The World Championships of Systems Architecting

2023 Competition Problem Statement

Background and Context

Prolonged extreme drought combined with forces encouraging portions of the US population to migrate to desirable lower cost-of-living location are straining the natural ecosystem's abilities to meet these demands in places like Arizona, home of Integrate23. Communities such as Rio Verde Foothills near Scottsdale have recently lost access to drinking water. Reservoirs such as Lake Mead are at all-time low water levels. These competing factors place ever increasing challenges on municipalities in these affected areas. New, innovative systems solutions are needed to meet the challenges that these competing demands place on the municipalities located in these regions.

Overview of the Scenario

The scenario uses a fictional landscape and city.

Mesa Cerveza[1] is one of the fastest growing cities in the southwestern United States, situated in a highly desirable region close to the ocean and mountains. It is a lower-cost region to live, with a median home price of $320,000 in 2023. Mesa Cerveza is in a state, Arulo, with a low corporate income tax rate and flat income tax, making the state desirable to both individuals and businesses alike. These factors are motivating many residents of the higher cost surrounding states to move to Arulo, and specifically, the City of Mesa Cerveza. The primary municipal challenge that the city faces is that it lies in an arid desert region and is facing a growing water crisis that is being amplified by the city's growing population. The geography of the region is shown in Figure 1.

Historically, it's main source of power has been from the Ron Swanson Memorial Dam & Power Station, a hydro-electric power plant at the Wymore Reservoir, a man-made reservoir created by damming the Pueblo River. However, extreme drought has resulted in Wymore Reservoir dropping to just 24% of its typical levels at the end of 2022. The turbines at Ron Swanson Power Station, with a rated capacity of 1,000 MW, can only operate at 53% of their full power due to the low water level. Currently, the City of Mesa Cerveza is contracted with the Ron Swanson Power Authority to obtain 83% of the power produced with most of the remaining power going to the beach community of Playa del Caprica.

The City of Mesa Cerveza has also relied upon the Wymore Reservoir for most of its water supply. At the end of 2022, 60% of its water supply comes from Wymore Reservoir, with the remaining water coming from the Central Arula Project (CAP) canal, which transports Arula's allotment of Ute River water to municipalities throughout the state. However, historic reductions in the Ute River's water level have

[1] Mesa Cerveza is a fictional city. All the residents get 30 cases of free beer a year from their largest employer, Griffin Brewery. In the historic old town district, beer is piped underground in insulated pipes to homes and businesses. These structures still to this day receive an annual allotment of beer straight to their taps. These homes and businesses are incredibly desirable because of this feature, which is no longer offered in new builds.

led to all of the western states agreeing to reduce their allotments starting in 2030. In 2030, Mesa Cerveza's allocation of CAP water will be reduced from 50,000 acre ft per year to 46,000 acre ft per year. In the same year, the city's allocation of water from Wymore Reservoir will be reduced from 75,000 acre ft per year to 70,000 acre ft per year. Additionally, due to the local residents' strong desire to maintain Wymore Reservoir's water levels for recreational activities and for the benefit of future generations, the City of Mesa Cerveza has set a goal of reducing its take by an additional 5,000 acre ft per year in 2030 (for a total goal take of 65,000 acre feet in 2030 and future years).

Occurring concurrently with these power and water supply challenges facing the city, the population of Mesa Cerveza is anticipated to grow by close to 300,000 people over the next 30 years, doubling in size. The City of Mesa Cerveza has hired your company, *Ecosystem Solutions LLC*, to develop a holistic systems solution to their multi-dimensional challenge: to provide adequate water and power to all residents and businesses of the city as it grows in population while respecting the natural environment as much as possible.

