A SunCam online continuing education course

Net Zero Principles for Engineers

by

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Course Outline:

Why Net Zero?

> *Net zero (or net-zero) is a commitment to implement processes that completely negate a negative environmental impact, such as greenhouse gas (GHG) emissions.*

Net zero is often synonymous with the term “carbon neutral”, with a subtle difference that net zero is often a commitment or roadmap while carbon neutrality is something already achieved. Also, the term net zero tends to be applied on a large scale, such as a country or large company, while carbon neutral is often applied to an individual product or process.

For example, a company that discharges 10 metric tons (mt) of carbon dioxide equivalent (CO_2e) per year achieves net zero status by committing to funding a carbon capture facility that will remove 10 mt CO_2e/yr. Eventually, the company also achieves carbon neutral status once the carbon capture facility is in operation and measurements confirm that the CO_2e captured meets or exceeds the CO_2e released.

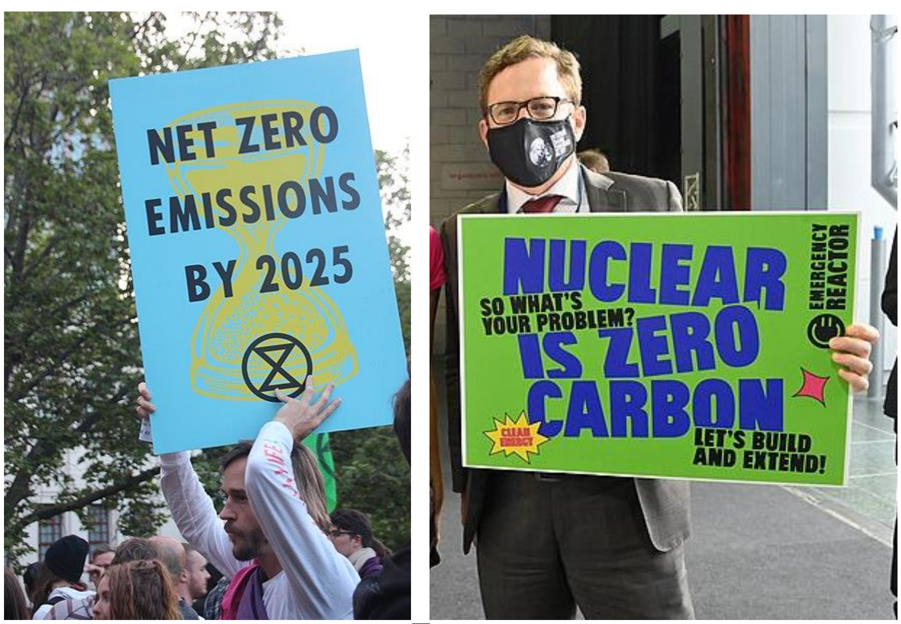


Figure 1: Demonstration signs expressing a desire for net zero GHG emissions.
Source: commons.wikimedia.org/wiki/File:Net_Zero_emissions_by_2025_-_-XRMelbourne_-_IMG_5700_%2848880735277%29.jpg, Takver, CC-BY-SA-2.0
commons.wikimedia.org/wiki/File:Net_Zero_World_(cop26_2023)_(51655794337).jpg, IAEA Imagebank

Climate Change

Most scientists agree that anthropomorphic (human caused) GHG emissions have resulted in climate change and global warming. It is hoped that climate change can be slowed, stopped, or even reversed by achieving net zero GHG emissions The following are the five main impacts of climate change along with examples:

1. Higher Temperatures
    a. Average surface temperature rise, as shown in Figure 2
    b. Record heat waves in India, South Korea, and Europe
    c. Average ocean temperature rise, consistent since the 1970's
    d. Receding glaciers around the world

2. Rising Sea Levels
    a. Sea levels are rising at a rate of 4 mm (0.15 inches) per year
    b. Sea level rise is accelerating in correlation with glacier melting
    c. Shrinking coastlines of island nations such as Tuvalu
    d. Increased flooding and record flood levels in coastal cities

3. More Severe Storms
    a. Hurricanes and typhoons are more frequent and more rapidly intensifying before landfall
    b. Record rainfall and flood events are more frequent
    c. Winter storm frequency and intensity has increased in the U.S.

4. Increase in Drought Conditions
    a. River and lake water levels have decreased in most arid biomes, such as the Colorado River and Lake Mead
    b. Ground water tables have decreased, and soil is generally dryer in most arid biomes around the world
    c. Irrigation management has become more difficult
    d. Wildfires have increased in western U.S. and southern Europe

5. Loss of Species
    a. Relatively sudden changes in the climate leads to decreased populations and extinctions
    b. Other anthropomorphic (human caused) factors include habitat loss, over-exploitation of wildlife, introduction of nonnative species, and pollution

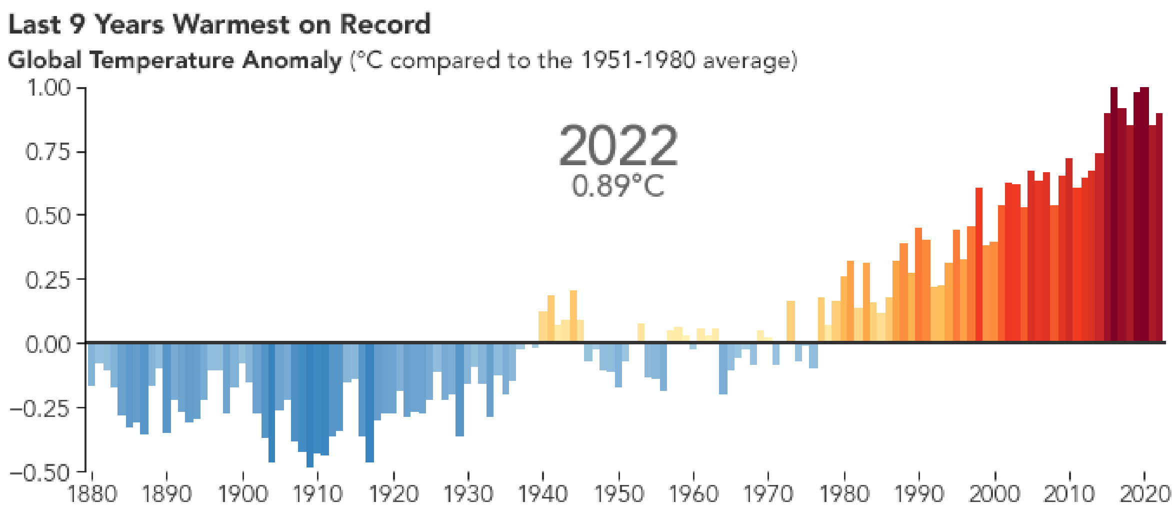


Figure 2:Average global surface temperature per year, showing an increase of 0.89 deg C in recent years. Net zero emissions aims to prevent further increases.
Source: https://earthobservatory.nasa.gov/world-of-change/global-temperatures (p.d.)

<u>Sustainability</u>
Net zero is part of a larger movement towards environmental sustainability. Sustainability strives to meet the needs of the present without compromising the ability to meet future needs. A key principle is to protect people and the natural environment from long-term negative impacts of the product, process, facility, or improvements being designed. It is increasingly common for engineers to consider sustainability during design.

Sustainability is commonly evaluated by considering the following three categories:

1. <u>Economic</u>: Maximize value, wealth, and profits in the economically viable dimension.
2. <u>Environmental</u>: Provide cleaner products with less raw material consumption and waste generation in the environmentally compatible dimension.
3. <u>Social</u>: Have more socially benign products, services, and impact in the socially responsible dimension.

These three categories are referred to as the “triple bottom line” or the three P’s: profit, planet, and people. The categories are depicted in Figure 3 with the overlap of the three being defined as sustainable.

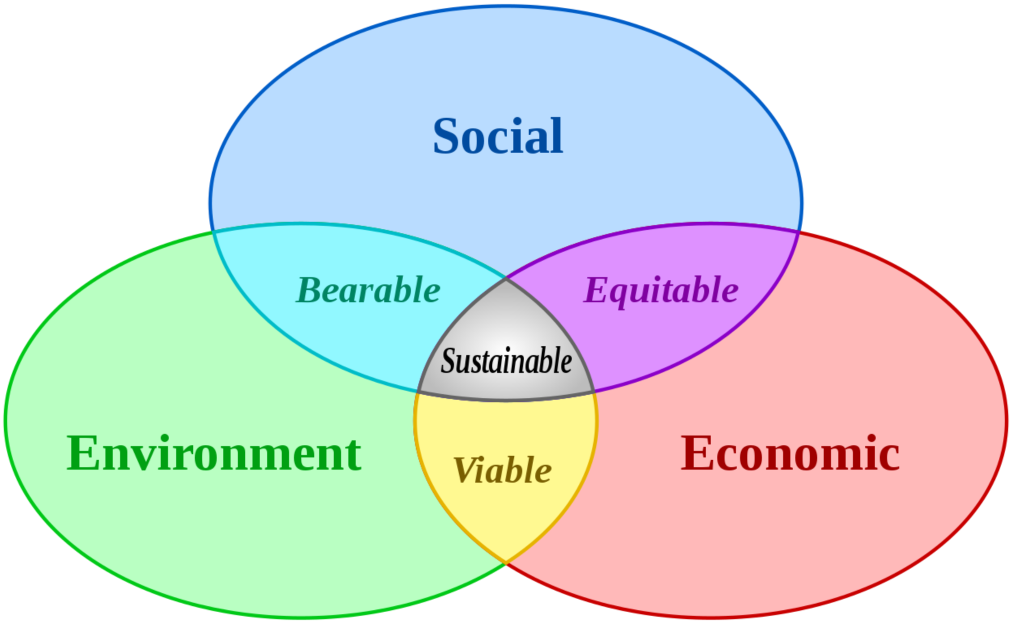


Figure 3: Triple Bottom Line for Sustainable Development

Within each category, there are a number of criteria (also called indicators) that can be used to numerically assess the sustainability of the item being considered. This allows an engineer to express sustainability numerically and make comparisons between entities or alternatives.

GHG emissions is a criteria in the environment category. Net zero GHG emissions is considered a sustainable approach that gains positive points in the environment category, has minimal impact in the social category, and has varied impact in the economic category. The economic cost for achieving net zero varies by application and is highly dependent on technological advances.

Energy, Waste, and Water

The US Department of Energy (DOE) has a Federal Energy Management Program which promotes sustainable infrastructure with net zero principles. The program goes beyond reducing GHG emissions. It requires federal buildings and campuses to achieve Net Zero Energy, Net Zero Waste, and Net Zero Water, as described in more detail later in this course. See Figure 4 for an example of a net zero campus.

