Throughout this course, you've explored how Earth's systems are deeply interconnected — from the global water cycle and climate dynamics to land use, atmospheric processes, and infrastructure. This project challenges you to apply systems thinking to a cutting-edge innovation: the evaporation-driven engine.

In earlier lessons, you studied how evaporation and transpiration fuel the hydrological cycle; how relative humidity, wind, and solar radiation drive atmospheric moisture movement; and how soils, vegetation, and infrastructure influence water storage and flow. You analyzed regional differences in water availability, modeled sediment and nutrient fluxes, and examined how green, gray, and human infrastructures interact. All of these concepts now become essential tools as you investigate a real-world energy solution that relies directly on these Earth system interactions.

Evaporation-driven engines represent a novel class of energy harvesting devices that convert the chemical potential difference of water during evaporation into mechanical work. These engines exploit water-responsive (WR) materials, including hygroscopic substances like bacterial spores or synthetic polymers, which undergo reversible mechanical deformation in response to changes in relative humidity (RH). When positioned above the surface of a body of water, the engine operates through a cyclic process: the WR material absorbs water vapor at high chemical potential from the water surface, generates mechanical force through this absorption, then releases the absorbed water to the atmosphere at lower chemical potential, extracting work in the process. (Note: impeding a substance as it tries to go from high potential to low potential is how all engines operate. Examples include hydropower (catching falling water and robbing it of some of its speed) to car engines (hot air in the engine expands against the pistons) to electronic devices (which impede the flow of electrons as they move from high voltage to low).)

The power output of these engines depends on the ambient environmental conditions. As you will observe, favorable meteorological conditions include low RH, high solar radiation, and high wind speeds. A preliminary analysis of U.S. water bodies indicates potential total power generation of 325 GW from lakes and reservoirs >0.1 km², with highest power densities occurring in arid southwestern regions where water scarcity is most acute.

Project Goal

To investigate the feasibility of such an evaporation-driven engine in your home region, both in terms of power output for a given area of water and in terms of the availability of open surfaces of water in your region. This analysis will take into account your local weather (including the variables listed above) and your region's geography. Your ability to analyze these variables builds on the models and lessons that you've worked with throughout this course — from regional precipitation models to land-use change, evapotranspiration, and the energy-water nexus. We want to stress that the feasibility of these engines has only been investigated in a small number of places, almost all confined to the U.S., so the work you're doing here is novel. As this is an active area of research, even these studies have been theoretical, based on simulations as opposed to actual observations of large-scale evaporation-driven engines.

Project Outline

Before diving into the analysis, the next few lessons cover the science behind their operation: how evaporation works, how WR materials work, and how evaporation and WR materials combine to form an evaporation-driven engine. Then you'll look at the math behind the evaporation engine’s power output in more detail and explore an interactive demonstration that should help to build your intuition for how the output depends on the engine’s ambient environment. Then you'll dive into the analysis: using local weather data and geographic data, you'll write a report on the feasibility of an evaporation-driven engine in your home location.