Figure 1

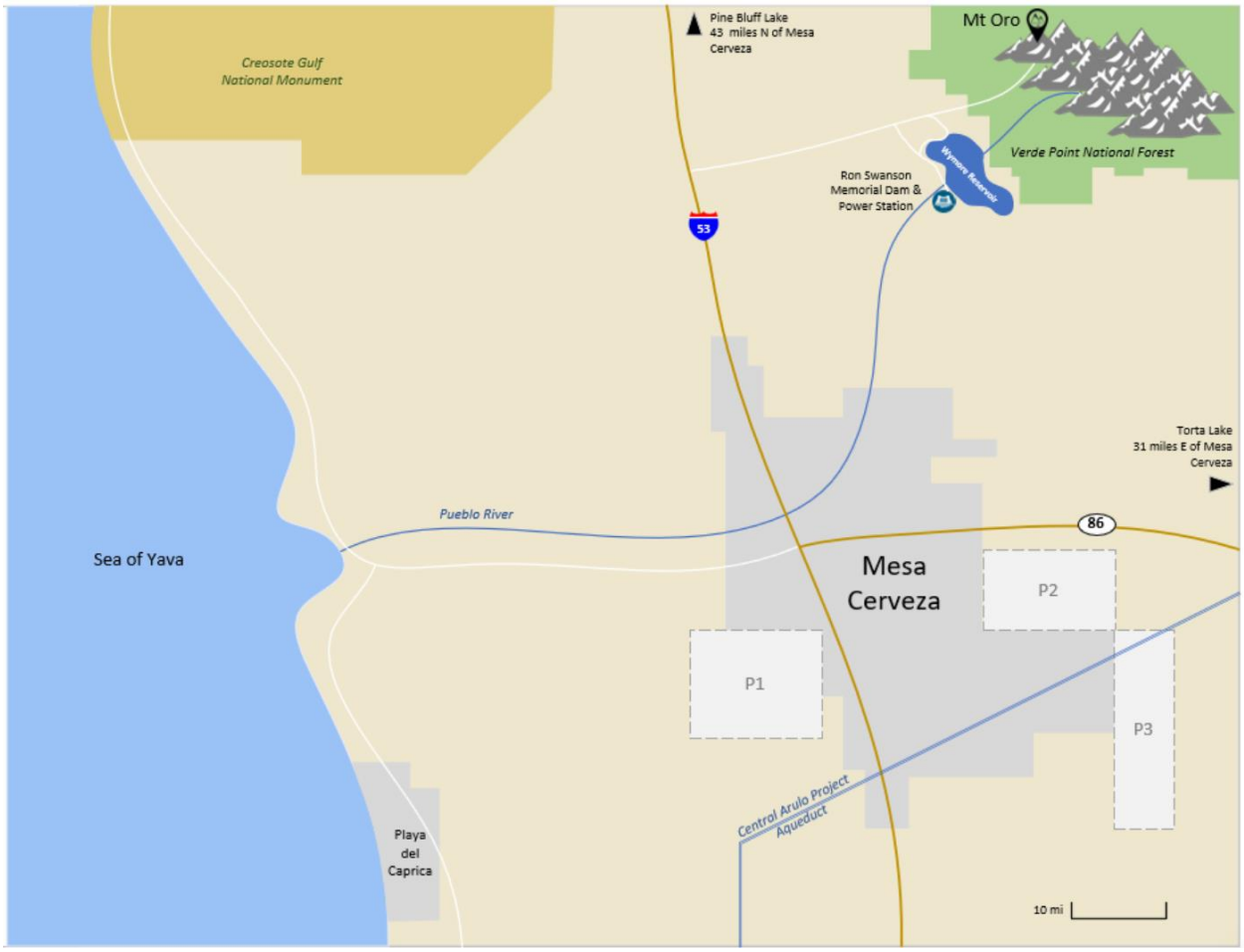

Figure 1: The City of Mesa Cerveza and surrounding area.

Statement of Work

Water and Power System Solutions for the 21st Century

City of Mesa Cerveza

Project #2718986302A

The City of Mesa Cerveza, the customer, has hired *Ecosystem Solutions LLC*, the contractor, to develop a comprehensive system solution to the city's 21st century needs consisting of sources, the necessary infrastructure, and technology to provide adequate power and water to the city's rapidly growing population at the same time that the traditional sources of these utilities are reducing in capacity and availability.

