SAND2019-8320PE

Long-Term Water Viability at Palo Verde Generating Station

Bobby Middleton, PhD, PE

Sandia National Laboratories

Advanced Nuclear Concepts Department

06/06/2019

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Presentation Outline

- Background on Palo Verde (PV) Water Use and Efforts to Reduce Future Water Footprint
- Background on Sandia National Labs' (SNL) Waterless Thermoelectric Power Program
- History of Current SNL/PV Collaboration
- Current Modeling Efforts (Phase 1)
- Future Plans

Background on Palo Verde

Construction began on PV in 1976

Unit 1's license was issued on 06/01/1985

Current license for Unit 3 expires 11/25/2047

Largest producer of electricity in US, by net production (~32.5 GWh/yr)

All 3 units are licensed for 3990 MWt

In 1970, Phoenix metro population was ~ 1.0 Million

In 2017, Phoenix metro population was ~4.7 Million

Water is much more expensive now than during planning phases of PV Generating Station.

Background on Palo Verde

Palo Verde is already a leader in conscientious water use.

- Only nuclear plant to use reclaimed water for cooling.

Palo Verde water use totals ~75,000 AF/yr (Evap, BD, Drift, other)

- ~ 95% is evaporated to cool the plant.
- ~ 5% is blowdown, drift, etc.
- Most of this water is obtained from the 91st AVE WWTP.
- Current license guarantees up to 80,000 AF/yr of water through 2050, but…
  - Costs increasing each year.
  - Go to a tiered structure in 2026 that will make water even more expensive if PV does not decrease water use, especially in summer months.
  - If owners decide to apply for license extension, water contract would have to be renegotiated as well.

Palo Verde's Tertiary Treatment Process

Water is piped in from various sources.
- Magnesium is typically higher in winter months.
- Chlorides are typically higher in summer months.

1st Stage Clarifiers
- Addition of Lime to reduce Magnesium and Silica.

2nd Stage Clarifiers
- Addition of Ash and CO2 to reduce Calcium.

Gravity Filters
- Addition of Sulfuric Acid to lower pH to prevent scaling in CTs.
- Addition of Hypochlorite to prevent organic growth in CTs.

Palo Verde's Cooling Loop

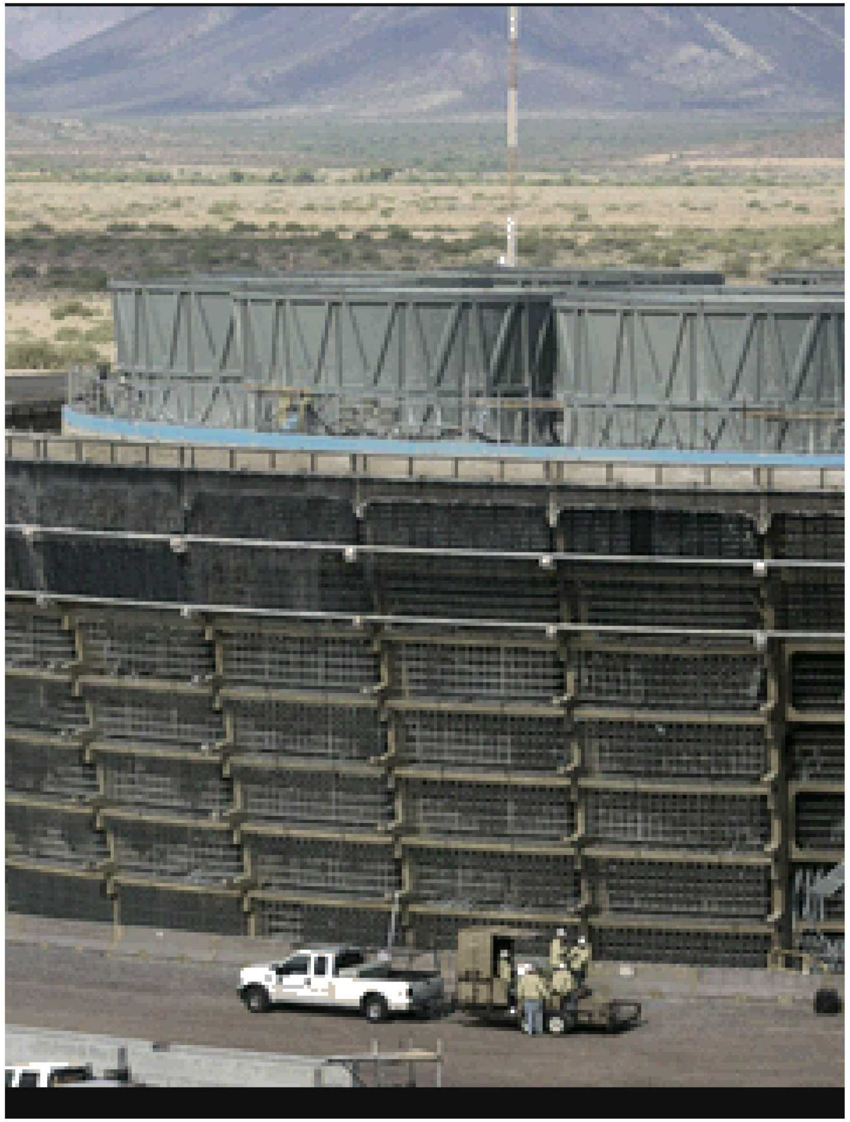
Each of Palo Verde's 3 reactors needs to reject ~2600 MW of heat.