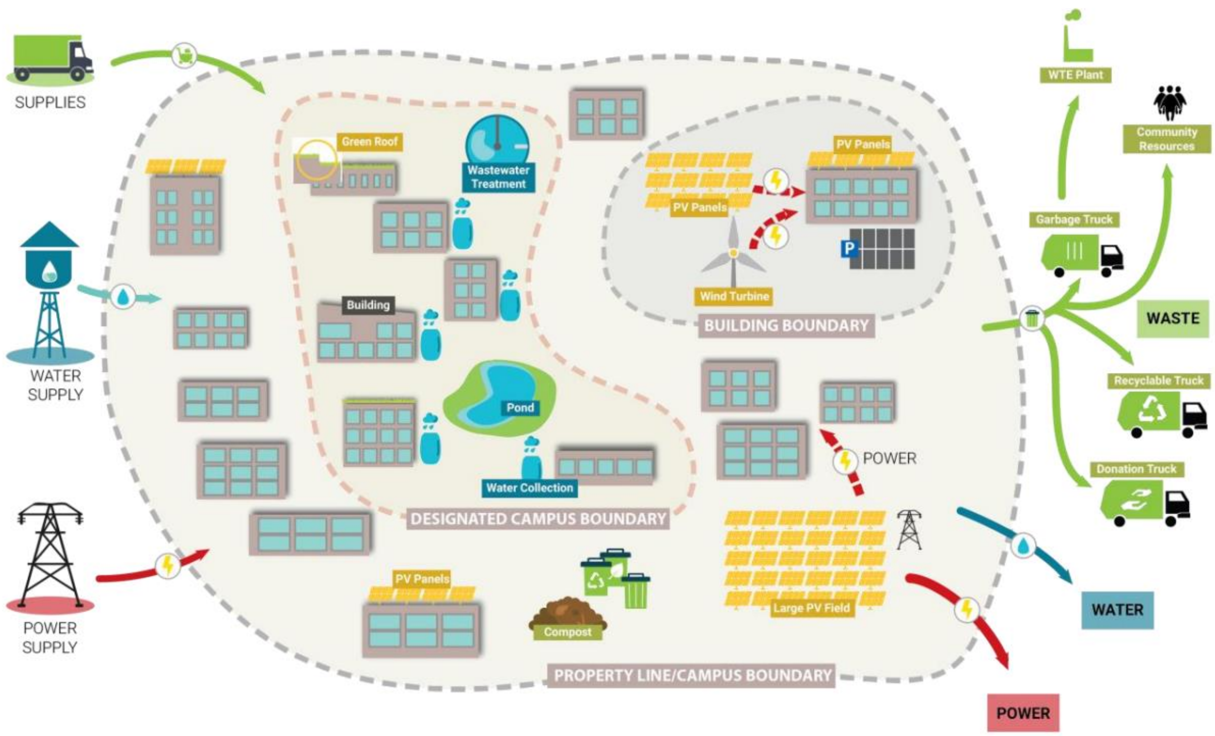


Figure 4: A net zero campus with balanced inputs and outputs.
Source: www.energy.gov/eere/femp/net-zero-energy-water-and-waste-handbooks

These net zero strategies are often applied to non-federal buildings as well. Several private companies have declared their facilities to be net zero in terms of emissions, energy, waste and/or water.

The Environmental Protection Agency (EPA) is also promoting this threefold approach to net zero, even developing the logo in Figure 5. The EPA website provides the following definition:

> *"Simply put, Net Zero means consuming only as much energy as produced, achieving a sustainable balance between water availability and demand, and eliminating solid waste sent to landfills."*

Figure 5: Logo for the EPA promotion of Net Zero for Energy, Waste & Water
Source: origin-awswest-www.epa.gov/water-research/net-zero (p.d.)

The U.S. Army has a "Army Net Zero" initiative with a similar threefold approach:

> *"The Armys Net Zero (NZ) Initiative is built upon the Armys long-standing energy efficiency and sustainability practices. It is a strategy for managing existing energy, water, and solid waste programs with the goal of exceeding minimum targets, where fiscally responsible…"*

Figure 6: Army Net Zero Logos
Source: origin-awswest-www.epa.gov/water-research/net-zero (p.d.)

<u>Net Zero GHG Emissions</u>

Net zero is most commonly associated with reducing greenhouse gas (GHG) emissions. Achieving net zero emissions (NZE) means the total GHG emissions released are completely offset by the following options:

- Capturing GHG from the atmosphere
- Preventing GHG release from natural processes
- Restoring natural areas that capture GHG

<u>Greenhouse Effect</u>
Scientists inform us that certain gases, called greenhouse gases (GHGs), in the atmosphere can trap heat and warm the earth. This is called the greenhouse effect. Scientists nearly unanimously agree that increases in the concentrations of heat-trapping GHGs can be linked to the increase in the Earth's average surface temperature and other aspects of climate change. See Figure 7 for a graphical depiction of the greenhouse effect.

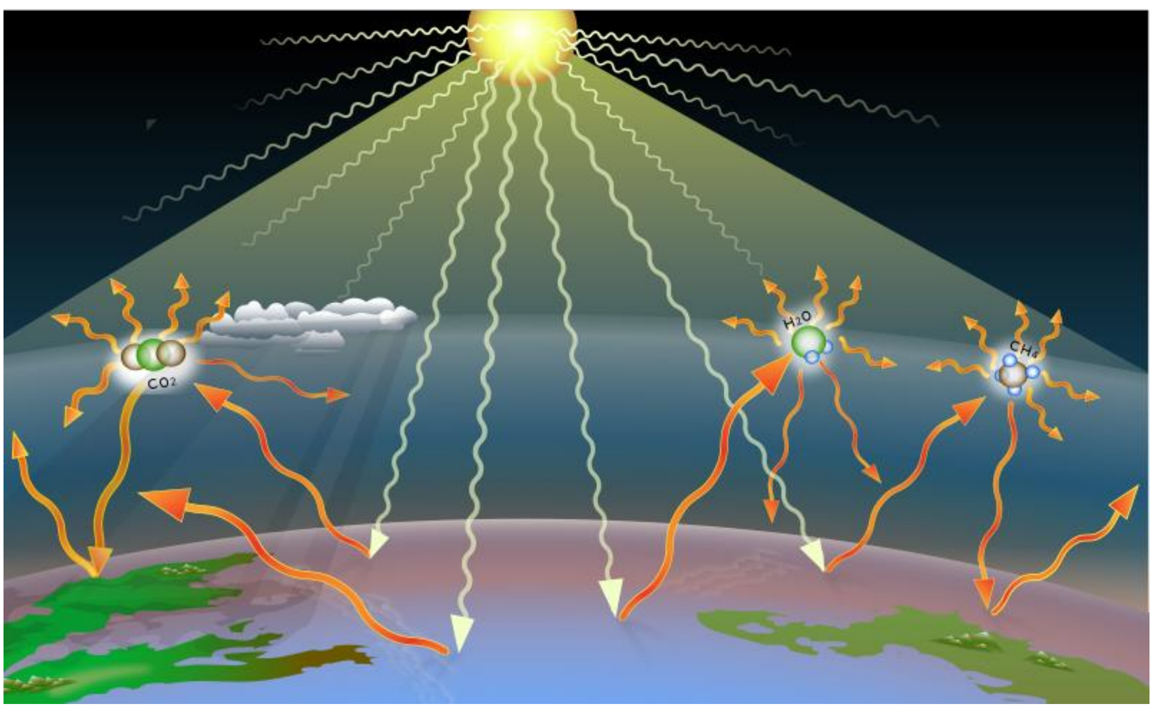


Figure 7: Illustration of how greenhouse gases reflect heat back to the earth's surface, thus increasing the surface temperature.
Source: commons.wikimedia.org/wiki/File:Greenhouse-effect-t2.svg, A loose necktie, CC-BY-SA-4.0

Greenhouse Gases
Naturally occurring GHGs include:

- Water vapor (H_2O)
- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Ozone (O_3)

Human generated greenhouse gases, mostly from industrial sources, include the same natural GHGs and several classes of halogenated substances that contain fluorine, chlorine, or bromine. Figure 8 shows basic formulas for major GHGs.

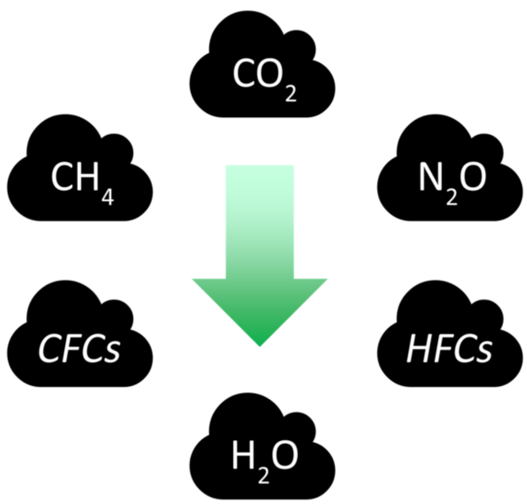


Figure 8: Chemical formulas of common greenhouse gases. The CFCs (chlorofluorocarbons) and HFCs (hydrofluorocarbons) are human made gases.

Carbon dioxide accounts for approximately 80% of all GHG emissions from human activities. However, it is also the least potent GHG as explained in the next section.

Global Warming Potential

The Global Warming Potential (GWP) of a GHG is the relative warming impact over a period of time as compared to carbon dioxide. Each GHG has a different GWP based on these two factors:

1. Ability to absorb energy, also called "radiative efficiency"
2. Time in the atmosphere, also called "lifetime"

The units for GWP are CO_2 equivalents (CO_2e). Table 1 lists the GWP for major GHGs according to the IPCC's Sixth Assessment Report (AR6, 2021). Note that water vapor emissions are considered to have negligible GWP since humidity is in continual flux and water vapor only lasts a few weeks before falling as precipitation.

Table 1: GWP of Common GHGs
with 100 Year Time Horizon in Bold

Gas	Chemical Formula	Lifetime (years)	GWP (CO_2e)		
			50 years	**100 years**	500 years
Carbon Dioxide	CO_2	30 to 95	1	**1**	1
Methane	CH_4	12	82	**40**	7.6
Nitrous Oxide	N_2O	109	273	**273**	130
CFC-11	$CFCl_3$	52	8,321	**1,526**	436
CFC-12	CCl_2F_2	100	11,000	**10,900**	5,200
HFC-134a	CF_3CH_2F	14	4,144	**1,526**	436
HFC-23	CHF_3	222	10,800	**12,400**	12,200
HCFC-22	$CHClF_2$	12	5,160	**1,810**	549
PFC-14	CF_4	50,000	5,301	**7,380**	10,587
Hexafluoroethane	C_2F_6	10,000	8,630	**12,200**	18,200
Sulfur hexafluoride	SF_6	3,200	17,500	**23,500**	32,600
Nitrogen trifluoride	NF_3	740	12,300	**17,200**	20,700
Hydrogen	H_2	4 to 7	33	**11**	N/A

Carbon Footprint

It is common to express the amount of GHGs released as a “carbon footprint”. The term “carbon footprint” is a measure of the amount of GHGs released into the atmosphere due to human activities, expressed as carbon dioxide equivalents (CDE).