Water-Responsive Materials

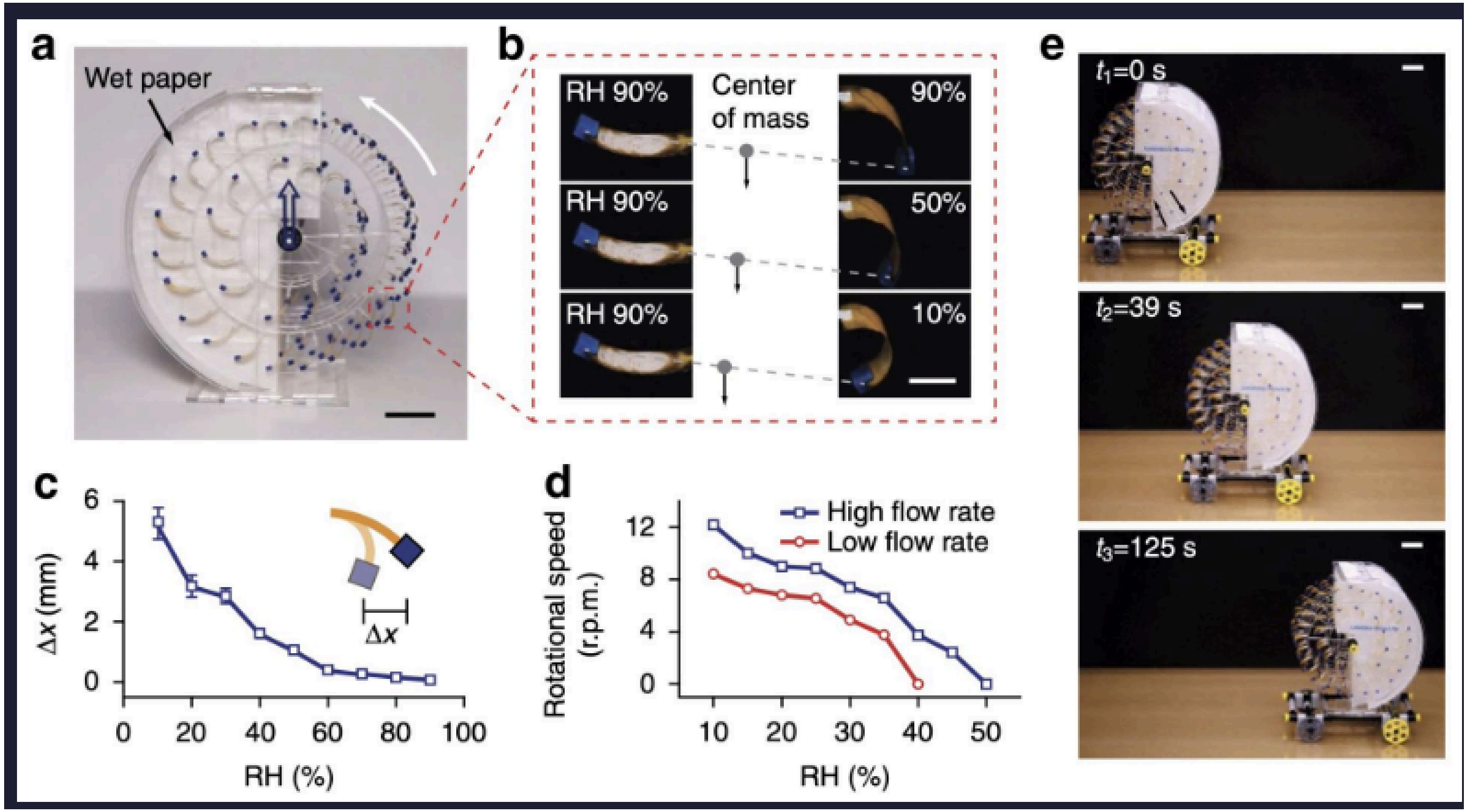
Water-responsive (WR) materials are solids that mechanically deform (actuate) in the presence of water, in particular due to moisture in the air. At a microscopic level, they swell when they absorb water and shrink when they release it, converting the water’s chemical potential energy to mechanical energy that we can harness. Since the swelling/shrinking process is reversible, there is no theoretical limit to how much energy can be extracted from the environment; as long as the ambient humidity continues to cycle between wet and dry, a WR material will continue to actuate indefinitely. (Of course, this doesn't imply that WR materials are an infinite source of energy. The transport of moisture through the air itself requires energy — energy that in our case ultimately comes from the Sun, which will eventually run out of fuel.)

The actuation of WR materials is driven by how water behaves at material interfaces. Water molecules get divided into two populations: bound water that interacts strongly with material surfaces through hydrogen bonding, and mobile water that behaves like bulk water with weaker interactions. Recent work shows that materials begin exerting force when the ratio of bound to mobile water reaches a threshold value. This suggests that actuation stems from the chemical potential from the confinement of water rather than simple bulk water absorption, which helps explain why some materials generate far more force per mass than others despite similar water uptake.

Below is a video of three strips of films made of silk, a WR material, responding to a change in ambient moisture.

Applications

The application of WR materials that this project will focus on is evaporation-driven engines, although we describe additional applications below. Evaporation-driven engines sit atop the surface of a body of water and run autonomously, converting naturally-occurring evaporation into motion. Some prototypes generate electricity by coupling this motion to generators, while others drive miniature vehicles. The systems work over both fresh and saltwater, which means you could potentially deploy them on lakes, offshore, or at industrial sites like cooling towers and evaporation ponds. Geography strongly affects the engine's power output — arid climates generate roughly twice the evaporation potential of humid ones. (We'll explore the drivers of evaporation in more detail in the next lesson.) At the same time, arid environments are less likely to have open bodies of water to begin with. Below are some prototypes of evaporation-driven engines that use the ambient humidity instead of a whole body of water.