- (~7800 MW total).

Each reactor is fitted with 3 Marley Class 700 evaporative cooling towers.

- ~ 186,000 GPM Circulating Water flow for each tower.
- Design range of 32° F.
- TDS limit of 30,000 ppm.
- Makeup water from Tertiary treatment plant of ~1100 ppm.

Recent maintenance makes it probable that all 9 cooling towers will survive til end of life of plant.



Blowdown and Evaporation Pond Disposition

Blowdown is ~ 650 GPM/Reactor (~2000 GPM for plant) on average.
- TDS ~30,000 ppm.

Since Palo Verde is a Zero-Liquid-Discharge (ZLD) plant, PV has 650 acres of evaporation ponds to contain BD as it evaporates.

Ponds are lined to ensure salts have no pathway to entering groundwater.

Degradation of pond lining over time will require re-lining.
- A tentative schedule for re-lining is in place.
- Under some scenarios, adequate capacity for storage of BD may not exist in the future.
- If adequate evap pond capacity is not available, this could entail required construction of a new pond.

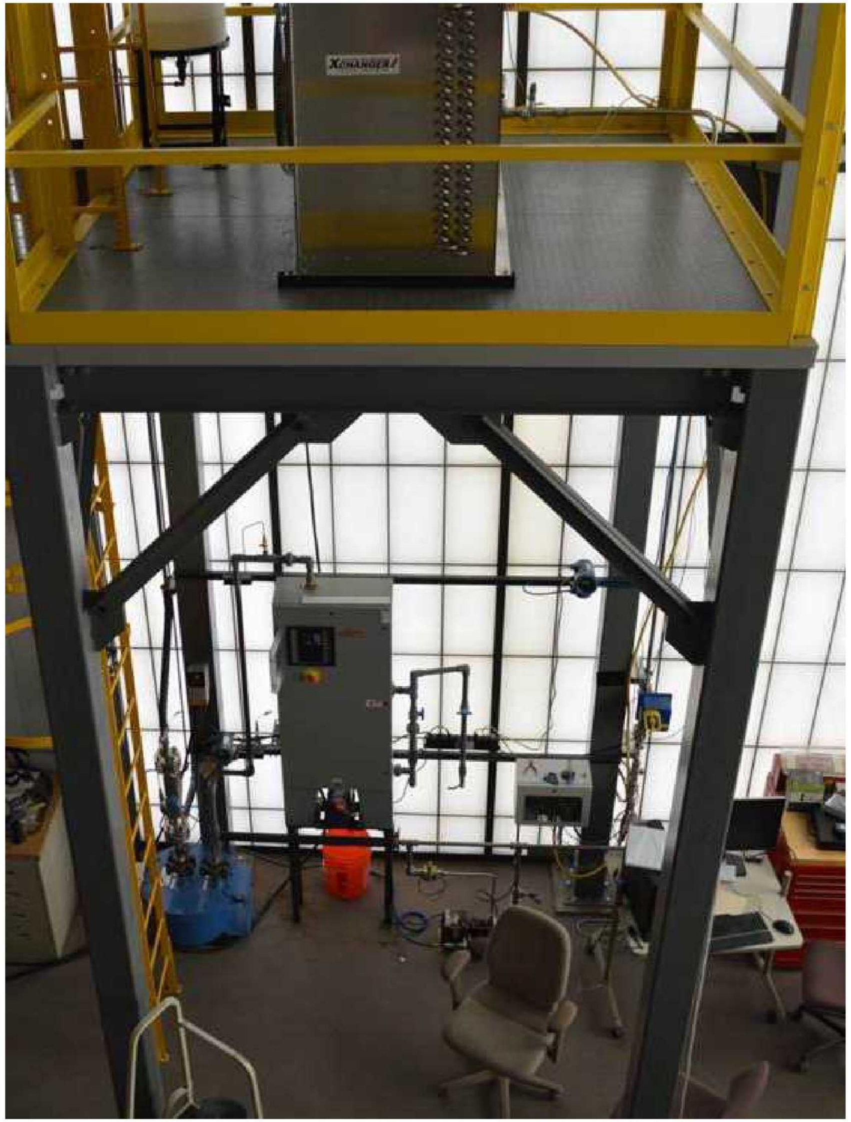
Sandia's Waterless Thermoelectric Power Program

Began with internally funded project (LDRD) to determine viability of a sCO2 waste heat rejection system for SMRs (2012-2015).

From this, a patent application was submitted (awarded in December, 2018).

Currently have around 20 patents, patent applications, technical advances, etc., related to water savings and water treatment.

Prior to this program, Sandia has over 30 years of history related to water programs, with some of the world's leading experts in water conservation and water treatment.



Current SNL/PV Collaboration

Aug. 2016
Presentation to PWROG in Las Vegas, NV

Apr. 2017
Invited to APS HQ to discuss Palo Verde's Long-Term Water plans with Palo Verde personnel.

2017
Multiple follow-on discussions throughout 2017.

Jan. 2018
Initial funding from APS/PV in January, 2018.

Summer, 2018
Phase 1, Part 1 completed Summer, 2018.

Oct. 2018
Phase 1, Part 2 began October, 2018.

Summer, 2019
Wrapping up Phase 1 mid-Summer, 2019.