Typical units are tons or tonnes of CO_2 equivalents (CO_2e or CDE), where:

- 1 ton = 2,000 lbs
- 1 tonne = 1 metric ton = 1,000 kg = 1,000,000 g = 1 Mg = 1 MTCDE
- 1 teragram (Tg) = 10^{12} g = 1 million metric tons = 1 MMT = 1 MMTCDE

A less common way to express emissions is with units of carbon equivalents (CE), where 12 units of CE equal 44 units of CDE.

For vehicles, it is common to express the GHG emissions as grams of CDE per mile (gCDE/mile) or per kilometer (gCDE/km). The average gasoline-driven passenger car emits 404 gCO_2e/mile, and travels 10,050 miles/yr. These equals 4.06 MTCDE. Electric vehicles do not directly release GHGs, however they indirectly produce GHG emissions from electricity consumption, as explained in the next subsection.

Example Problem 1

Staff engineer Becky needs to calculate the carbon footprint of her company's fleet of vehicles for years 2022 and 2023. She also needs to determine the percent decrease due to replacing half the fleet with hybrid and electric cars in late 2022.

Table 2: Company Fleet Data for Problem 1			
Type of Vehicle	Emissions (gCDE/mile)	Miles Driven	
		2022	2023
Gas Car	400	100,000	50,000
Electric Car	200	0	50,000
Gas Truck	800	100,000	50,000
Hybrid Truck	300	0	50,000

Solution

Becky calculated the emissions for each vehicle type for each year and added these values to create the following revised table. She converted grams to metric tons (1 million grams = 1 MT), which is abbreviated as MTCDE.

Table 3: Company Fleet Data for Problem 1					
Type of Vehicle	Emissions (gCDE/mile)	2022		2023	
		Miles	MTCDE	Miles	MTCDE
Gas Car	400	100,000	40	50,000	20
Electric Car	200	0	0	50,000	10
Gas Truck	800	100,000	80	50,000	40
Hybrid Truck	300	0	0	50,000	15
Total		200,000	**120**	200,000	**85**

The carbon footprint decreased from 120 to 85 MTCBE from 2022 to 2023 due to the addition of hybrid and electric vehicles. This is a decrease of (120 - 85) / 120 * 100 = **29%**.

Indirect GHG Emissions

Direct GHG emissions are released directly from the item of concern. Indirect GHG emissions are incidentally associated with the item of concern, such as GHGs from the initial creation, ongoing maintenance, energy consumption or disposal. Examples include:

- Electrical power production emissions
- Fuel production emissions
- Manufacturing emissions
- Construction related emissions
- Transportation emissions
- Maintenance related emissions
- Demolition and disposal emissions

Electrical power emissions are often the largest of indirect emissions. The level of GHG emissions depends on the energy sources used at the local power plant. Each energy source releases a different amount of GHG, as shown in Figure 9. The USEPA's Emission & Generation Resource Integrated Database (eGRID) provides the GHG emissions per MWh for each region in the USA, as shown in Figure 10. Emissions factors are listed for the highest region, lowest region, and overall US average.

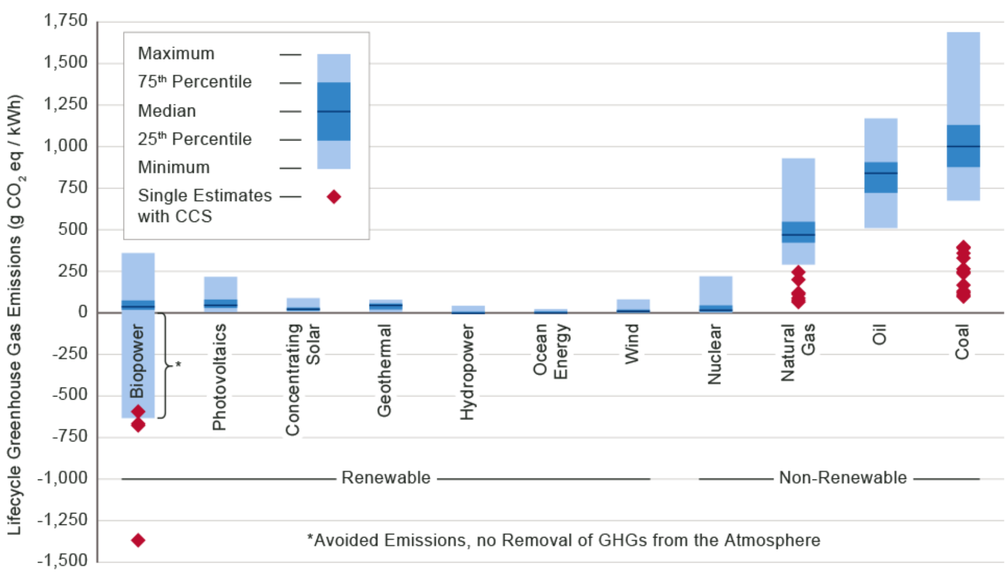
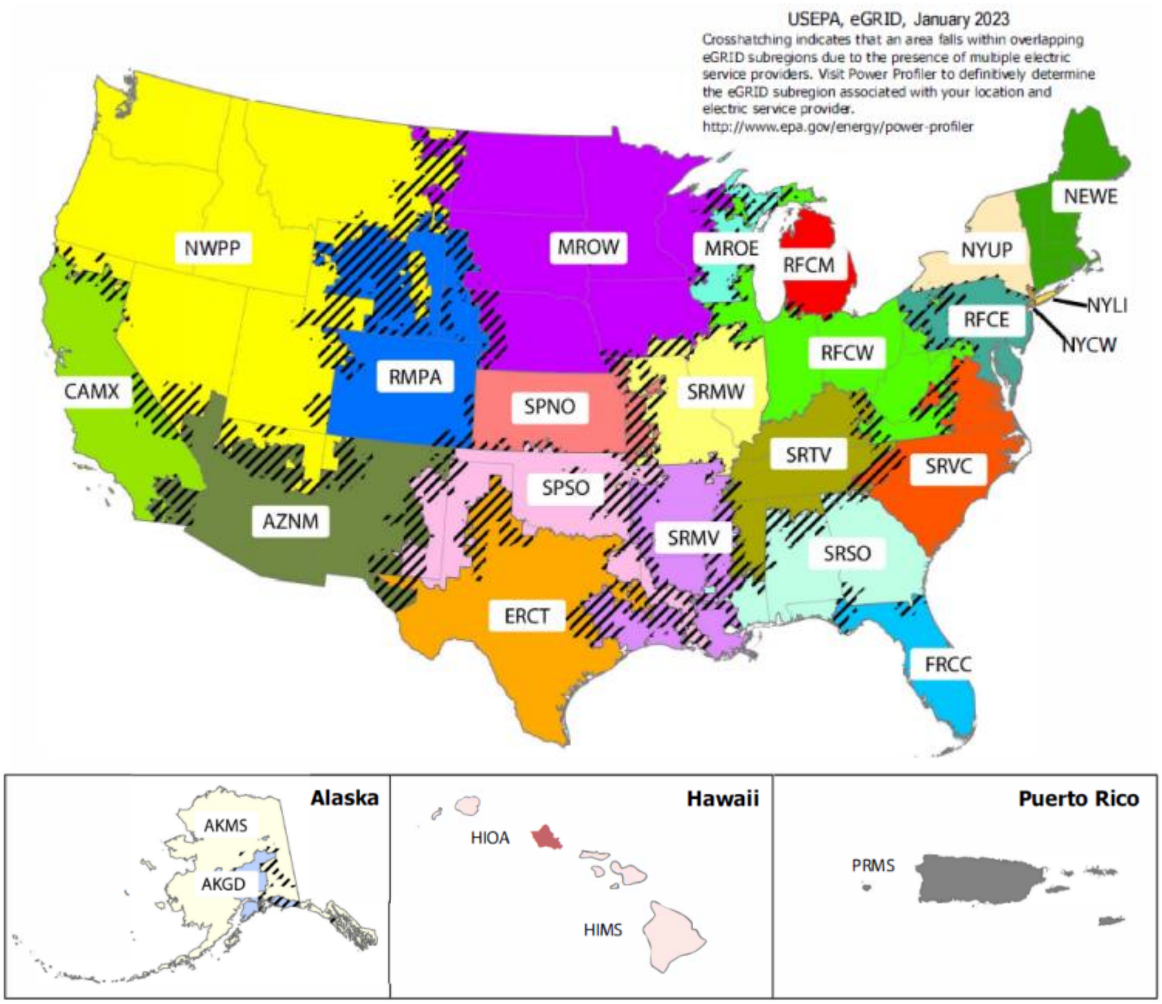


Figure 9: Chart of GHG emissions for various energy sources.
Source: www.usaid.gov/energy/mini-grids/environment-health-safety/emissions (p.d.)



Subregion Name	Abbrev.	Emission Factors w/ 100 Year GWP			
		lbs CO_2/MWh	lbs CH_4/MWh	lbs N_2O/MWh	GWP Rank
HICC Oahu, HI	HIOA	1,633.1	0.176	0.027	Highest
NPCC Upstate NY	NYUP	233.1	0.015	0.002	Lowest
Entire US	Average	852.3	0.071	0.010	N/A

Figure 10: US Map with eGRID Subregions and example emission factors.
Source: www.epa.gov/system/files/documents/2023-01/eGRID2021_technical_guide.pdf, (p.d.)

Example Problem 2

Continuing with Problem 1, Becky realizes that the Electric vehicle emissions rate of 200 gCDE/mile is based on the US average, but the Company is located in the NYUP region (NPCC Upstate New York) which uses clean energy sources. To more accurately reflect the carbon footprint, Becky must calculate the actual emissions per mile based on the factors in Figure 10 and the vehicle efficiency of 0.35 kWh per mile.

Solution

First, Becky calculates the total CDE/MWh for region NYUP by summing the CO_2, CH_4, and N_2O contributions. The 100 year GWP factors from Table 1 are used to convert CH_4 and N_2O to CO_2 equivalent (CDE) emissions. The formula is as follows:

$$\frac{lbs\ CDE}{MWh} = \frac{lbs\ \mathrm{CO_2}}{MWh} + \frac{lbs\ \mathrm{CH_4}}{MWh} \times 40 + \frac{lbs\ \mathrm{N_2O}}{MWh} \times 273$$

$$= 233.1\frac{lbs\ \mathrm{CO_2}}{MWh} + 0.015\frac{lbs\ \mathrm{CH_4}}{MWh} \times 40 + 0.002\frac{lbs\ \mathrm{N_2O}}{MWh} \times 273$$

$$= 233.1 + 0.6 + 0.5 = 234.2$$

Next, the following formula to calculate the emissions rate:

$$Emissions\ Rate = 0.35\frac{kWh}{mile} \times 234.2\frac{lbs\ CDE}{MWh} \times \frac{1MWh}{1{,}000\ kWh} \times \frac{454\ g}{1\ lb} = \mathbf{37}\frac{\boldsymbol{g\ CDE}}{\boldsymbol{mile}}$$

Carbon Capture

A strategy to achieve net zero emissions (NTE) is to “capture” GHG’s from a polluted air stream or from the atmosphere. The capture and storage of CO_2 is often called carbon sequestration. The following abbreviations are often used for carbon capture projects:

- Carbon capture, utilization and storage (CCUS)
- Carbon capture, utilization and sequestration (CCUS)
- Carbon capture and storage (CCS)
- Direct air capture (DAC)

Figure 11 depicts different methods for carbon sequestration. Captured CO_2 can also be used to make building materials, chemicals, commodities, fuel, and carbon materials. Natural areas such as forests and peatland are “carbon sinks” that naturally remove CO_2. Soil can be engineered to maximize carbon uptake.