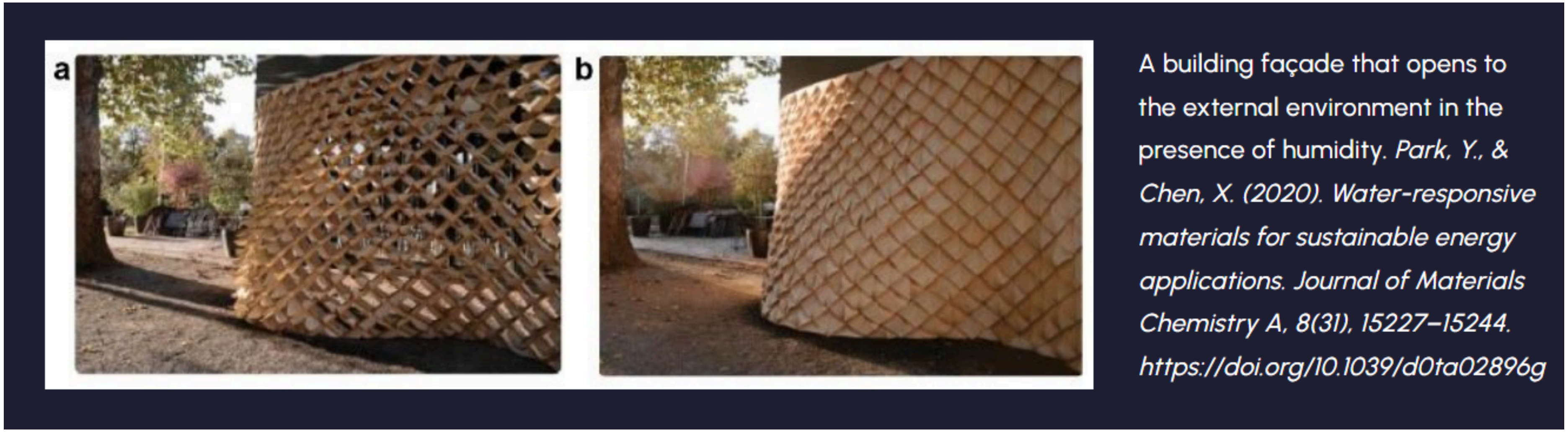


An evaporation driven engine that uses changes in humidity to rotate and drive itself forward. The engine utilizes WR strips that curl and uncurl in response to humidity, causing the blue weights at the ends of the strips to move towards or away from the center of the wheel; see images (a) and (b). When one side of the wheel is more humid than the other, the resulting imbalance in weight causes the wheel to turn.

A live demonstration of an evaporation-driven engine at the American Museum of Natural History

In robotics, WR materials could solve problems where conventional motors hit size and power constraints. Robotic hands need small, powerful linear actuators that current motors struggle to provide at small scales. Researchers have built soft robots that crawl using bilayer WR structures and autonomous seed carriers that dig themselves into soil for aerial seeding (as some seeds already do naturally, as discussed below).

Passive systems include building façades that respond to humidity (shown below) without external power, bioelectronic interfaces that adapt to physiological conditions, and self-powered air circulation systems. A similar application is smart textiles: fabric with ventilation flaps that open when you start sweating. The benefit of these systems is that they operate by automatically harvesting ambient humidity fluctuations instead of requiring electricity from the grid.



A building façade that opens to the external environment in the presence of humidity. Park, Y., & Chen, X. (2020). Water-responsive materials for sustainable energy applications. Journal of Materials Chemistry A, 8(31), 15227–15244. https://doi.org/10.1039/d0ta02896g

Natural WR Materials

Bacterial spores are one high-performance WR material. They respond in fractions of a second and generate energy densities far exceeding conventional actuators or mammalian muscles. The first evaporation-driven engines used spores, but scaling up to the macroscopic level remains difficult; current devices only achieve about one-thousandth of what the nanoscale properties suggest is possible. Recent work has focused on using bacterial cell walls instead, which can be 3–4 times more powerful per volume of material.

Spider silk shrinks and expands dramatically with humidity, which in nature helps maintain web structure and capture prey. Dragline silk (the strongest silk that web-building spiders produce) generates particularly high stress and energy density during water-responsive actuation. Unfortunately, it is not yet practical to farm spiders for their silk. Silkworm silk works as a farmable alternative, particularly regenerated silk fibroin, which can be processed into films, scaffolds, particles, and fibers. Treating silk with different post-processing methods alters the distribution of bound versus mobile water populations, which changes actuation performance. Below is a video of a silk film pulling a weight in response to humidity.