Phase 1: PVWCM

Coupled Water Treatment, Heat Transfer, Evaporation, Economics Model

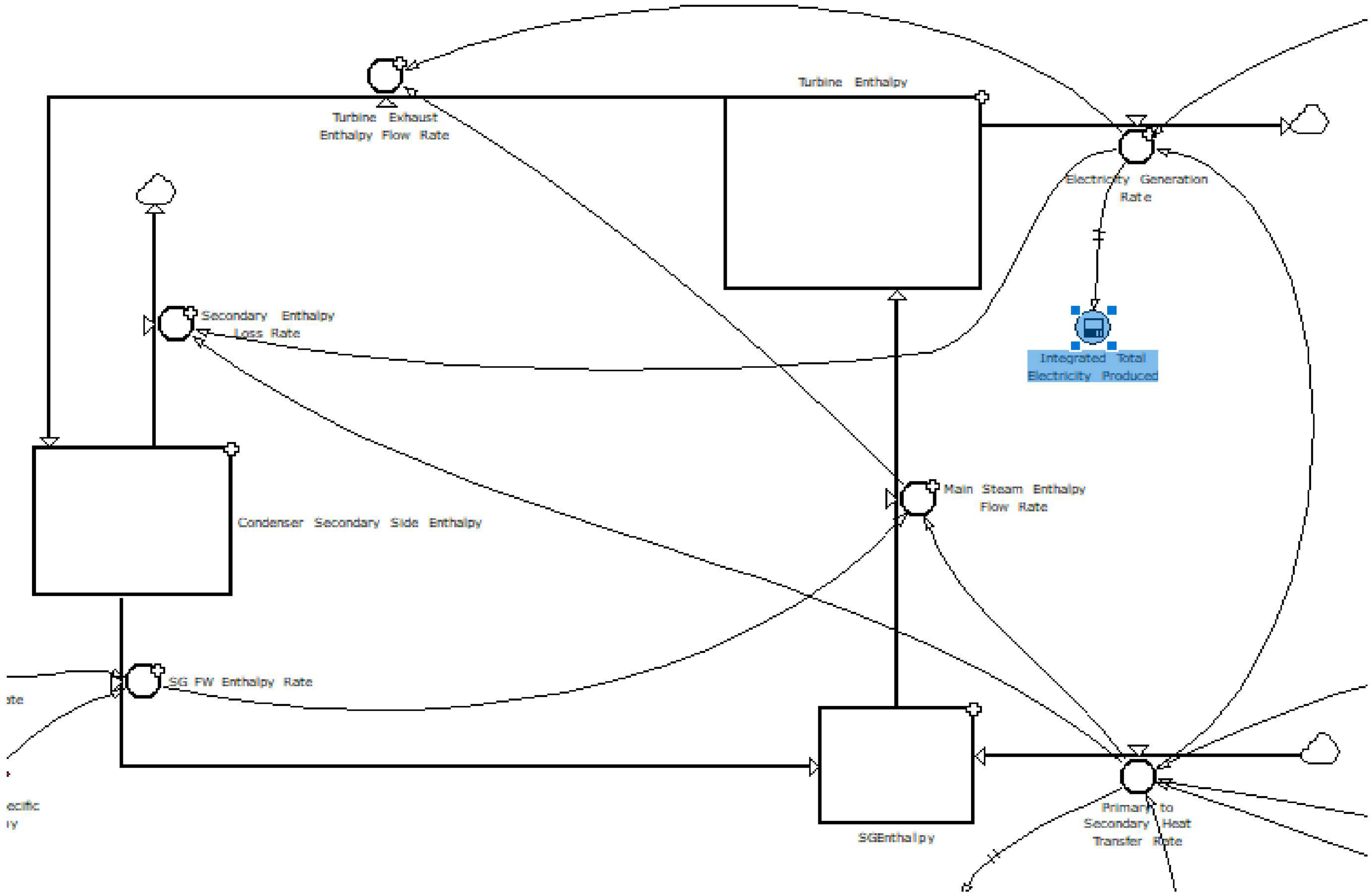
Uses System Dynamics (PowerSim Studio Software) to solve coupled ordinary differential equations describing:

- Water Mass Flow – Tracked from source through Tertiary Treatment, to Cooling Loop as Makeup, to evaporation in Cooling Towers or to Blowdown to Evaporation Ponds, then evaporated (using Penman Monteith model).
- Heat Flow – From reactors to Cooling Loop through condensers, then to evaporation or loss to ambient.
- Chemistry Balances – 20 chemical species tracked from water source to evaporation ponds.
- Economic Impacts – Water, chemicals, labor, power, residuals, and options; both actual and NPV.