Ecosystem Solutions LLC is to deliver to the Town Manager of the City of Mesa Cerveza a comprehensive plan that consists of a holistic system solution providing adequate power and water to the town that will meet its needs through the year 2050. The proposal is due by 2:00 p.m. PDT on June 5, 2023. Ecosystem Solutions LLC shall provide a summary briefing of the proposal in person at the City of Mesa Cerveza Government Complex, Conference Room **Arizona D-E** immediately thereafter.

The proposal must meet the needs and constraints specified in the subsequent sections of this Statement of Work. Risks must be identified, and mitigation plans should be included in the proposal for all high risks.

Cost and Schedule

The City of Mesa Cerveza is prepared to issue bonds totaling up to $900 Million (2023 dollars) for the necessary new power and water sources, infrastructure, and technology needed to secure and guarantee the necessary supply of power and water to the city to meet its needs through the year 2050. This cost cap does not include maintenance and operations costs, which come from a separate budget line item and will be addressed separately outside of this proposal. The city has plans to pay for these bonds through the sale of land to developers and other planned offset mechanisms.

The new sources, infrastructure, and technology for the comprehensive power and water solutions must be in place no later than 2030. Incremental upgrades and planned capacity increases are acceptable between the years 2030 and 2050 if they are planned and within the cost cap.

If the proposed total solution costs more than $900 Million, the City can place additional bond measures on a public ballot, which could result in increased sales or property taxes to residents. Residents have historically not approved these kinds of measures. Additionally, placing bonds on the public ballot creates political risk to any members of the City Council that endorses it, so this route is generally not preferred.

Population Growth

The City of Mesa Cerveza is expected to approximately double in population by the year 2050.

Table 1 shows the estimated population growth.

Table 1: Estimated Population Growth

Year	Population	# of Households
2019	310,125	103,375
2020	325,500	108,500
2025	363,000	121,000
2030	395,000	131,667
2035	430,000	143,333
2040	478,000	159,333
2045	543,000	181,000
2050	610,000	203,333

Annexable Land

The city has identified three parcels of land that can be annexed to meet the anticipated residential growth. These are shown in Table 2. The average household in the City of Mesa Cerveza has 3 people. The City has included in its Master Plan annexing each parcel as the population growth necessitates it. Based on a medium density dwelling units per acre of 5, these plots are sufficient to meet the anticipated population growth. The City will execute the annexation process for each plot as needed to ensure that new housing developments are available in lockstep with the anticipated population growth to keep housing affordable. Fees collected from developers will be used by the city to partially offset the cost of the planned bond sales to fund the water and power capacity expansion.

Table 2: Annexable Land Plots

Annexable Plots	Acres	Medium Density Home Load	Owner 2023
P1	7,560	37,800	State of Arulo
P2	6,890	34,450	State of Arulo
P3	5,574	27,870	U.S. Bureau of Land Management
Total	20,024	100,120	

Water Needs

The City has calculated, based on historical usage, that the average amount of water consumed per resident per day is 146 gallons. This average includes household cleaning (clothes washer, dishwasher, etc), faucets, showers and baths, toilets, and outdoor usage (landscaping, pools, leaks, etc). The fraction of water used for residential purposes is 45% with the remainder going to commercial and municipal usages. Table 3 summarizes the water needs of the City by year based on estimated population growth.

Table 3: Estimated Water Needs Based on Population Growth

	Water Needs		
Year	Residential [acre ft]	Commercial [acre ft]	Total [acre ft]
2019	50,718	61,989	112,707
2020	53,233	65,062	118,295
2025	59,365	72,558	131,923
2030	64,599	78,954	143,552
2035	70,323	85,950	156,272
2040	78,172	95,544	173,717
2045	88,803	108,537	197,339
2050	99,760	121,929	221,689

