New York	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%
NE	New England	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%

Figure 6. The matrix indicating what percentage of concentrating solar power (CSP) electricity consumed in the "TO" EIoF region is assumed to be generated by power plants located in the "FROM" EIoF region. When the "TO" and "FROM" regions are the same, this means that wind electricity originates within the EIoF region itself.

- Concentrating Solar Power (CSP)
    - The EFD assumes that some percentage of CSP generation for consumption in the user's chosen EIoF region can come from neighboring EIoF regions. These percentages are fixed as shown in Figure 7.

FROM \ TO	NW Northwest	CA California	MN Mountain North	SW Southwest	CE Central	TX Texas	MW Midwest	AL Arkansas-Louisiana	MA Mid-Atlantic	SE Southeast	FL Florida	NY New York	NE New England
NW Northwest	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CA California	25%	80%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
MN Mountain North	25%	10%	100%	0%	20%	0%	0%	0%	0%	0%	0%	0%	0%
SW Southwest	0%	10%	0%	100%	20%	0%	0%	0%	0%	0%	0%	0%	0%
CE Central	0%	0%	0%	0%	60%	0%	50%	30%	0%	0%	0%	0%	0%
TX Texas	0%	0%	0%	0%	0%	100%	0%	30%	0%	0%	0%	0%	0%
MW Midwest	0%	0%	0%	0%	0%	0%	30%	0%	30%	0%	0%	0%	0%
AL Arkansas-Louisiana	0%	0%	0%	0%	0%	0%	20%	40%	0%	0%	0%	0%	0%
MA Mid-Atlantic	0%	0%	0%	0%	0%	0%	0%	0%	10%	0%	0%	0%	0%
SE Southeast	0%	0%	0%	0%	0%	0%	0%	0%	60%	100%	0%	0%	0%
FL Florida	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%
NY New York	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%
NE New England	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%

Figure 7. The matrix indicating what percentage of concentrating solar power (CSP) electricity consumed in the "TO" EIoF region is assumed to be generated by power plants located in the "FROM" EIoF region. When the "TO" and "FROM" regions are the same, this means that CSP electricity originates within the EIoF region itself.

Assumptions for Choosing 2050 Fuels for Light-Duty Vehicles

The light-duty vehicle miles traveled (VMT), their distribution among regions, and fuel economies are assumed fixed for each region as shown in Table 1. The differing fuel economies are based on the historical regional differences in LDV fuel economy. For more detailed assumptions and methodology within the EFD for modeling the energy consumption for light-duty vehicles, see the Energy Infrastructure of the Future webpage.

Table 7. The regional distribution of LDV VMTs fuel economy assumed for 2050.

EIoF Region	LDV Miles Traveled, 2050 (millions of miles)	LDV liquid fuel economy, 2050 (miles per gallon)	Percent of LDV VMTs (%)	LDV EV fuel economy (mile/kWh)
Northwest (NW)	126,229	38.2	3.7	3.47
California (CA)	380,257	38.2	11.0	3.47
Mountain North (MN)	191,992	40.0	5.6	3.63
Southwest (SW)	113,420	41.8	3.3	3.79
Central (CE)	127,849	40.2	3.7	3.65
Texas (TX)	397,554	32.9	11.5	2.99
Midwest (MW)	431,770	38.9	12.5	3.53
Arkansas-Louisiana (AL)	83,235	38.50	2.4	3.50
Mid-Atlantic (MA)	504,793	36.5	14.6	3.31
Southeast (SE)	544,371	40.8	15.8	3.71
Florida (FL)	305,230	41.4	8.8	3.76
New York (NY)	117,366	37.4	3.4	3.40
New England (NE)	131,221	36.2	3.8	3.29

Assumptions Affecting 2050 CO_2 Emissions

The EFD does not include the full variety of known or existing technologies for reducing energy-related carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions. The EFD also does not allow exploration of GHG mitigation technologies that might increase energy consumption or have other environmental impacts.

Notable omissions of GHG mitigation technologies are:

- Carbon capture and storage (CCS) associated with electricity generation from fossil fuels or biomass power plants
- Carbon capture and storage (CCS) associated with industrial fossil fuel consumption
- Direct air capture (DAC) technologies that can remove CO_2 directly from the atmosphere