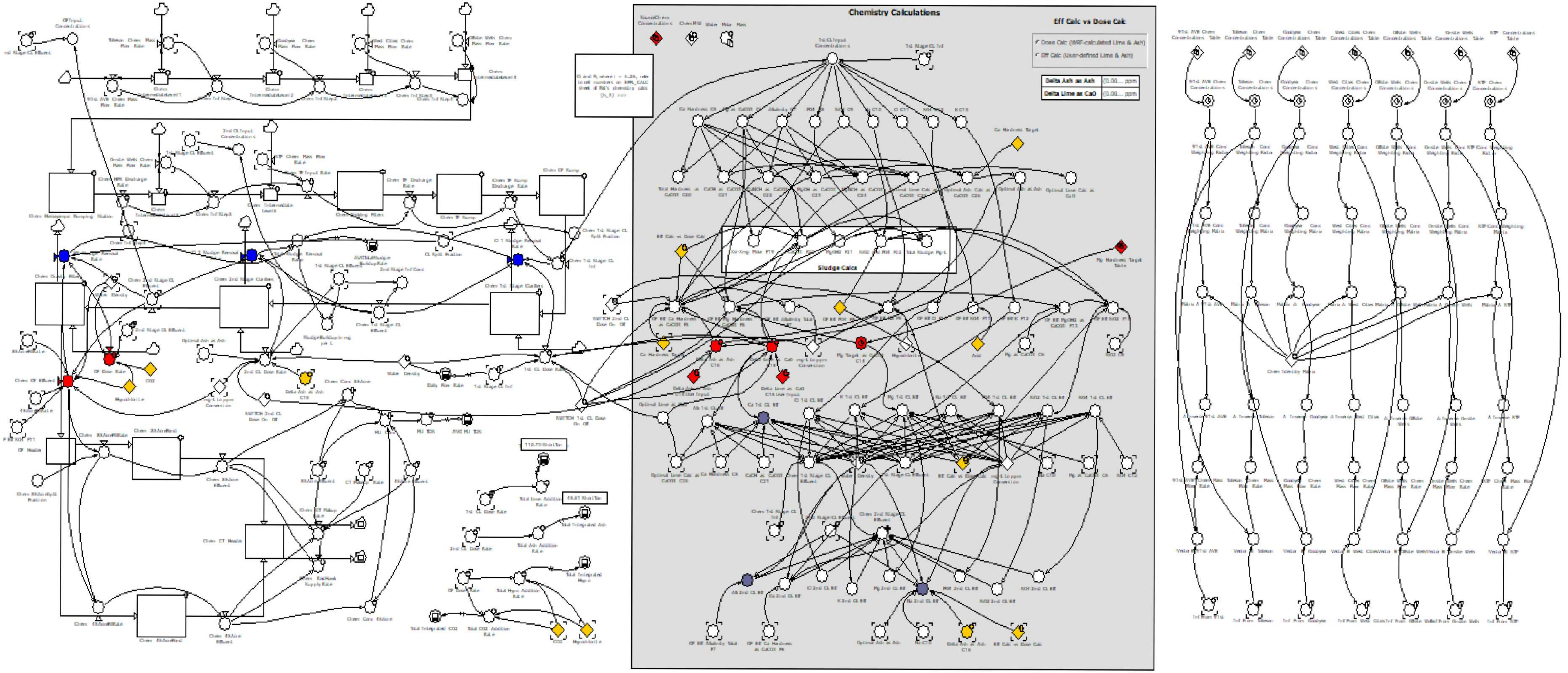
Uses VBA to store output for selected variables.

- Allows us to compare up to 6 runs simultaneously.