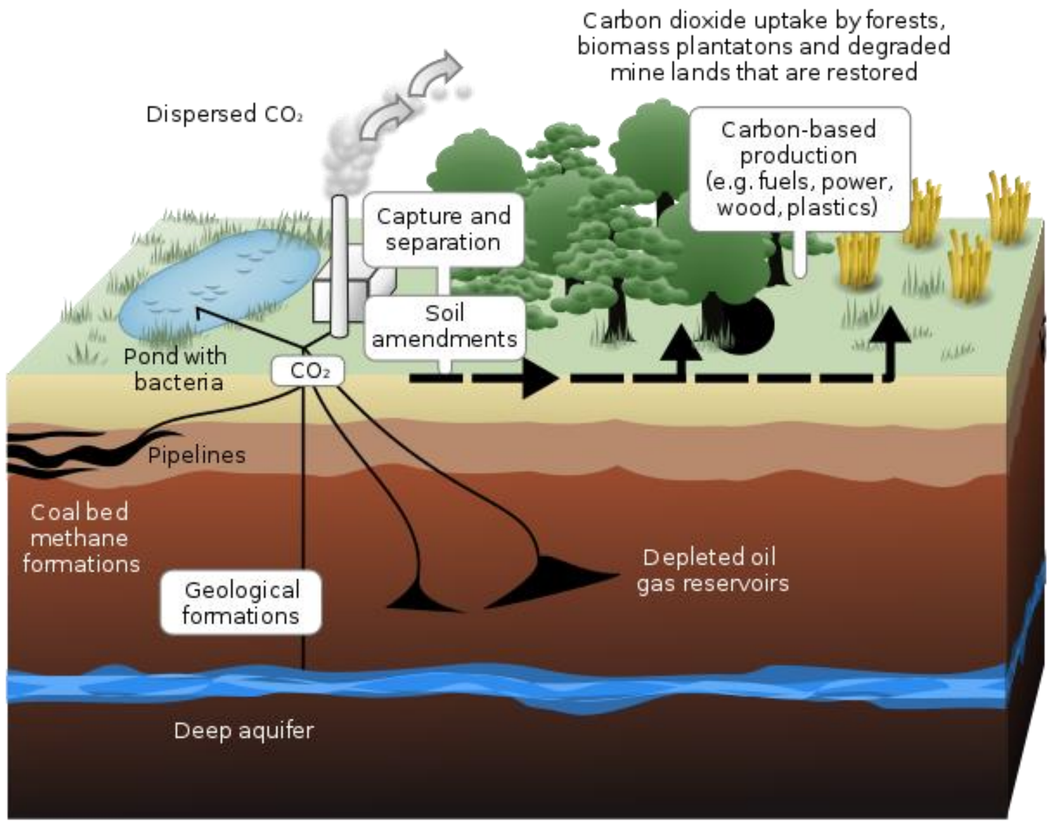


Figure 11: Examples of biological sequestration (dashed lines) and geological sequestration (solid black lines) for removing CO_2 emissions from a facility.
Source: commons.wikimedia.org/wiki/File:Carbon_sequestration-2009-10-07.svg, LeJean Hardin and Jamie Payne

Figure 12 shows an example of a CCS facility at the WA Parish power plant in Texas. The plant burns coal and gas. Flue gas emissions from coal burning are routed through a carbon capture facility that discharges the purified CO_2 in a pipeline to an oil field. The CO2 is injected into an oil reservoir to boost the pressure and force more oil into the production wells. This process is known as “enhanced oil recovery” or EOR.

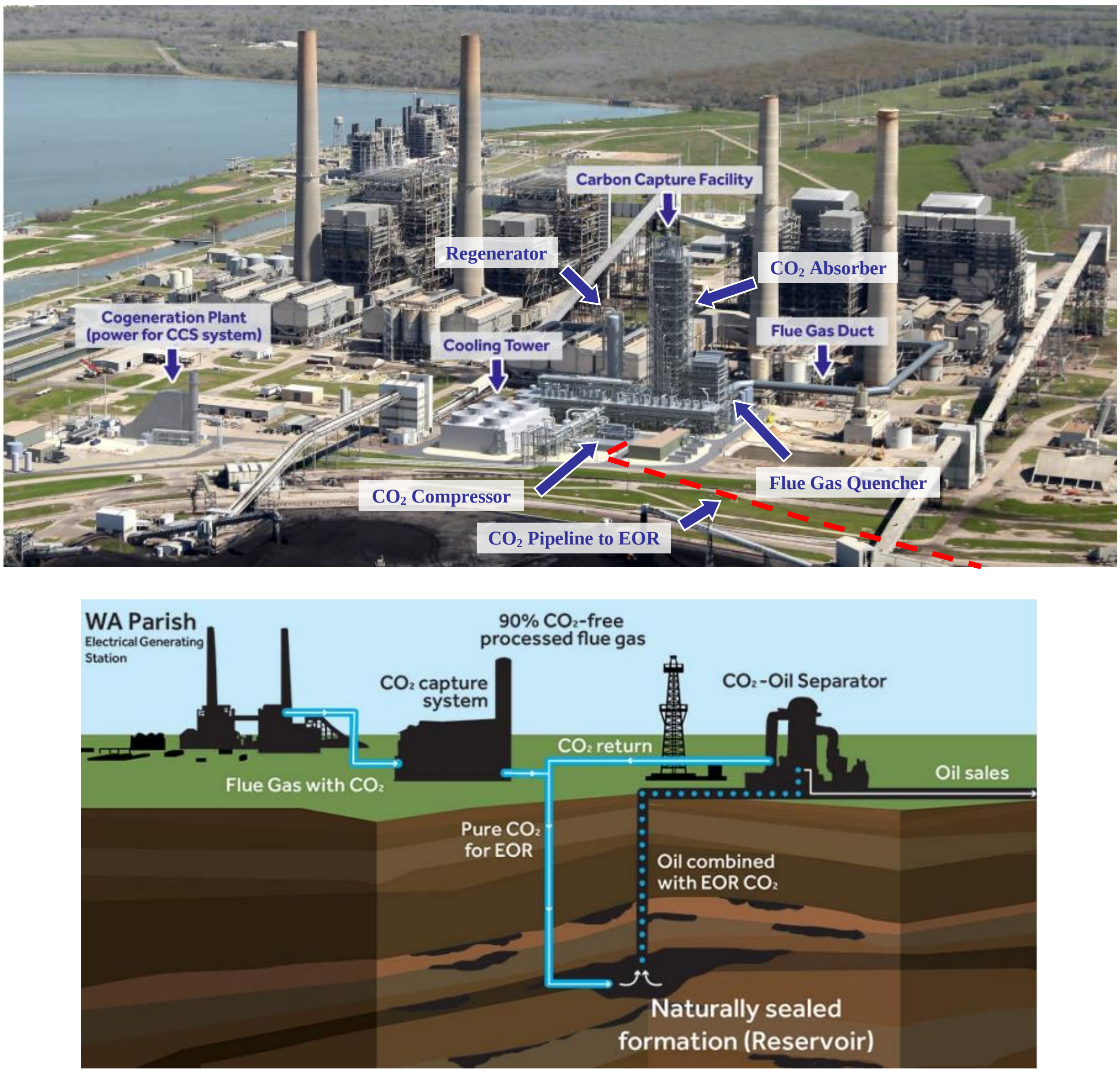


Figure 12: WA Parish power plant with CCS facility. Top: Aerial photo of power plant with CCS processes labeled; Bottom: Flow diagram for CCS and EOR.
Sources: www.nrg.com/sustainability/context.html and
www.iea.org/commentaries/can-co2-eor-really-provide-carbon-negative-oil (p.d.)

Direct Air Capture

To offset unavoidable GHG emissions, CO_2 and other oxides can be captured directly from the atmosphere, known as direct air capture (DAC). Two approaches are available to capture CO_2 from the air:

1. Solid DAC (S-DAC) passed air over solid adsorbents at low pressure and medium temperature (80 to 120°C), similar to a filter.
2. Liquid DAC (L-DAC) passes air through a series of basic chemical solutions (such as potassium hydroxide) at high temperature (300 to 900°C).

Capturing CO_2 from the air is more energy intensive and expensive than capturing it from a point source. This is because the CO_2 in the atmosphere is much more dilute and therefore takes additional processes to remove. As of 2023, there are around 20 such facilities in operation in Europe, the Unites States, and Canada. The number of facilities is anticipated to grow to 50 by 2035. Figure 13 shows the DAC growth projected with additional capture in yellow needed to be on track for a global 2050 NZE.

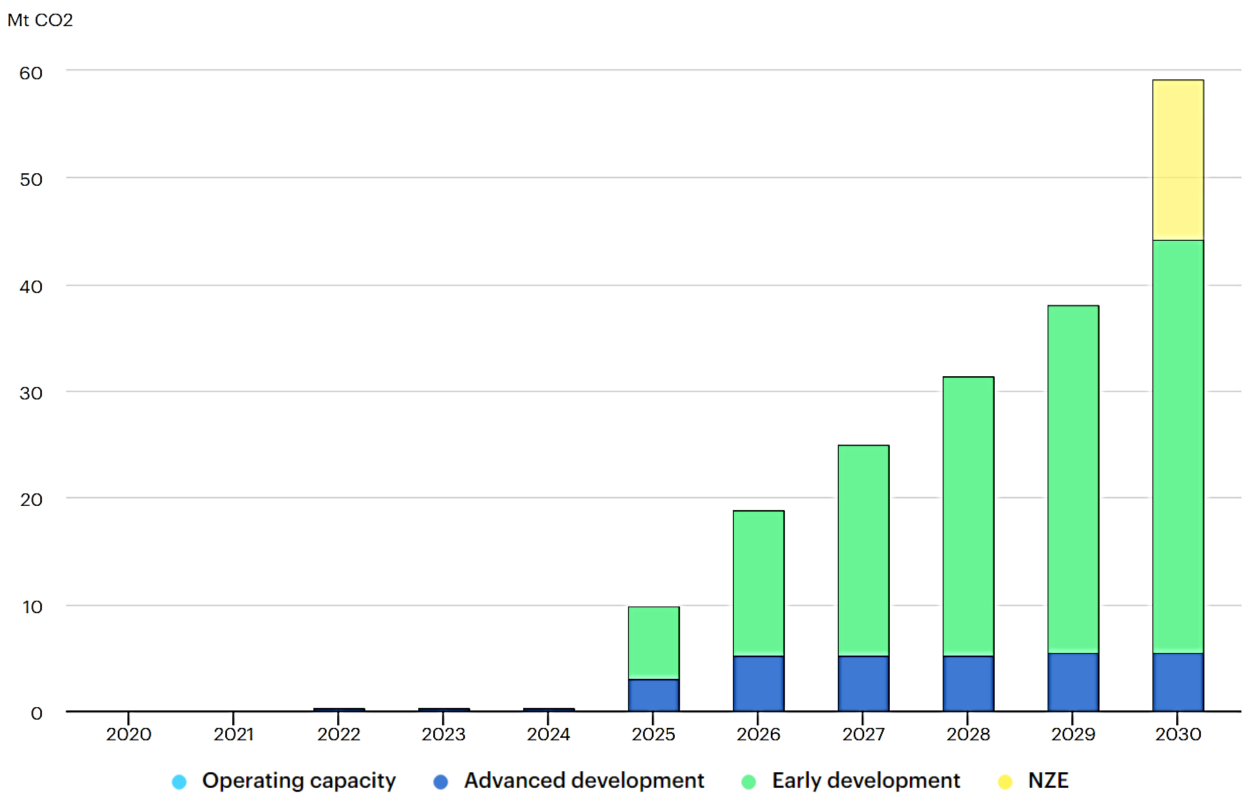


Figure 13: DAC carbon capture projections in metric tons (Mt) of CO_2
Source: www.iea.org/reports/direct-air-capture, CC BY 4.0