Plants have evolved bilayer structures where cellulose microfibrils orient differently in each layer. Pine cone scales, ice plant seed capsules, and plant awns (the bristle-like growths on the seeds of wheat and some other grasses) use this design, with one layer swelling more than the other when humidity changes, which causes the material to bend. In the case of pine cones and ice plant seed capsules, this releases the seeds only when the humidity is optimal for germination (such as after spring rainfall), keeping the seeds protected in the meantime. In the case of awns, once the seed has fallen, repeated bending and straightening of the awn can “walk” the seed to a favorable location from which to germinate, far from its parent plant. Some seeds like those of the Geraniaceae plant use cellulose arrangements that produce coiling instead, which helps them screw themselves into the soil. The key design principle is asymmetric swelling; different amounts of expansion in different directions drive not just a microscopic change in size, but a macroscopic change in shape as well. Crucially for the seed’s survival, none of these mechanisms require energy from the seed itself.

Synthetic WR Materials

Synthetic WR materials consistently fall behind natural ones by one to two orders of magnitude in energy density. Hydrogels swell substantially but they're mechanically weak and respond slowly, taking minutes to hours to actuate rather than seconds. Researchers have tried mimicking plant bilayer structures using polymers with aligned magnetic particles to create programmed bending and twisting motions. Carbon nanotube hybrid yarns and graphene fibers show relatively strong performance by facilitating water transport through nanotube channels. Titanium oxide nanotubes leverage capillary condensation in nanoscale channels. Metal-organic frameworks undergo substantial volume changes upon water exposure and can be patterned into structures that self-assemble into complex geometries. Despite these advances and the design flexibility that synthetic materials offer, nobody has established clear design rules for making high-performance synthetic WR materials that approach biological performance

The EvapoFlex Engine

Now that we've covered the science behind evaporation and water-responsive materials, we can talk about the EvapoFlex engine!

The EvapoFlex engine converts evaporation energy into continuous, rotational mechanical work by exploiting a humidity gradient across the engine’s body. The engine functions due to its placement at an air-water interface, where the humidity differs drastically across space. The lower region, close to the water’s surface, stays saturated at around 95% RH while the upper region is exposed to the ambient humidity, typically 20-70% RH in most climates.

We already saw the device’s basic architecture in the previous lessons, but we'll expand on it here. Strips of WR material (typically bacterial cell walls, cellulose films, or silk) are mounted on concentric rings that rotate freely on ball bearings around a central shaft. The strips in humid regions curl when humid and extend when dry, displacing their end from the center of the wheel. When small weights (roughly 15mg) are placed on the ends of the strips, this results in a torque imbalance on the wheel — the humid side, whose weights are closer to the axis, exerts less torque than the drier side, whose weights are farther, causing the wheel to rotate. As the strips go from dry air to humid air, they curl, and as they go from dry to humid they extend, and since the humidity gradient is (approximately) constant over time, the torque remains imbalanced even as the wheel rotates, and so the wheel can rotate indefinitely, or at least as long as the humidity gradient remains (which on Earth depends on the lifetime of the Sun).

From a thermodynamic perspective, the WR materials absorb water at a high chemical potential μ_s on the wet side ('s' for surface) and release it at a lower chemical potential μ_a on the dry side ('a' for air or atmosphere), where $\mu_s > \mu_a$. Like all engines, being positioned in the midst of a thermodynamic gradient — itself the result of a humidity gradient — is what allows for the extraction of energy. If the humidity were uniform over space, then there would be no torque imbalance and the wheel would not rotate.

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Energy Output

Now to answer the question that's almost certainly been sitting in the back of your mind: just how much power does one of these engines produce? The engine produces power by extracting some of the chemical potential energy from water vapor — the exact chemical energy that the liquid water is imbued with as it's vaporized. So the first thing we need to compute is the rate of evaporation.

The *Penman Equation*, shown below, is an empirical estimate of the depth of water that will evaporate in a day given certain ambient conditions weather conditions:

$$c_t L_v \rho_w E_{\mathrm{pr}} = \frac{\Delta \cdot R_n + 2.6 c_t L_v \rho_w \gamma (1 + 0.54 u_a) D_a}{\Delta + \gamma}$$

where:

- E_{pr} is the evaporation rate of water in $\mathrm{mm/day}$ — the number we're computing from the rest
- $c_t = 1 = \frac{1\,\mathrm{day}}{86400\,\mathrm{sec}}\frac{1\,\mathrm{m}}{1000\,\mathrm{mm}}\frac{10^6\,\mathrm{W\ sec}}{\mathrm{MJ}} = 0.01157\,\mathrm{W\ m\ day\ MJ^{-1} mm^{-1}}$ is a unit conversion constant
- $L_v = 2448\,\mathrm{MJ/Mg}$ is the latent heat of vaporization of water
- $\rho_w = 1\,\mathrm{Mg/m^3}$ is the density of water
- R_n is the net radiation above the surface in $\mathrm{W/m^2}$
- $\gamma = 0.067\,\mathrm{kPa/K}$ is the psychrometric constant, which relates the partial pressure of water vapor in air to the air temperature. It's not technically a constant, as it depends on air pressure, but we'll assume that it's approximately constant at a given altitude.
- $\Delta = \frac{\mathrm{d}e_s(T)}{\mathrm{d}T}$ is the rate of change of saturation vapor pressure with respect to temperature, at temperature T_{mean}, the daily average temperature — we'll discuss how to compute this below. (Note that while Δ usually goes before another variable to represent a change in that variable, here it is being used as a variable directly.)
- u_a is the wind speed in $\mathrm{m/s}$
- $D_a = (1 - \mathrm{RH_{air}}) \cdot e_s(T_{\mathrm{mean}})$ is the vapor pressure deficit, where $\mathrm{RH_{air}}$ is the relative humidity in the air (a number between 0 and 1) and $e_s(T_{\mathrm{mean}})$ is the saturation vapor pressure at temperature T_{mean}, as given by the Buck equation or a similar equation

The four meteorological variables are R_n (sunlight) and u_a (wind), which figure directly in the Penman Equation, and RH (humidity) and T_{mean} (temperature), which enter indirectly through their impact on Δ and D_a.

Clausius–Clapeyron relation

The Clausius–Clapeyron relation is an expression for the slope of the saturation vapor pressure curve with respect to temperature, which lets us compute Δ from above:

$$\frac{\mathrm{d}e_s}{\mathrm{d}T} = \frac{L_v e_s}{R_v T^2}$$

where T is the temperature **in Kelvin** and $R_v = 461.5\,\mathrm{J}/(\mathrm{kg\ K})$ is the *specific gas constant* for water vapor. If you've heard of *the* gas constant — the $R = 8.314\,\mathrm{J}/(\mathrm{mol\ K})$ in the ideal gas law, $PV = nRT$, which relates the internal energy of a (molar) quantity of substance to its temperature — the specific gas constant relates the internal energy of a quantity of substance to its temperature when the quantity is specified by mass instead of moles, so that $PV = mR_vT$. R_v is simply equal to *the* gas constant divided by the molar mass of water.

So, with all of the above, and the Buck equation from the previous lessons, we can compute the evaporation rate E_{pr} of a body of water (in millimeters per day). It is important to note that the Penmar Equation is an *empirical* equation: it was derived from experiment and applies only within the regime in which it was derived. In particular, despite the fact that all of the variables in the equation appear to be the values of quantities at a given instant in time, the Penman Equation gives the *average* evaporation r of a body of water *over the course of a day*, not the instantaneous evaporation rate at any given mome For this to make sense, the variables used in the equation must themselves be treated as daily averages not instantaneous values. This may feel like a coarse approximation, but in practice it works quite well.

Power Output

Finally, we can talk about power output! The *maximum* average power output over the course of a day i given by the following:

$$P/A = c_e E_{\mathrm{pr}} R T_{\mathrm{air}} \ln(\mathrm{RH}_{\mathrm{wet}}/\mathrm{RH}_{\mathrm{air}})$$

where:

where:

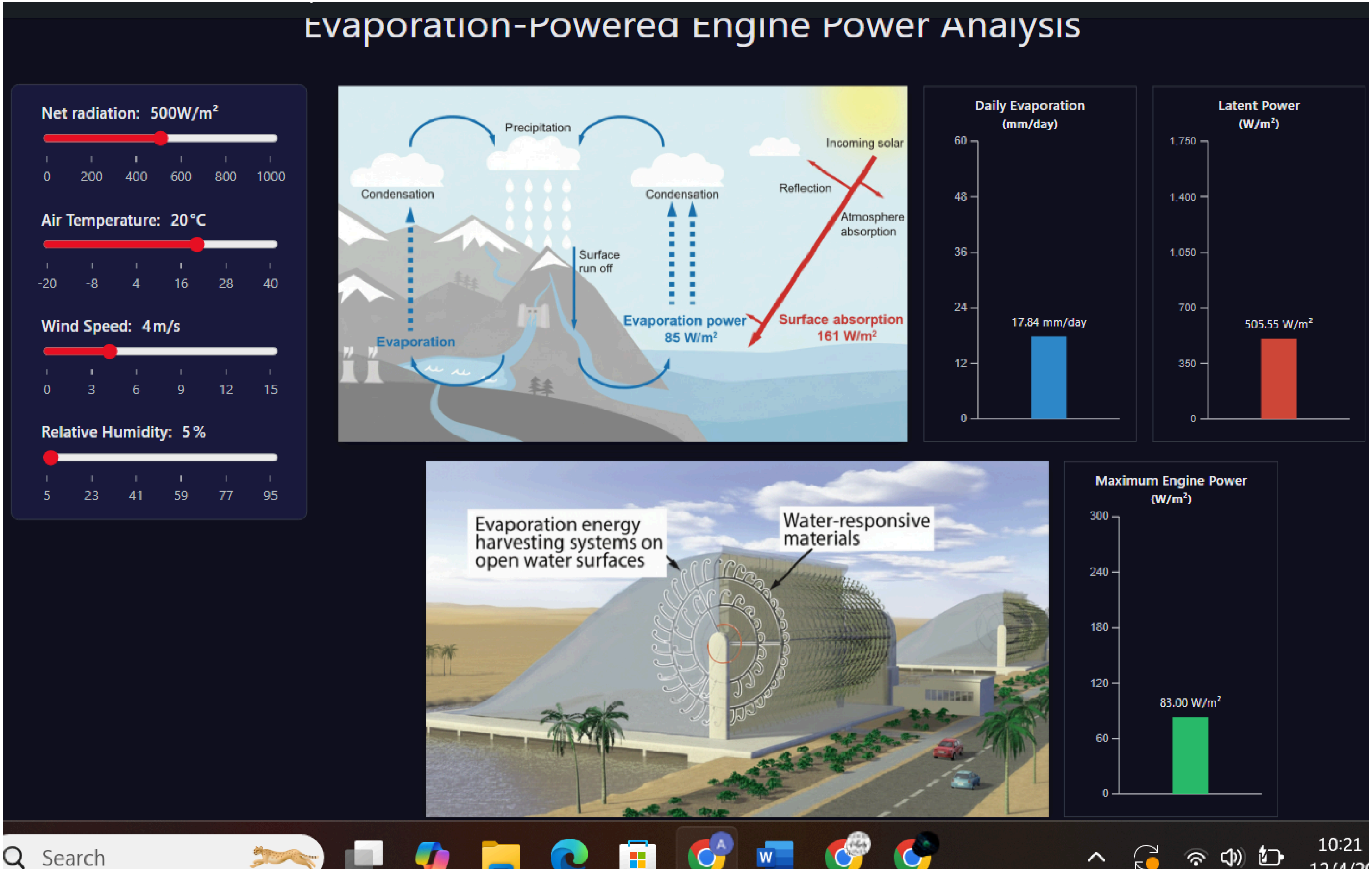
- P/A is the power per area in $\mathrm{W/m^2}$
- $c_e = 1 = \frac{1\ \mathrm{mol\ H2O}}{18.015\ \mathrm{g\ H2O}} \frac{10^6\ \mathrm{g\ H2O}}{\mathrm{m^3}} \frac{1\ \mathrm{m}}{1000\ \mathrm{mm}} \frac{1\ \mathrm{day}}{86400\ \mathrm{sec}} = 6.42465 \times 10^{-4}\ \mathrm{mol\ day\ mm^{-1} m^{-2}\ s}$ is a unit conversion constant
- E_{pr} is the evaporation rate, in millimeters evaporated per day, as given by the Penman Equation
- $R = 8.314\ \mathrm{J/(mol\ K)}$ is *the* ideal gas constant
- T_{air} is the temperature of the air in Kelvin
- $\mathrm{RH_{wet}}$ is the relative humidity just above the water's surface, where the air is nearly saturated — we can assume it's equal to roughly 0.975
- $\mathrm{RH_{air}}$ is the relative humidity in the air

If one could extract all of the energy from evaporation, this is the power the engine would produce. Of course, in practice this is not possible. For starters, extracting all of the energy from evaporation would require re-condensing the water vapor, which is not thermodynamically favorable as evidenced by the fact that the water evaporated in the first place. And, like all engines, the EvapoFlex engine has various inefficiencies. But the power output should be roughly proportional to the maximum power shown above.

Below is an interactive demonstration in which you can observe how the four meteorological variables, net radiation, air temperature, wind speed, and the ambient relative humidity affect the theoretical energy output of an evaporation-powered engine situated over a body of water. Note that as the Penman equation is an empirically derived equation from daily data, these variables should be taken to be daily averages, from which the total quantity of evaporated water per day, and then ultimately total latent energy and maximum engine power, are derived.

It is clear from everyday experience that these four variables all have an effect on the rate of evaporation of water, although precisely how they affect the rate at which water evaporates is much less obvious. The top left graph shows this relationship. The top right graph is connected to the top left graph through the latent heat of vaporization of water. When you divide the energy provided over the course of a day by the length of a day, you get the average latent power for the day.