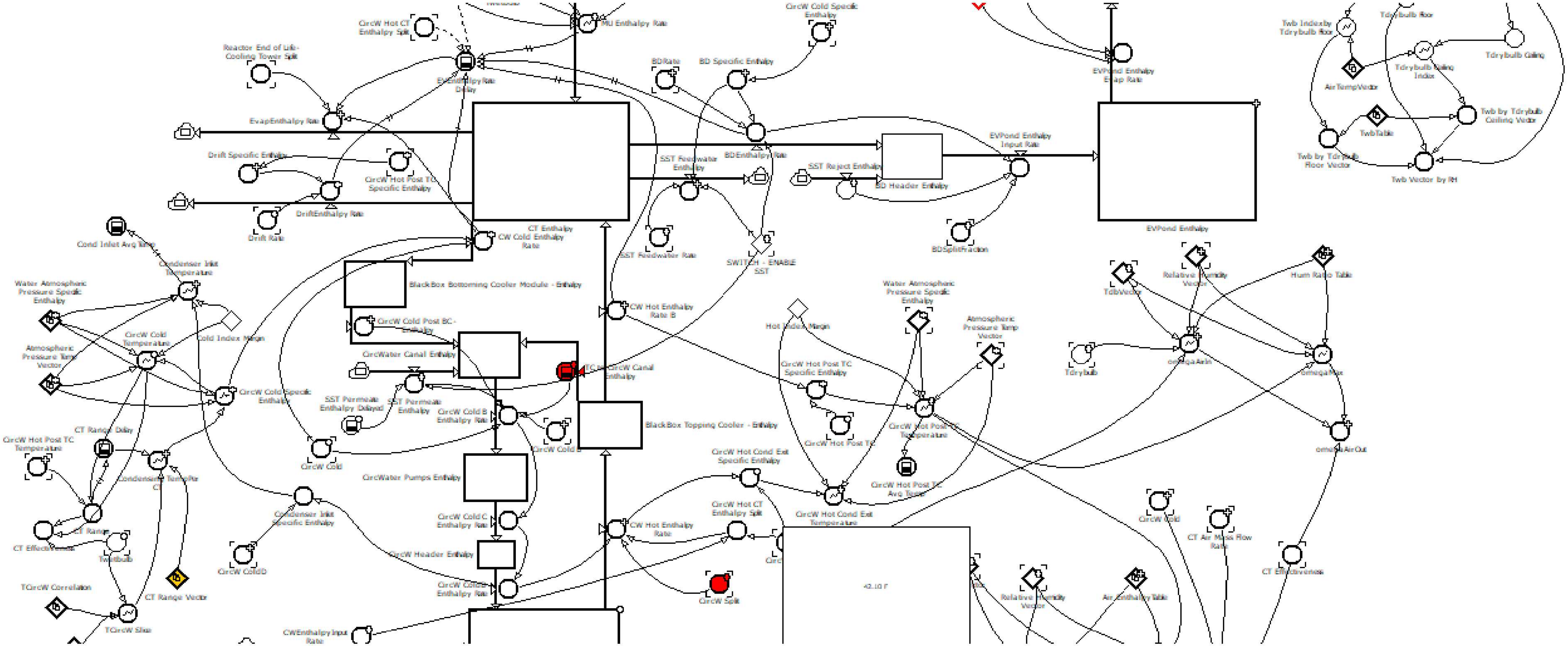
Power Conversion Loop



Tertiary Treatment



Cooling Loop



Topping Cooler

Placed after condenser and before cooling towers to remove top heat sensibly and decrease waste heat that needs to be rejected via evaporation.

- Reduces water evaporated.
- Increases CoC.
- Decreases blowdown.
- Decreases water to evaporation ponds, thereby increasing their effective lifetime.
- Dry heat rejection is expensive.
- Palo Verde is in a HOT climate.

Next Steps

- Optimize the economics.
- Combine with load shifting mechanism (PCM, etc.)

Bottoming Cooler

Bottoming Cooler – Placed after cooling tower and before condenser to cool the water sensibly before it is heated with reject heat from power conversion loop.

- Reduces water evaporated.
- Increases CoC.
- Decreases blowdown.
- Decreases water to evaporation ponds, thereby increasing their effective lifetime.
- Dry heat rejection is expensive.
- Palo Verde is in a HOT climate.
- Chilling can be very expensive.

Next Steps

- Optimize the economics.
- Combine with load shifting mechanism (PCM, etc.)

Blowdown Slipstream Treatment

Blowdown Slipstream Treatment – Allows a portion of blowdown to be treated via various mechanisms (RO, FO, others?).

- Decreases blowdown
- Decreases water to evaporation ponds, thereby increasing their effective lifetime.
- Economics are uncertain at this point.

Next Steps

- Understand economics.
- Combine with other options to see effects.

Manual Dosing

Currently, the Lime and Ash doses are modeled to provide:

- Pre-determined pH.
- Pre-determined Mg.
- Pre-determined Ca.

The Manual Dosing option allows a user to deviate from the optimum dosing of Lime and Ash to see what the effects would be on the plant and costs.

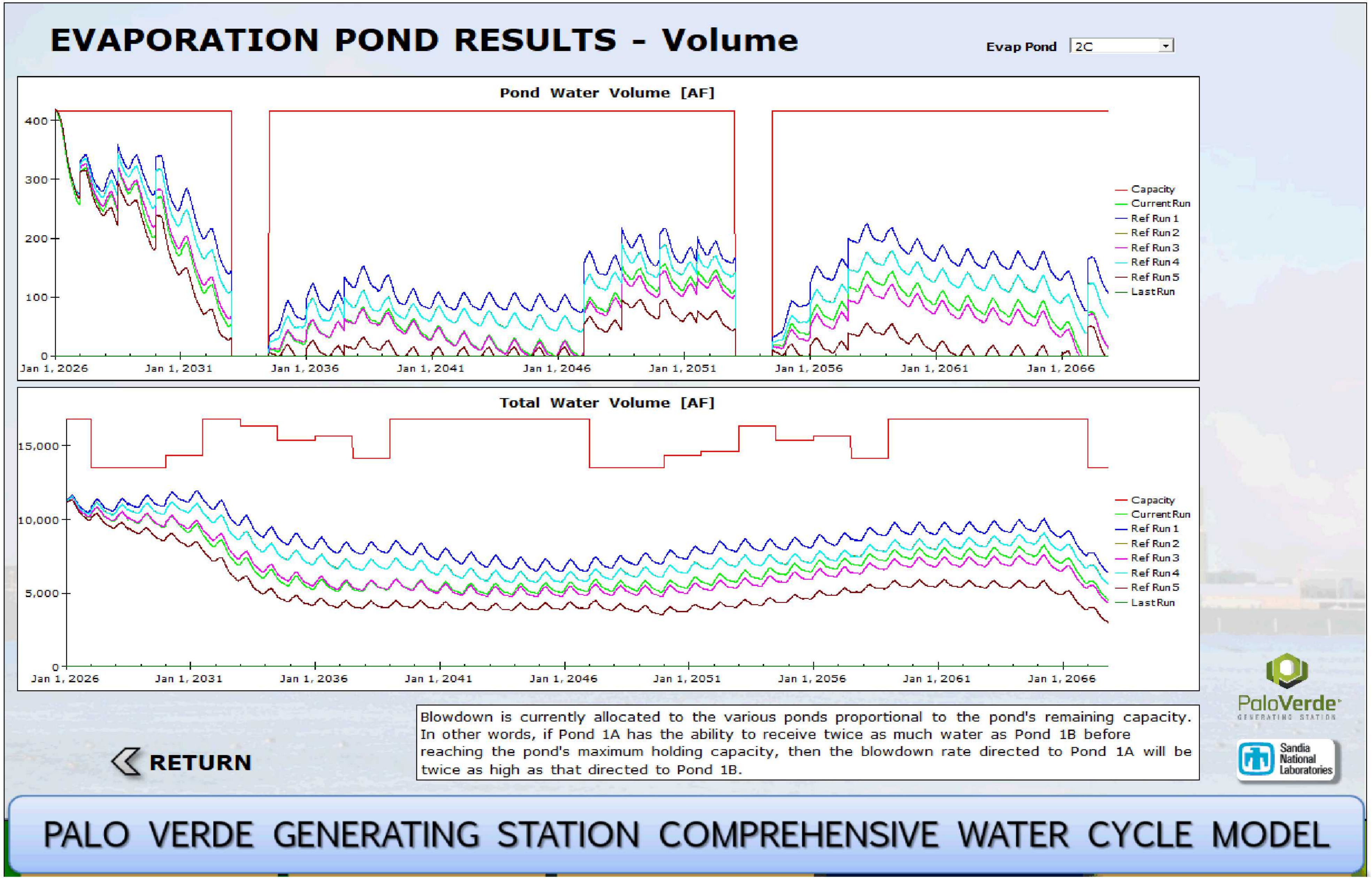
- Limited to about a 20% deviation.
- Assumes that some level of understanding of the chemistry is known by the user.