NZE 2050

Scientific studies have indicated that a global temperature rise of 1.5°C or greater above pre-industrial levels will result in severe and potentially irreversible climate change such as extreme storms, rising sea levels, diminishing Arctic Sea ice, coral bleaching, loss of sensitive ecosystems, increase in disease, decrease in crop yields, and water resource challenges. Decreasing GHG emissions is considered the best chance to prevent this 1.5°C increase.

To achieve this goal, many nations have committed to a net zero balance of GHG emissions by the year 2050, or some other year, as shown in Figure 14. This global movement is termed Net Zero Emissions by 2050 (NZE 2050). NZE 2050 is part of the Paris Agreement and other international agreements. The International Energy Agency (IEA) continues to promote and track progress towards NZE 2050.

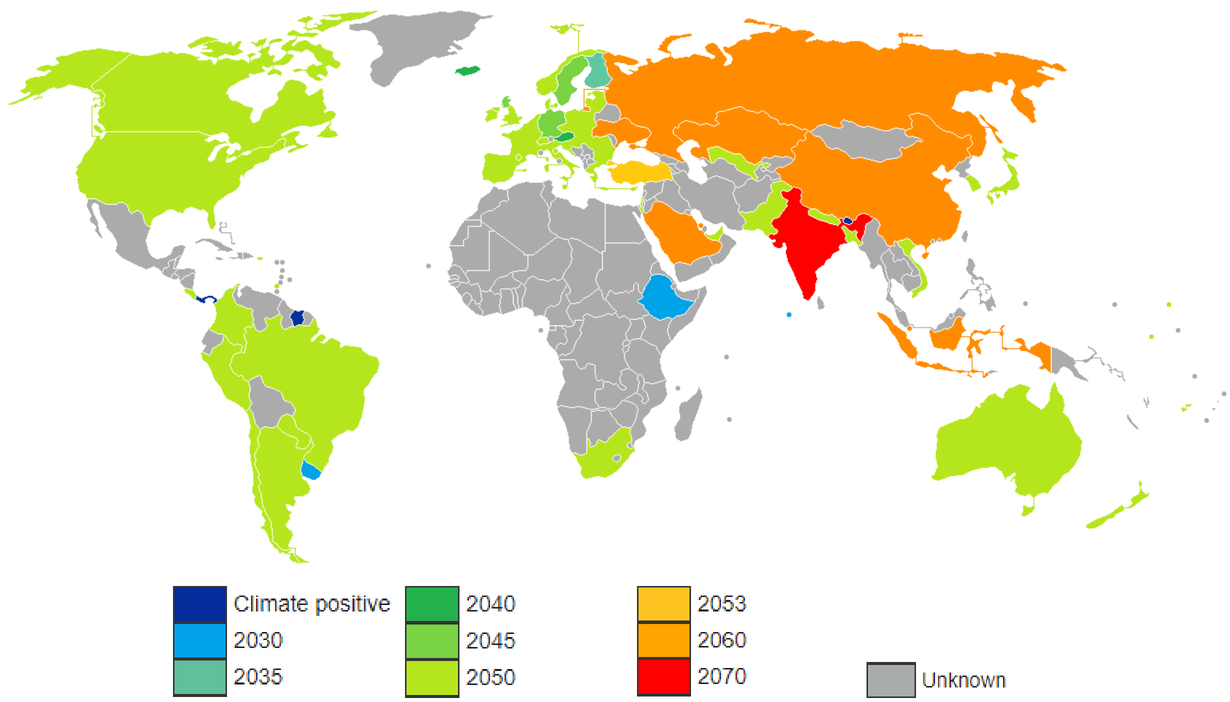


Figure 14: Map showing year of net zero commitment for each country, as of 2022. Dark blue indicates NZE has already been achieved. Grey indicates no commitment.
Source: commons.wikimedia.org/wiki/File:Countries_by_intended_year_of_climate_neutrality.png
!Nsadqa, CC-BY-SA-4.0

<u>United States NZE 2050</u>

In 2021, the United States committed to NZE 2050, as detailed in a document entitled "The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050". Figure 15 shows how GHG emissions must be decreased to achieve NZE 2050. Intermediate targets have been set for 2025 and 2030.

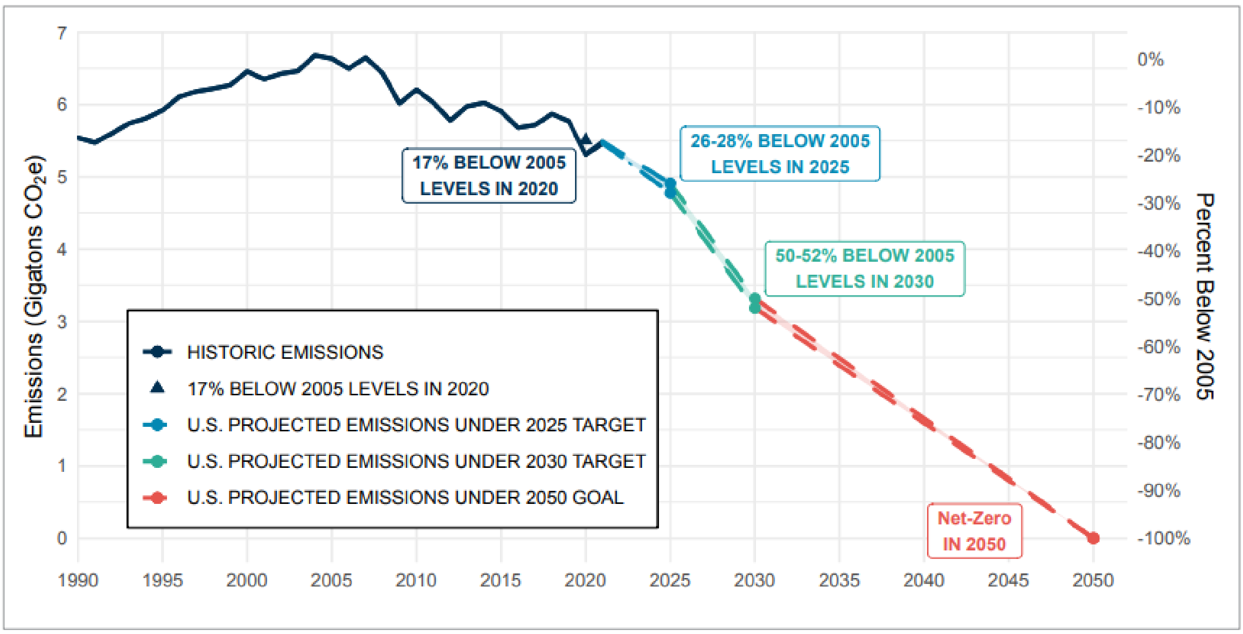


Figure 15: US historic GHG emissions and projected emissions to achieve NZE 2050.
Source: www.whitehouse.gov/wp-content/uploads/2021/10/US-Long-Term-Strategy.pdf (p.d.)

Key transformations required to achieve NZE 2050 are presented below, with the potential impact of each shown in Figure 16:

1. Energy Efficiency
    a. Increase efficiency, reduce loss, optimize processes
2. Decarbonize Electricity
    a. Solar, wind, and nuclear power
3. Energy Transitions
    a. Electrify cars, buildings, & industrial processes
    b. Switch aviation and shipping to hydrogen or biofuel
4. Non-CO_2 Reductions
    a. Switch to natural coolants instead of HFCs
    b. GHG emissions removal technologies and leak detection
5. Land Sink
    a. Restore natural areas, forest growth, soil carbon sequestration
6. CO_2 Removal Technologies
    a. Direct air capture (DAC), biomass carbon removal, enhanced mineralization, ocean-based CO_2 removal (CDR)

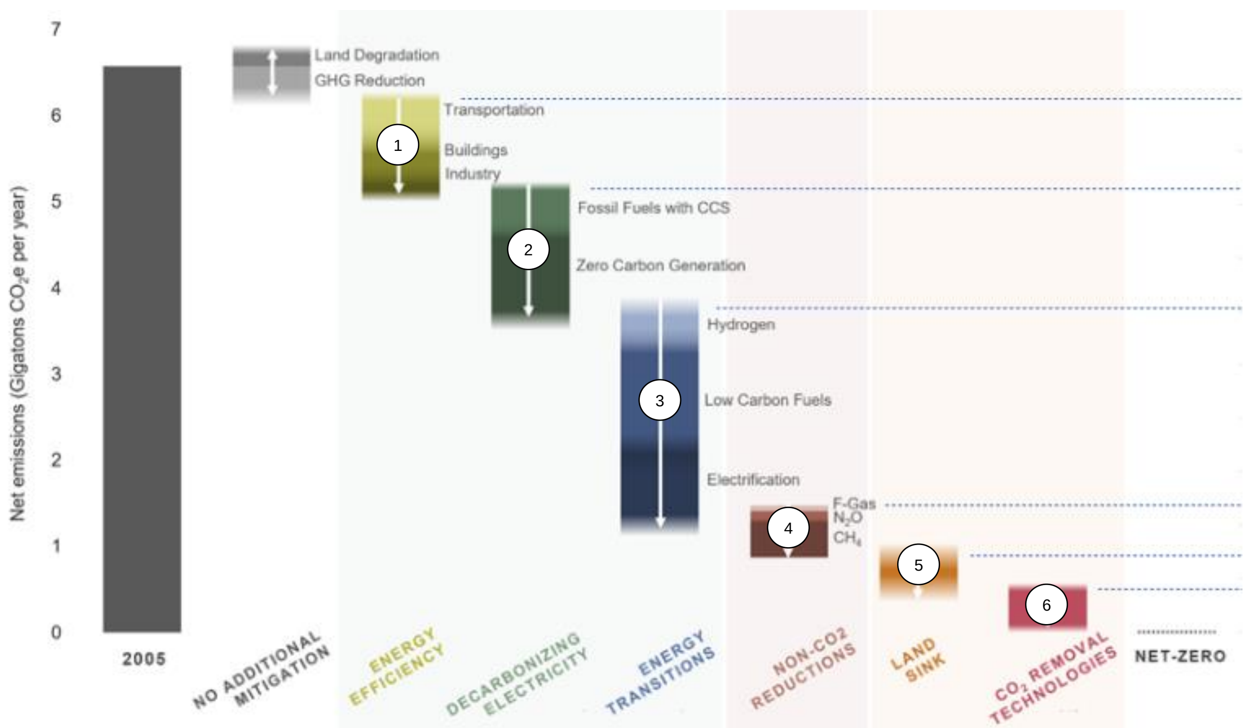


Figure 16: US proposed emissions reductions to achieve NZE 2050.
Source: www.whitehouse.gov/wp-content/uploads/2021/10/US-Long-Term-Strategy.pdf, (p.d.)