The engine pulls the energy it harnesses out of evaporated water, but it cannot extract all of the energy, and ambient humidity is a big reason why not. Just above the surface of a body of water, the air and the water are in equilibrium, constantly passing water molecules back and forth between each other. The equilibrium point of this process determines the relative humidity. The more humid it is, the more water vapor the air has to return to the water, and when water vapor condenses out of the air, it does exactly the opposite as when it evaporates: it returns energy from the environment to the water, preventing the engine from making use of that energy. In the bottom graph, you can see how all four variables — but in particular temperature and humidity — affect the maximum theoretical power output of an evaporation driven engine.


Evaporation-Powered Engine Power Analysis
Net radiation: 500W/m²
0 200 400 600 800 1000
Air Temperature: 20°C
-20 -8 4 16 28 40
Wind Speed: 4 m/s
0 3 6 9 12 15
Relative Humidity: 5 %
5 23 41 59 77 95
Precipitation
Condensation
Condensation
Incoming solar
Reflection
Atmosphere absorption
Surface run off
Evaporation power 85 W/m²
Surface absorption 161 W/m²
Evaporation
Daily Evaporation (mm/day)
60 48 36 24 12 0
17.84 mm/day
Latent Power (W/m²)
1,750 1,400 1,050 700 350 0
505.55 W/m²
Evaporation energy harvesting systems on open water surfaces
Water-responsive materials
Maximum Engine Power (W/m²)
300 240 180 120 60 0
83.00 W/m²
Search
10:21

Jot down some observations of the behavior of these graphs. (The top two are related by a constant, so you only really need to consider one of them.) Consider the following questions and any others you come up with. Remember that air temperature is given in celsius, but absolute temperature uses Kelvin (so, for instance, 40°C is not twice as hot as 20°C, but only about 7% hotter).

- Which variables have the greatest effect on the top graphs? Does your answer change depending on the values of other variables? How about for the bottom graph?
- What is the relation between total latent energy and maximum engine power? Which variables most strongly affect this relationship, and how? (Pay attention to the ratio of these two outputs.)
- How do the three outputs depend on the four variables? Linearly? Sub-linearly (e.g., logarithmically)? Super-linearly? Something else?
- As we saw in the previous lesson, the equation for the engine's power output per area is $P_{\text{per area}} = c_e ERT_{\text{air}} \ln(\text{RH}_{\text{wet}}/\text{RH}_{\text{air}})$. It looks like this should be infinity when the ambient humidity is zero. Why *doesn't* this equation imply that one can extract infinite energy from evaporation? (Hint: energy is the sum of instantaneous power of time.)

Now it's time to analyze some weather data and evaluate the feasibility of an evaporation-driven engine in your location. Before you begin, based on what you learned in the previous lesson about how the engine's power output depends on different environmental variables, form a hypothesis: how effective would such an engine be where you are located? Consider the following:

At a high level, would your local climate make an evaporation-driven engine feasible?

How would the engine’s power change over the course of a year? Are there times of the year when it would be more effective than others? How much area would have to be devoted to such an engine? Is open water plentiful or scarce?

Now it's time to analyze some data! We recommend you read all of the instructions below before beginning.

To start, we need some data to analyze. Copy the following URL into a text editor and replace the four variables, LATITUDE, LONGITUDE, START_DATE, and END_DATE, with the latitude and longitude of your location and the start and end dates of the period you would like to analyze. This period should be at least a year long, but can be longer, and the dates should be formatted as YYYY-MM-DD, e.g. 2025-12-31. Then visit the resulting URL in your browser and a CSV should be automatically downloaded. This CSV contains hourly weather data for your location and includes the long list of variables specified in the URL.
https://archive-api.open-meteo.com/v1/archive?format=csv&timeformat=unixtime&latitude=LATITUDE&longitude=LONGITUDE&start_date=START_DATE&end_date=END_DATE&hourly=temperature_2m,relative_humidity_2m,dew_point_2m,apparent_temperature,precipitation,wind_speed_10m,wind_speed_100m,wind_direction_100m,wind_direction_10m,wind_gusts_10m,rain,weather_code,cloud_cover,cloud_cover_low,cloud_cover_high,cloud_cover_mid,et0_fao_evapotranspiration,vapour_pressure_deficit,wet_bulb_temperature_2m,is_day,sunshine_duration,albedo,shortwave_radiation,direct_radiation,diffuse_radiation,direct_normal_irradiance,global_tilted_irradiance,terrestrial_radiation,shortwave_radiation_instant,direct_radiation_instant,diffuse_radiation_instant,direct_normal_irradiance_instant,global_tilted_irradiance_instant,terrestrial_radiation_instant