Representative Model Results

The next few slides are REPRESENTATIVE of model capabilities only.

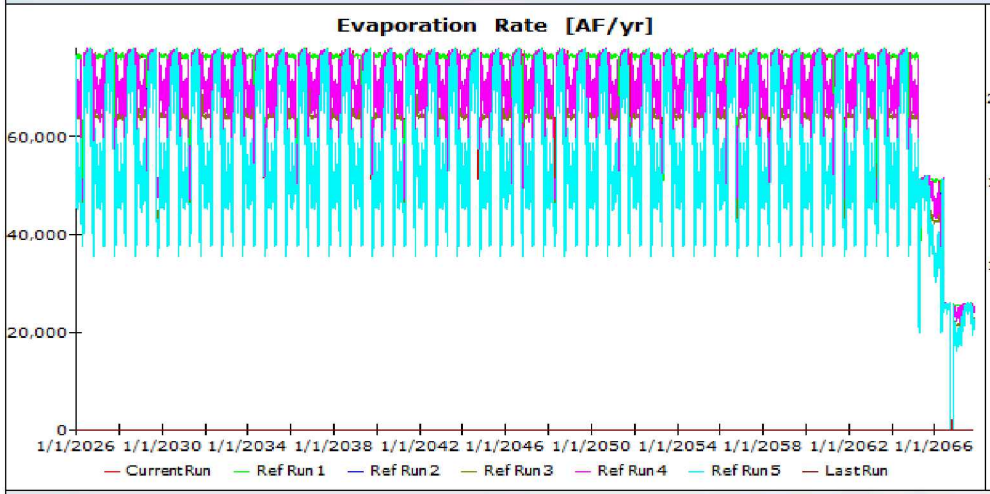
They are not meant to portray any actual cost or performance comparisons for any realistic scenarios.

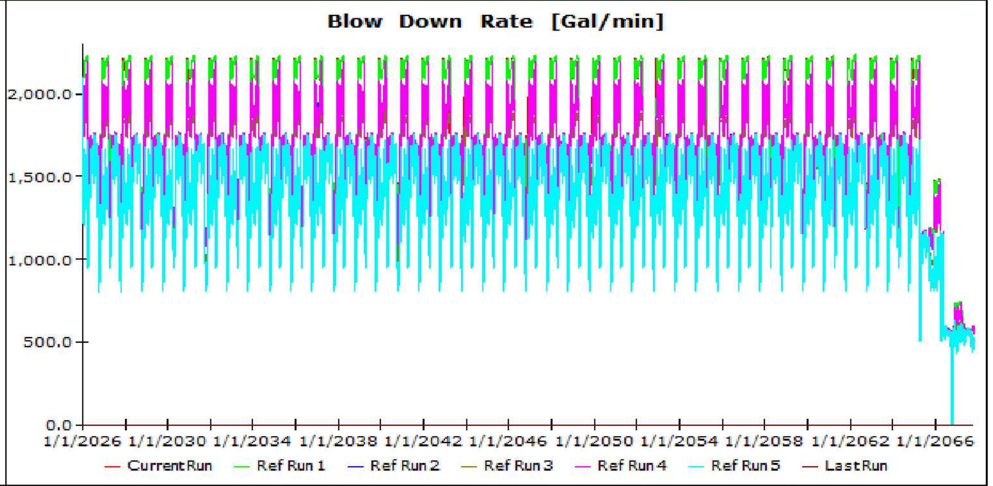
Evaporation Pond Levels



Water Use Results

WATER USE RESULTS





Evaporation Rate [AF/yr]

Current Simulation

	CT 1	CT 2	CT 3	Reactor	Running AVG
Unit 1	0.00	0.00	0.00	0.00	22,680.91
Unit 2	0.00	0.00	0.00	0.00	23,343.86
Unit 3	8,535.57	8,535.57	8,535.57	25,606.72	24,119.28