Example Problem 3

The Like a Rock Mining Company has committed to NZE 2050. The have planned the following improvements to reduce GHG emissions:

- Capture and utilize 80% of 1 MMT CO_2/yr emissions
- Remove 90% of 0.2 MMT CH_4/yr emissions
- Remove 90% of 0.005 MMT N_2O/yr emissions
- Add an anaerobic digester to produce biogas for heat and electricity
- Utilize solar panels for remaining energy needs
- Utilize all electric vehicles to eliminate fossil fuel usage
- Convert an old mine to a carbon sink forest to remove 0.2 MMT of CO_2/yr

How much additional carbon capture (MMTCDE/yr) would be needed to achieve net zero?

Solution

The first step is to calculate the annual GHG emissions in terms of CDE by using the 100 year GWP factors from Table 1. Note that 1 MMT = 1 million metric tons.

$$\mathrm{CO_2}\ Emissions = 0.2 \times 1\ MMT\ \mathrm{CO_2} \times \frac{1\ CDE}{1\ \mathrm{CO_2}} = 0.2\ MMT\mathrm{CDE}$$

$$\mathrm{CH_4}\ Emissions = 0.1 \times 0.2\ MMT\ \mathrm{CH_4} \times \frac{40\ CDE}{1\ \mathrm{CH_4}} = 0.8\ MMT\mathrm{CDE}$$

$$\mathrm{N_2O}\ Emissions = 0.1 \times 0.005\ MMT\ \mathrm{N_2O} \times \frac{273\ CDE}{1\ \mathrm{N_2O}} = 0.1\ MMT\mathrm{CDE}$$

The net CDE emissions are the sum of the above minus the carbon sink value:

$$Net\ CDE = \ 0.2 + 0.8 + 0.1 - 0.2\ = 0.9\ MMT\ \mathrm{CDE}$$

Therefore, an additional 0.9 MMTCDE must be captured to achieve net zero.

Net Zero Energy

The goal of Net Zero Energy is to decrease energy consumption, promote onsite renewable energy, and decrease dependance on offsite non-renewable energy sources. The DOE explains the strategy as follows:

> *A net zero energy federal building (constructed, renovated, or existing) is operated to maximize energy efficiency, implement energy recovery opportunities where feasible, and balance the actual annual source energy consumption with on-site renewable energy generation.*

A Zero Energy Building (ZEB) is an energy-efficient building where, on an annual basis, the actual delivered energy is less than or equal to the exported renewable energy. See Figure 17 for the boundaries on a building, facility, or campus for performing an energy balance calculation.

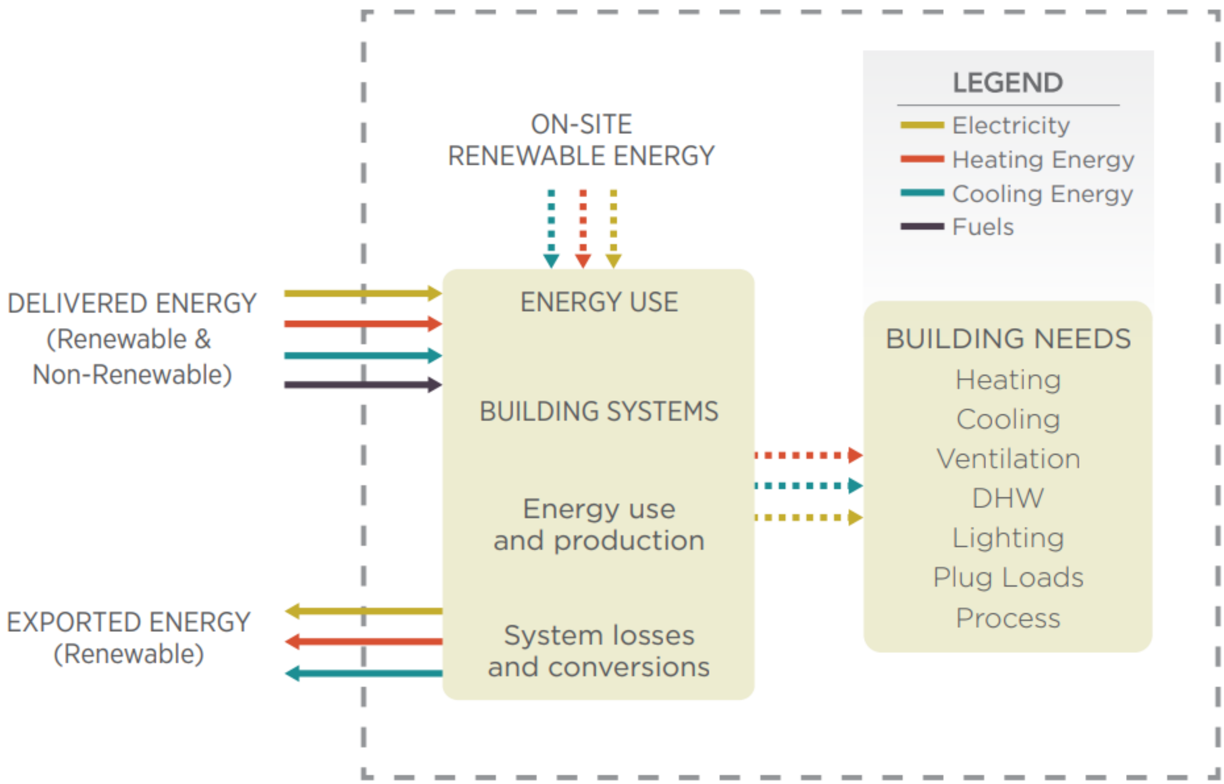


Figure 17: Depiction of site boundary for energy balance.
The solid lines are used for zero energy accounting.
Source: www.energy.gov/sites/default/files/2015/09/f26/bto_common_definition_zero_energy_buildings_093015.pdf

A building or campus would be considered net zero when the difference between energy delivered and energy generation is equal to zero or a negative value. The balance calculation is made with the following formula:

$$\textbf{Net Energy Use} = \sum \left[\text{Delivered Energy by Type} \right] \times \left[\text{Source Energy Conversion Factor(s)} \right] - \sum \left[\text{Exported Renewable Energy by Type} \right] \times \left[\text{Source Energy Conversion Factor(s)} \right] \leq \mathbf{0}$$

$$= \sum_i (E_{del,i} r_{del,i}) - \sum_i (E_{exp,i} r_{exp,i})$$

$E_{del,i}$ is the delivered energy for energy type i;

$E_{exp,i}$ is the exported on-site renewable energy for energy type i;

$r_{del,i}$ is the source energy conversion factor for the delivered energy type i;

$r_{exp,i}$ is the source energy conversion factor for the exported energy type i;

In the formula, both delivered and exported energy is multiplied by a "source energy conversion factor" (values in Table 4) to account for the following:

- Energy consumed in the extraction, processing and transport of primary fuels
- Energy losses in thermal combustion in power generation plants
- Energy losses in transmission and distribution to the building site

Table 4: Source Energy Conversion Factors

Energy Form	Source Energy Conversion Factor
Imported Electricity	3.15
Exported Renewable Electricity	3.15
Natural Gas	1.09
Fuel Oil (1,2,4,5,6)	1.19
Propane & Liquid Propane	1.15
Steam	1.45
Hot Water	1.35
Chilled Water	1.04
Coal or Other	1.05

<u>Example Problem 4</u>

A manufacturing facility has the following energy values for last year:

- Delivered:
    - 180 MBTU electricity (when demands exceed solar capacity)
    - 90 MBTU chilled water
    - 5 MBTU fuel oil
- Exported:
    - 200 MBTU electricity, solar (sellback to grid during peak hours)
    - 50 MBTU natural gas, from an anaerobic digester
- On-site Renewable:
    - 400 MBTU electricity, solar

Does the facility meet Net Zero Energy?

<u>Solution</u>

The delivered and exported energy values are entered into the net energy use formula. Each energy value is multiplied by the corresponding source energy conversion factor from Table 4. The on-site renewable value is not used in the formula since only the delivered and exported values are utilized for a net zero calculation.

$$\begin{aligned} Net\ Energy\ Use &= [(180\ MBTU \times 3.15) + (90\ MBTU \times 1.04) + (5\ MBTU \times 1.19)] \\ &\quad -[(200\ MBTU \times 3.15) + (50\ MBTU \times 1.09)] \\ &= 667\ MBTU - 684\ MBTU = -17\ MBTU \end{aligned}$$

Since the Net Energy Use is less than zero, the facility would meet Net Zero Energy.

Net Zero Waste

The goal of Net Zero Waste is to minimize the waste footprint and have zero solid waste going to a landfill or incinerator. The DOE explains the strategy as follows:

> *A net zero waste federal building is operated to reduce, reuse, recycle, compost, or recover solid waste streams (with the exception of hazardous and medical waste) thereby resulting in no waste disposal to landfills or incinerators.*

See Figure 18 for the boundaries on a building, facility, or campus for performing a solid waste balance calculation.