https://archive-api.open-meteo.com/v1/archive?format=csv&timeformat=unixtime&latitude=LATITUDE&longitude=LONGITUDE&start_date=START_DATE&end_date=END_DATE&hourly=temperature_2m,relative_humidity_2m,dew_point_2m,apparent_temperature,precipitation,wind_speed_10m,wind_speed_100m,wind_direction_100m,wind_direction_10m,wind_gusts_10m,rain,weather_code,cloud_cover,cloud_cover_low,cloud_cover_high,cloud_cover_mid,et0_fao_evapotranspiration,vapour_pressure_deficit,wet_bulb_temperature_2m,is_day,sunshine_duration,albedo,shortwave_radiation,direct_radiation,diffuse_radiation,direct_normal_irradiance,global_tilted_irradiance,terrestrial_radiation,shortwave_radiation_instant,direct_radiation_instant,diffuse_radiation_instant,direct_normal_irradiance_instant,global_tilted_irradiance_instant,terrestrial_radiation_instant

Now that you have the data, you can start analyzing it to find out how effective an evaporation-driven engine at your location would be. How you analyze this data is up to you and your group — you can use Excel, Google Sheets, or your programming language of choice — but whatever tools you use, you'll want to follow the outline laid out below.

Convert the “time” column to a human-readable date. This column is given in Unix time, also called epoch time, which is the number of seconds that have elapsed since January 1, 1970 at 12am in the UTC time zone (approximately the same thing as Greenwich mean time), which is the standard for specifying the time of an event in computing. (Because it's given as a duration as opposed to a time of day, Unix time is independent of your local timezone). We'll leave it to you to figure out how to do the conversion — chances are a quick Google search will reveal it's more or less built into whatever analysis tool you're using.
Then, to determine what constitutes a single day (midnight to midnight) in your time zone, convert this date-time to your local time zone. To do this, you will need to look up your time zone offset from UTC. We will ignore the fact that local time zones can change relative to UTC due to e.g., daylight savings, which would mean that midnight-to-midnight might not be 24 hours, and instead assume that your UTC offset is constant throughout the year.
The Penman equation only describes the daily quantity of evaporation, not the instantaneous (or hourly) evaporation. To continue with the hourly data you've downloaded, we'll make a crude assumption and plug daily averages of the input variables into the Penman equation. Therefore, for each day, you should compute the average of each input variable (which is the average of 24 values, one for each hour) before computing estimated daily evaporation. Food for thought: how does this approximation impact your analysis? Under what circumstances would this be a particularly good or bad approximation?
Once you have an expected quantity of water evaporated per day (given in mm/day), compute how much energy the evaporation-engine would produce on each day (or more accurately, would produce if it were 100% efficient, which we know it's not), and then plot your data. What is the average power output of the engine over a year? How much does it vary from day to day and over the course of a year? (For instance, in most parts of the world we would expect the engine to produce more power in the summer than the winter — but how much more?) If you looked at multiple years of data, how steady was the power output from year to year?
Engine performance is just one piece of the puzzle — another is whether building such an engine is feasible at all. An evaporation-driven engine requires a body of water to sit over. Do some research on bodies of water in your area. How abundant are they, how much area do they cover, and how consistently are they full? Do you think an evaporation-driven engine would be possible to build in your location? Why or why not?
Now write your report! You should include the process you followed to obtain and analyze the data, any plots you produced, and the results of your analysis, including but not limited to the questions in the above two bullets. Also be sure to include any assumptions or simplifications you made (such as the daily averaging of data) and how it might affect your analysis.

Finally, upload your report to this Google Drive folder, then leave a link below. You can (and should!) also post below with any questions or comments you have or anything interesting you've noticed as you complete the project.

1. Successfully download the dataset and confirm it opens correctly.
2. Implement the required equations as functions in your chosen tool or programming environment.
3. Use your data and functions to compute the missing columns in the weather dataset (e.g., vapor pressure).
4. Group the data by day to calculate daily averages of the relevant variables.
5. Apply the Penman equation to the daily data to obtain average power (or energy) per day.
6. Collect results over the course of a year (likely by plotting) and analyze them to answer the questions outlined in the lesson.
7. Compare your findings with other locations.

After you've completed the above, we have a bonus challenge for you: based on what you now know about how these evaporation-driven engines work and where they work best, and your preexisting geographical knowledge, where on the globe do you think an evaporation-driven engine would produce the most energy in a year? Once you've picked a place, download its weather data and repeat your analysis from above. (It should be much faster this time, as all you're doing is swapping out the data.) For a little friendly competition, compare your chosen location to other scholars' — who did b