Reference Simulation

	CT 1	CT 2	CT 3	Reactor	Running AVG
Unit 1	0.00	0.00	0.00	0.00	18,223.52
Unit 2	0.00	0.00	0.00	0.00	18,770.62
Unit 3	6,764.39	6,764.39	6,764.39	20,293.16	19,465.37

Blow Down Rate [Gal/min]

Current Simulation

	CT 1	CT 2	CT 3	Reactor	Running AVG
Unit 1	0.00	0.00	0.00	0.00	561.19
Unit 2	0.00	0.00	0.00	0.00	577.46
Unit 3	194.41	194.41	194.41	583.24	596.12

Reference Simulation

	CT 1	CT 2	CT 3	Reactor	Running AVG
Unit 1	0.00	0.00	0.00	0.00	440.00
Unit 2	0.00	0.00	0.00	0.00	453.14
Unit 3	154.90	154.90	154.90	464.70	469.64

Choose Reference Simulation: Ref Run 5

RETURN

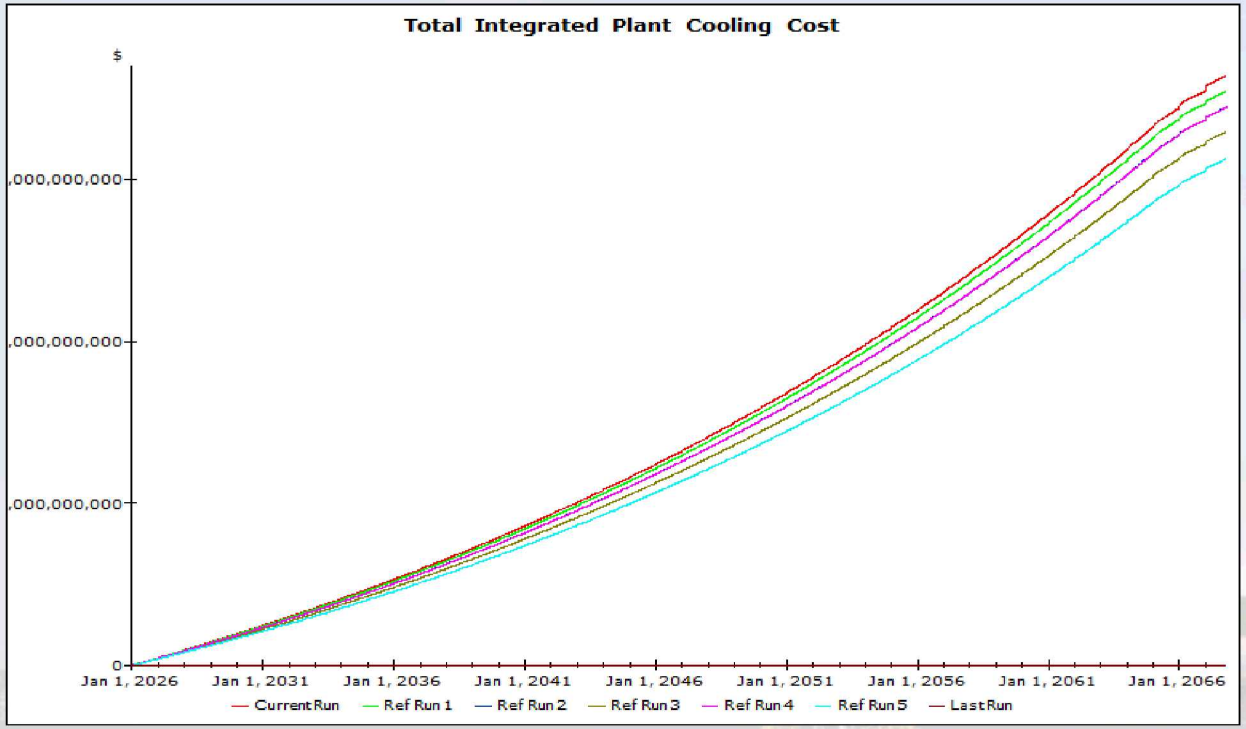
PaloVerde GENERATING STATION

Sandia National Laboratories

PALO VERDE GENERATING STATION COMPREHENSIVE WATER CYCLE MODEL

Costs

FINANCIAL RESULTS - Actual Costs (Simulation Lifetime Totals)



Actual Cooling Cost Comparison

Plant Lifetime Cooling Costs (In Actual Dollars)

Current Run	3,642,651,230.29 $
Ref Run 1	3,547,957,567.42 $
Ref Run 2	3,447,612,540.96 $
Ref Run 3	3,296,789,987.78 $
Ref Run 4	3,446,688,718.38 $
Ref Run 5	3,129,671,309.09 $

Plant Life

Unit 1	82.00
Unit 2	81.00
Unit 3	80.00

Option OPEX 0.00 $

Option CAPEX 0.00 $

Lifetime Total Savings

Choose Reference (Below): Ref Run 5

	WRF Water Supply Cost	WRF Chemical Cost	WRF Labor Cost	WRF Electricity Cost	WRF Residuals Cost	WRF Total Cost
Current	1,682,811,587.53 $	686,966,599.59 $	744,001,806.57 $	103,727,347.13 $	425,143,889.47 $	3,642,651,230.29 $
Reference	1,318,515,078.02 $	558,218,290.96 $	743,991,971.33 $	83,807,699.44 $	425,138,269.33 $	3,129,671,309.09 $