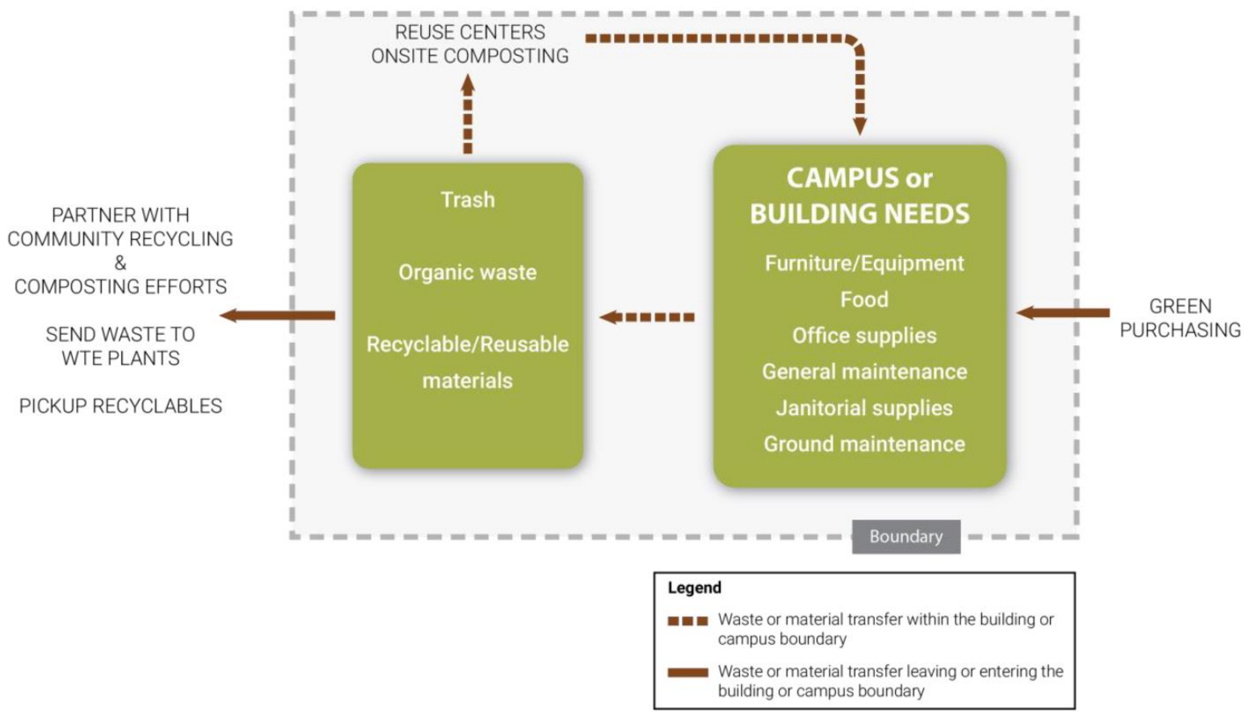


Figure 18: Depiction of site boundary for waste balance.
Source: www.energy.gov/eere/femp/net-zero-energy-water-and-waste-handbooks

Net Zero Waste design elements are as follows:

1. Assess likely waste stream composition
2. Develop a green procurement program that minimizes waste generation
3. Design reuse, recycling, and compost programs to minimize waste generation
4. Design appropriate space to manage these programs
5. Identify alternative paths for remaining waste streams, including:
    a. Disposal to a waste-to-energy (WTE) facility where garbage is burned to produce electricity
    b. Anaerobic digestion of organic wastes along with wastewater
    c. Donation of reusable items and materials
    d. Community programs (recycling & reuse organizations, specialty cleaners, community composting facilities, etc.)

After the facility has been constructed and has operated for a year, the net zero status can be verified as follows:

- Review procurement records to verify compliance with green procurement requirements.
- Verify that applicable net zero clauses within solid waste removal service contracts are being honored and that they are managing waste as stated.
- Review recycle, reuse, and compost records (e.g., invoices, weight) to verify that waste diversion and handling took place as expected.
- Review WTE records to determine whether any materials were included that should have been diverted through other means.

If waste was reduced or diverted properly through reuse, recycling, composting, WTE, donation, and other methods, and no waste was landfilled or incinerated, the building is considered Net Zero Waste.

Net Zero Water

The goal of Net Zero Water is to minimize the water footprint and return the volume of water used to the original water source. The DOE explains the strategy as follows:

> *A net zero water federal building is operated to minimize total water consumption, maximize alternative water sources, minimize wastewater discharge from the building, and return water to the original water source such that the annual water consumption is equivalent to the alternative water use plus water returned to the original source over the course of a year.*

A Net Zero Water designation means the amount of alternative water used plus the water returned to the original water source is equal or greater than the building's total freshwater (utility/potable water) consumption. This is depicted in Figure 19.

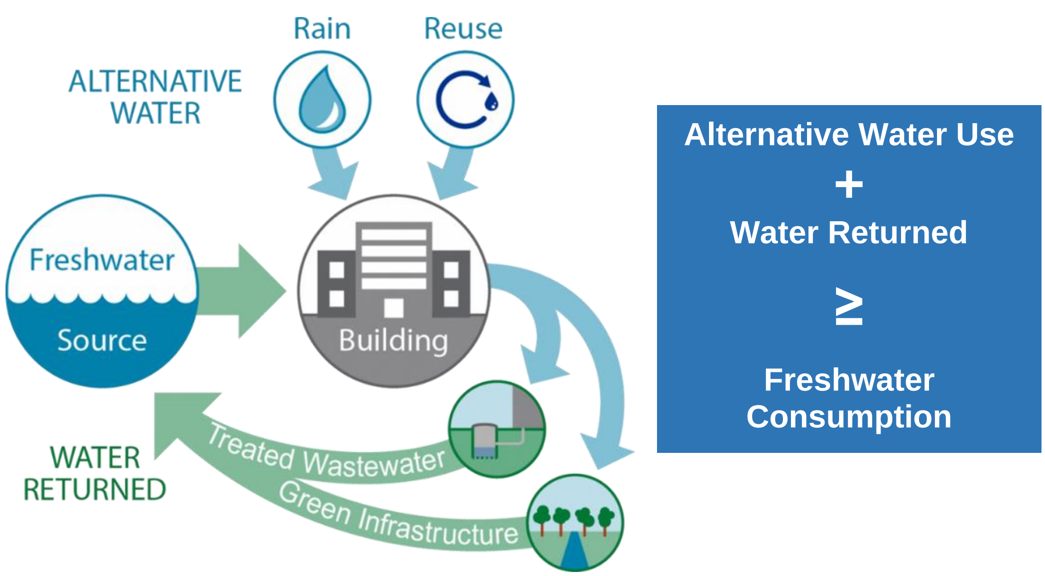


Figure 19: Left, depiction of major elements to achieve Net Zero Water.
Right: Water balance equation for achieving Net Zero Water.
Source: www.energy.gov/eere/femp/net-zero-water-building-strategies

See Figure 20 for the boundaries on a building, facility, or campus for performing a water balance calculation. Note that stormwater infiltration through green infrastructure can count towards water returned to the original water source.

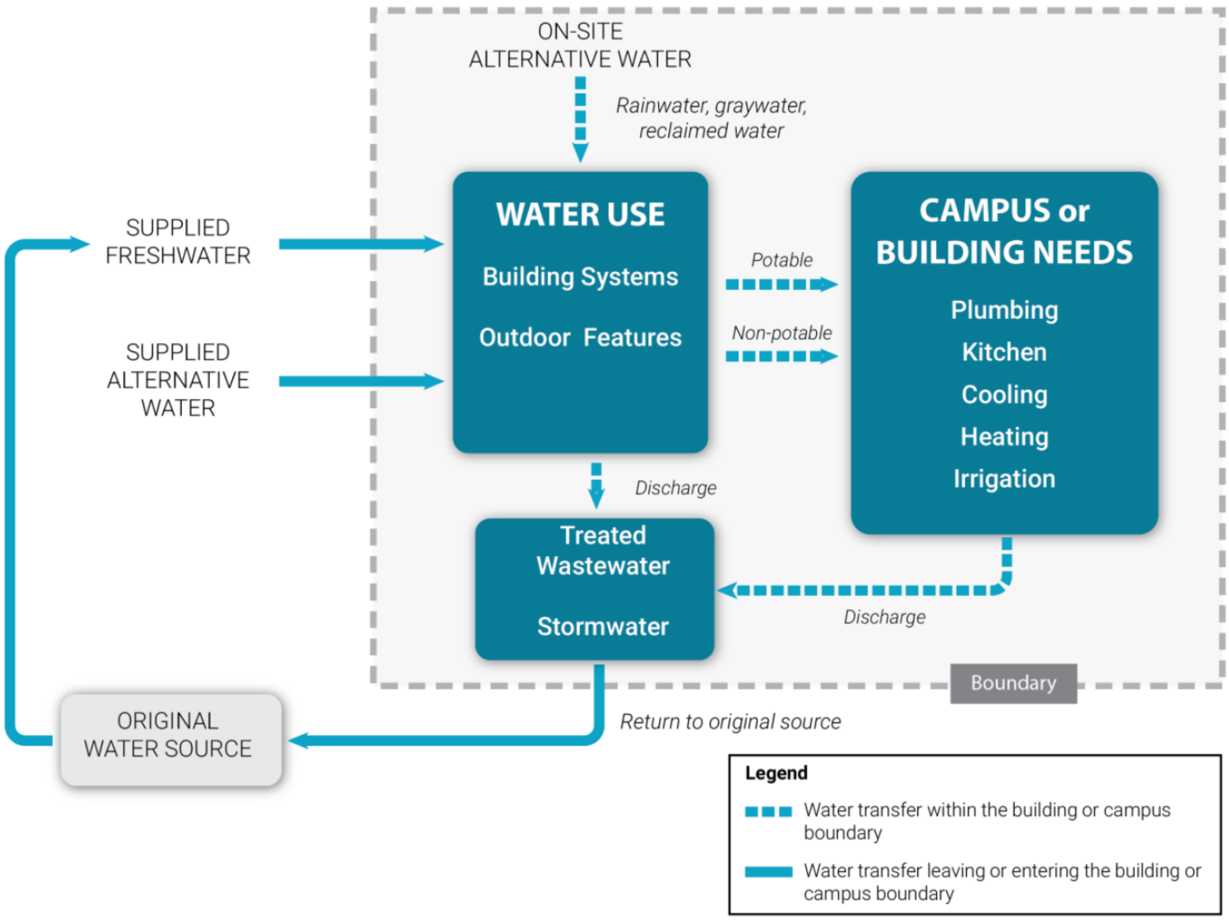


Figure 20: Depiction of site boundary for water balance.
Source: www.energy.gov/eere/femp/net-zero-energy-water-and-waste-handbooks

Water Reuse

Maximizing water reuse helps achieve Net Zero Water status. Water reuse is utilizing treated wastewater as the water source for a useful application. The original clean water is used once, becomes wastewater, is treated, and then is used a second time. Hence the water is "reused." The reused water is also called "reclaimed" or "recycled" water.