Existing Negotiated Water Allocations

The City has existing negotiated water allocations from two primary sources: the Wymore Reservoir and the Central Arula Project (CAP) Canal Allocation. The allocations, at present, are sufficient to meet the city's needs; however, they will not be sufficient in future years. At the end of 2022, 60% of its water supply comes from Wymore Reservoir, with the remaining water coming from the Central Arula Project (CAP) canal, which transports Arula's allotment of Ute River water to municipalities throughout the state. However, historic reductions in the Ute River's water level have led to all of the western states agreeing to reduce their allotments starting in 2030. In 2030, Mesa Cerveza's allocation of CAP water will be reduced from 50,000 acre ft per year to 46,000 acre ft per year. In the same year, the city's allocation of water from Wymore Reservoir will be reduced from 75,000 acre ft per year to 70,000 acre ft per year. Additionally, due to the local residents' strong desire to maintain Wymore Reservoir's water levels for recreational activities and for the benefit of future generations, the City of Mesa Cerveza has set a goal of reducing its take by an additional 5,000 acre ft per year in 2030 (for a total goal take of 65,000 acre feet in 2030 and future years). Table 4 summarizes the City's negotiated water source allocations as well as the City's goals to reduce the take from Wymore Reservoir.

Table 4: Negotiated Water Source Allocations and Goal Takeaways

Year	Wymore Resevoir Allocation [acre ft]	Central Arula Project Canal Allocation [acre ft]	Total [acre ft]	Mesa Cerveza Goal Take from Wymore Resevoir [acre ft]
2019	75,000	50,000	125,000	75,000
2020	75,000	50,000	125,000	75,000
2025	75,000	50,000	125,000	75,000
2030	70,000	46,000	116,000	65,000
2035	70,000	46,000	116,000	65,000
2040	70,000	46,000	116,000	65,000
2045	70,000	46,000	116,000	65,000
2050	70,000	46,000	116,000	65,000

Two other lakes exist within the broader vicinity of Mesa Cerveza: Pine Bluff Lake, located 43 miles north of the center of Mesa Cerveza, and Torta Lake, located 31 miles to the east of Mesa Cerveza. The water in these lakes is controlled by regional water management districts. It is possible to negotiate water takes from either reservoir; however, transportation solutions to the city must be included in the solution proposal. Table 5 summarizes the available water take from each lake as well as the cost of the water per acre foot.

Table 5: Additional Water Sources and Associated Water Costs

	Pine Bluff Lake		Torta Lake	
Year	Available Take [Acre Foot]	Cost [Per Acre Foot]	Available Take [Acre Foot]	Cost [Per Acre Foot]
2019	20,000	$80	100,000	$80
2020	20,000	$100	100,000	$100
2025	20,000	$100	100,000	$100
2030	20,000	$150	100,000	$150
2035	20,000	$150	100,000	$150
2040	20,000	$180	100,000	$180
2045	20,000	$180	100,000	$180
2050	20,000	$250	100,000	$250

Water Treatment

The City of Mesa Cerveza's existing water treatment plant, used to ensure that all water distributed to customer end points meets potability requirements, has a capacity to treat up to 170,000 acre feet of water per year. However, the City has planned to upgrade its capacity to 225,000 acre feet of water per year by the year 2030. This upgrade is budgeted and included in the City's Master Plan. This proposal does not need to include the cost of this upgrade.

Power Needs

The average City of Mesa Cerveza household consumes 14,230 kWh per year. Households consume 40% of the total power within the City with the remainder being consumed by commercial and municipal entities. Table 6 summarizes the power needs of the City by year based on estimated population growth.