RETURN

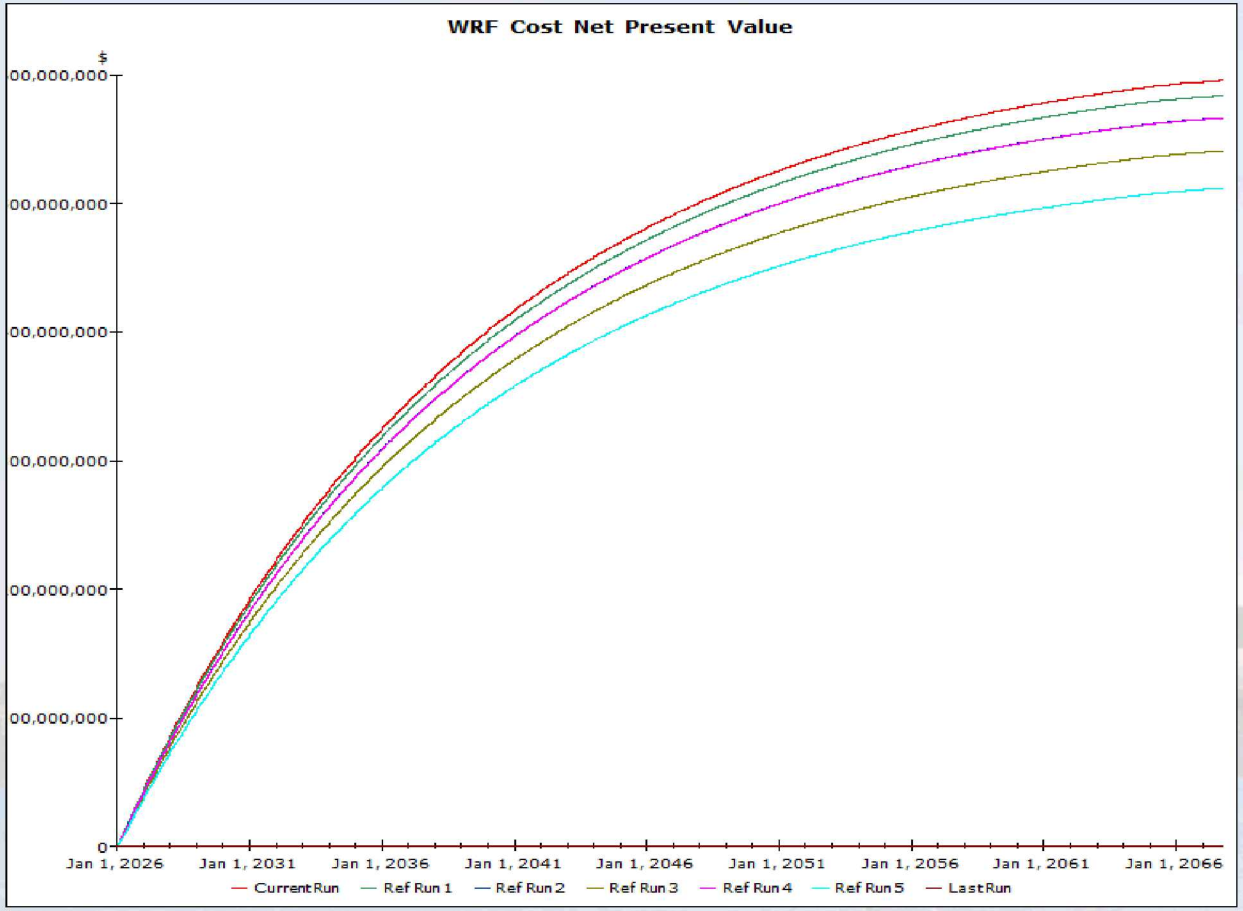
PaloVerde GENERATING STATION

Sandia National Laboratories

PALO VERDE GENERATING STATION COMPREHENSIVE WATER CYCLE MODEL

NPV Costs

FINANCIAL RESULTS - NPV (Simulation Lifetime Totals)



Net Present Value Cost Comparison

Plant Lifetime Cooling Costs	Current Run	596,067,318.16 $
	Ref Run 1	584,066,921.47 $
	Ref Run 2	566,674,180.47 $
	Ref Run 3	540,851,038.28 $
	Ref Run 4	566,508,823.52 $
	Ref Run 5	511,845,664.93 $
In Current Dollars for Year		2026
Discount Rate		10.20 %/y
Plant Life	Unit 1	82.00
	Unit 2	81.00
	Unit 3	80.00
Lifetime NPV Savings*		-84,221,653.23 $
Choose Reference to Compare		Ref Run 5

*Savings reflect the current simulation vs. the chosen reference run, assuming the reference as baseline.

PaloVerde GENERATING STATION

Sandia National Laboratories

« RETURN NPV SAVINGS »

PALO VERDE GENERATING STATION COMPREHENSIVE WATER CYCLE MODEL

Next Steps

Finish Model Details

- 2 more chemistry options to be added.
- Checking details of topping cooler, bottoming cooler.
- Validate load-shifting options.

Complete Cooling and Chemistry Technologies Report.

Phase 2 (Tentative) – Down-select technology options to determine which offer best opportunities for Palo Verde.

Phase 3 (Tentative) – If Phase 2 is successful, testing of down-selected technologies.

Questions?