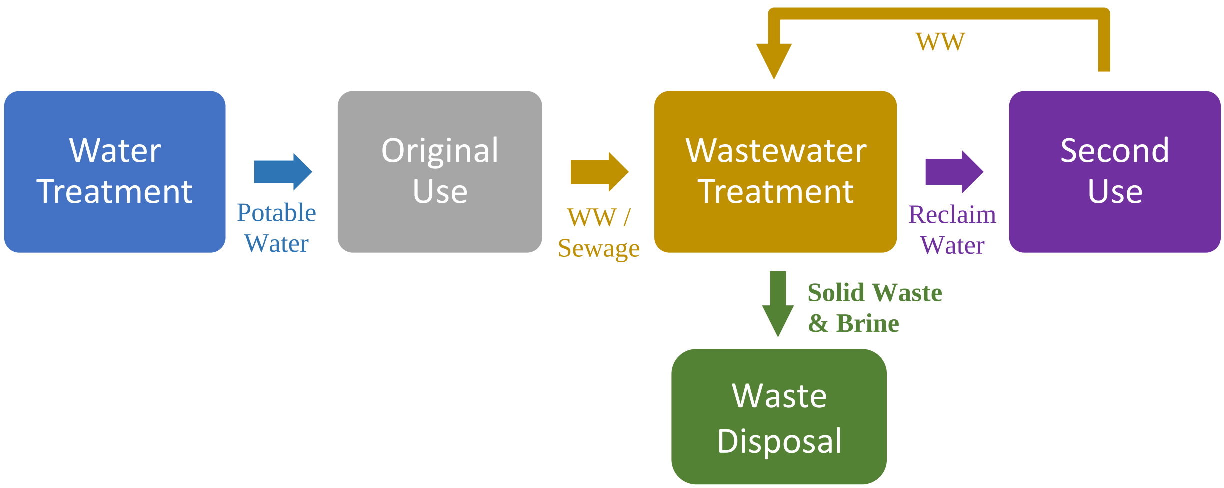


Figure 21: Water to wastewater flow diagram with water reuse in purple.
Source: Author

Applications for water reuse include the following:

- Agricultural (irrigation of crops, aquaculture, hydroponics)
- Industrial (cooling towers, boilers, cooling, steam, process water)
- Urban (toilet water, fire protection, street & vehicle washing, fountains, snow, ice)
- Landscaping (irrigation, ponds)
- Potable (drinking water, indirect, direct, unplanned)
- Environmental (wetlands, restore aquatic habitats, stream & lake augmentation)
- Groundwater Recharge (deep well injection, saltwater intrusion prevention)

For a typical commercial facility, the following are common water reuse applications:

- Landscaping
- Roof gardens
- Cooling tower make-up water
- Toilet water
- Fire protection water

See Figure 22 for a depiction of common forms of reclaimed water in orange. In this case, the original water sources are surface water (river) and groundwater, which are augmented by reclaimed water in various forms.

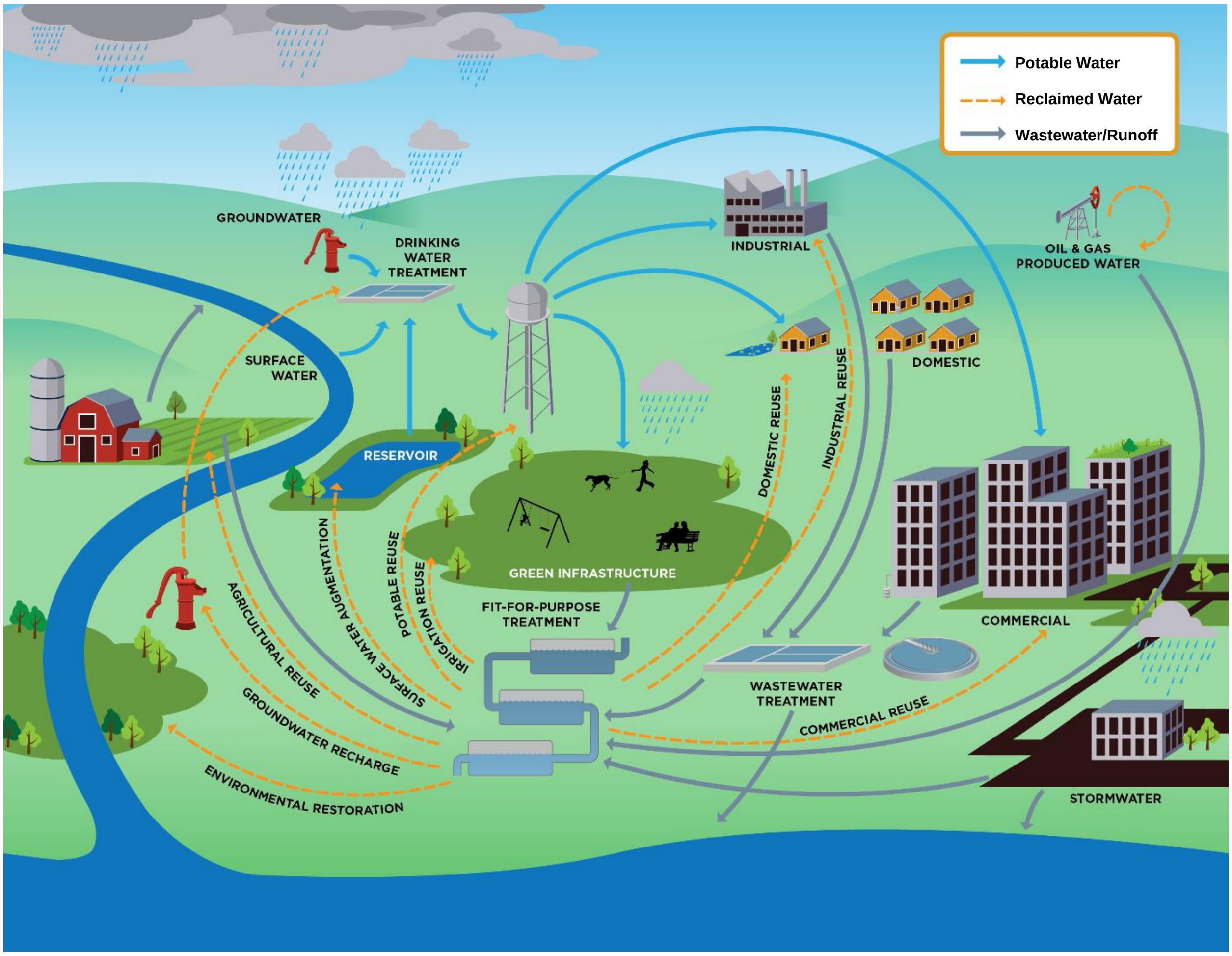


Figure 22: Sustainable anthropomorphic water cycle with potable water (blue), reused/reclaimed water (orange dashed), and wastewater or runoff (grey).
Source: www.epa.gov/waterreuse/basic-information-about-water-reuse, public domain

Example Problem 5

Determine if Net Zero Water is achieved for the building shown in Figure 23.

Solution

The water balance equation is applied to the building. Water reuse through Rainwater and Gray Water are considered “Alternative Water Use”. Recharge Water (stormwater returned to groundwater) is considered “Water Returned”. The Potable Water Supply is the “Freshwater Consumption”.

Alternative Water Use	+	Water Returned	≥	Freshwater Consumption
[Rainwater + Gray Water]	+	Recharge Water	≥	Potable Water Supply
[18kgal/yr + 12kgal/yr]	+	26kgal/yr	≥	26kgal/yr
	56kgal/yr		≥	26kgal/yr

The equation is true; therefore, Net Zero Water is achieved.

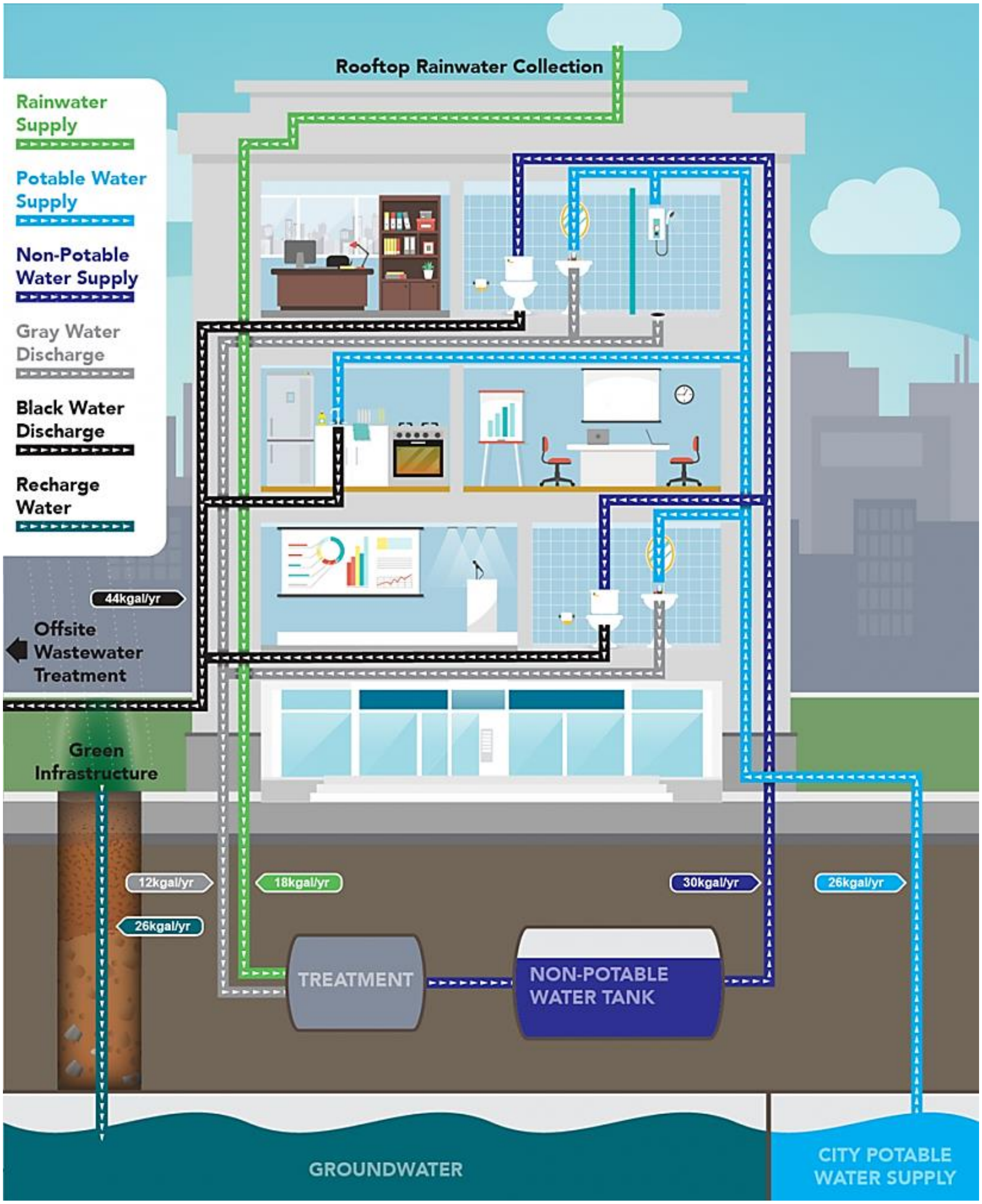


Figure 23: Depiction of water balance for Example Problem 5.
Source: www.energy.gov/eere/femp/scenario-2-mainstream-net-zero-water-building

Helpful References

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