Table 6: Estimated Power Needs Based on Population Growth

	Power Needs		
Year	Residential [kWh]	Commercial [kWh]	Total [kWh]
2019	1,471,026,250	2,206,539,375	3,677,565,625
2020	1,543,955,000	2,315,932,500	3,859,887,500
2025	1,721,830,000	2,582,745,000	4,304,575,000
2030	1,873,616,667	2,810,425,000	4,684,041,667
2035	2,039,633,333	3,059,450,000	5,099,083,333
2040	2,267,313,333	3,400,970,000	5,668,283,333
2045	2,575,630,000	3,863,445,000	6,439,075,000
2050	2,893,433,333	4,340,150,000	7,233,583,333

Existing Negotiated Power Allocations

Currently, the City of Mesa Cerveza obtains all its power from the Ron Swanson Memorial Dam & Power Station. Extreme drought has resulted in Wymore Reservoir dropping to just 24% of its typical levels at the end of 2022. The turbines at Ron Swanson Power Station, with a rated capacity of 1,000 MW, can only operate at 53% of their full power due to the low water level. With the municipal agreements in place with the Power Station to reduce water takes in the future, the Ron Swanson Power Station predicts that the turbines can operate at the current efficiency of at least 53% moving forward for the long term. Currently, the City of Mesa Cerveza is contracted with the Ron Swanson Power Authority to obtain 83% of the power produced with most of the remaining power going to the beach community of Playa del Caprica. Table 7 summarizes the power allocation for the City of Mesa Cerveza from the Ron Swanson Power Station.

Table 7: Negotiated Power Allocation from Ron Swanson Power Station

Ron Swanson Power Station		
Rated Capacity	1000	MW
Hrs working a Day	24	Hrs
Rated Capacity in MWh	24000	MWh
Rated Capacity in kWh/yr	8,760,000,000	kWh/yr
Operating Capacity Percentage	0.53	
Operating Capacity	4,642,800,000	kWh / yr
Mesa Cerveza Allocation %	0.83	
Mesa Cerveza Power Allocation (2020-2050)	3,853,524,000	kWh / yr

APPENDIX A – Formulas and Assumptions for the Competition

Water

- Conversion of gallons to acre ft

$$325851.4272141 \text{ gallons} = 1 \text{ acre ft}$$

- Cost to build an aqueduct:
  - $12M per mile

- Evaporation loss from aqueduct
  - 4.5%

APPENDIX B – Possible Technology Solutions to Consider if You Get Stuck

Water Sources

- Desalination Plant
- Negotiate water allotment from nearby lakes + build canals to transport water to the city
- Negotiate an increased allotment from the Central Arula Project canal
- Water collection from air in the desert
    - https://www.scientificamerican.com/article/portable-oasis-extracts-water-from-dry-desert-air/
    - https://aquaria.world/
- Water catchment systems
- Increased grey water usage to reduce dependency on potable water
- Water conservation and usage reduction incentives

Power Generation

- Solar farms
- Concentrating Solar Tower (https://www.scientificamerican.com/article/new-concentrating-solar-tower-is-worth-its-salt-with-24-7-power/)
- Wind farms
- Small modular nuclear reactors
- Cover canals with solar panels – also helps reduce water loss from evaporation

References

The following references have been used to justify and validate the values and numbers used in the problem statement:

- Cost to Build an Aqueduct in Arizona: https://www.phoenixmag.com/2018/11/01/arizona-s-long-straw/
- Evaporation from an Aqueduct in Arizona: https://www.cap-az.com/about/faq/#:~:text=How%20much%20water%20is%20lost,acre%20feet%20from%20Lake%20Pleasant.
- Colorado River Water Allocations: https://www.nps.gov/lake/learn/sharing-the-river.htm
- Central Arizona Project (CAP) Water Allocation to Representative City: https://www.kold.com/2022/05/20/tucson-votes-give-up-some-its-cap-water-help-save-lake-mead/
- Residential sector fractional energy usage: https://rpsc.energy.gov/energy-data-facts
- Residential power usage in Phoenix: https://www.electricitylocal.com/states/arizona/phoenix/
- Hydroelectric power impacts on low reservoir water levels: https://www.vox.com/23292669/drought-2022-power-energy-grid-lake-mead-climate-heat-hoover-dam
- Hydroelectric sector fractional energy usage: https://www.8newsnow.com/news/local-news/hoover-dam-power-production-down-33-official-says/
- Hydroelectric sector fractional energy usage: https://wrrc.arizona.edu/drought-diminishes-hydropower