National Institutes of Health (NIH) Bethesda Campus Central Utility Plant (CUP) Data-Driven Operational Excellence

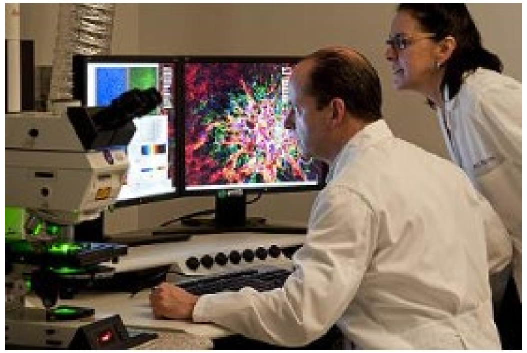
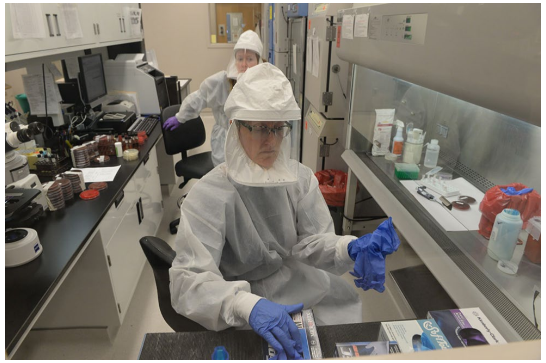
Dan Wheeland, P.E.

Director, Office of Research Facilities

National Institutes of Health

National Institutes of Health

- An Operating Division of the U.S. Department of Health and Human Services, NIH is the nation’s medical research agency — making important discoveries that improve health and save lives.
- Annual funding ~ $37 billion
- 27 biomedical research institutes
- Sites in Maryland, Montana and North Carolina

NIH National Institutes of Health
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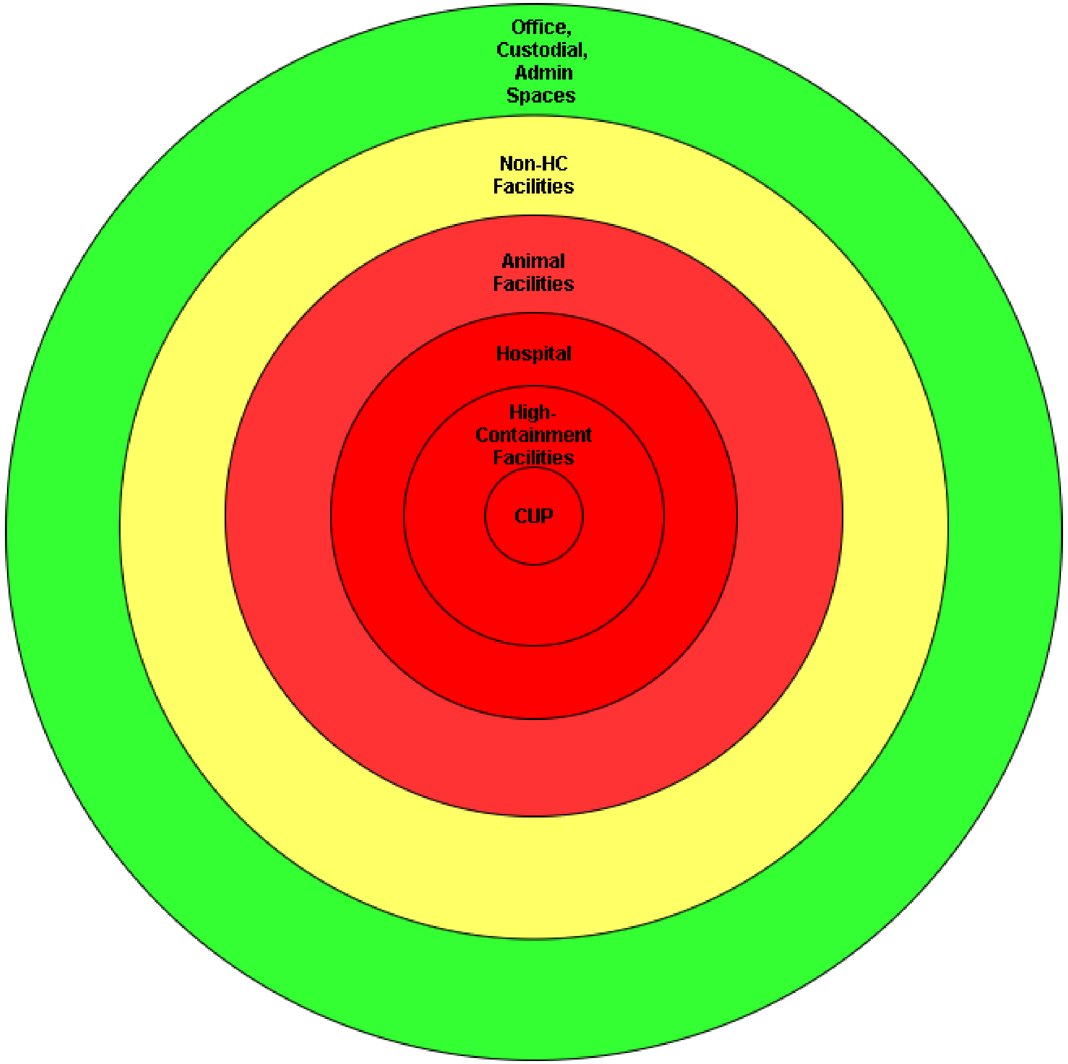
NIH's Bethesda Campus

- 75 buildings over 300 acres
- Total area~12 million sf, many state-of-the-art biomedical research facilities
- 240-Bed Research Hospital, including Special Clinical Studies Unit
- Research Labs, some housing infectious disease research
- Research Animal Housing
- One-pass air for biosafety
- Clean rooms for cell therapy, drug compounding, intravenous admixtures tailored to unique patient needs
- High Performance Data Center

What Makes NIH CUP So Special?

- Reliability is crucial for the mission critical spaces served
  - High Containment Facilities
  - Research Labs
  - Animal facilities
  - World Renowned Research Hospital

NO CUP = NO FUNCTIONING NIH



Organizational Alignment and Priorities

- Prior to 2014, the CUP was managed by the Division of Facilities Operation, which placed pressure on Building Maintenance leadership to balance the needs of customers with the needs of the CUP; over time, customer demands were causing the CUP to be neglected.
- In 2014, we reorganized in a manner that Building Maintenance was led by one division and the CUP was managed by another; this seems to work better for NIH. It does, however, require that the two Divisions work well together. In practice, this resembles a typical utility provider – building owner relationship – utilities are provided up to the 5' line or meter.
- Pride, performance, professionalism and accountability seem to be enhanced when managers effectively align the workforce to the real property assets; alignment could be by building, building system, or a combination/matrix.
- Related: prior to 2014, the primary focus of the CUP was on meeting the cooling/heating demand (at any cost); there were no tangible goals regarding efficiency, a behavior which was reinforced by the budgetary environment that treated utilities as a non-discretionary bill that is not as heavily scrutinized as other budget areas. For example, on a hot day, 12 chillers were energized. Now, with new alignment, efficiency is a high priority.
- While the rest of this presentation is technical in nature, the organizational alignment, organizational priorities and performance measurement aspects are heavily related with these technical advances.

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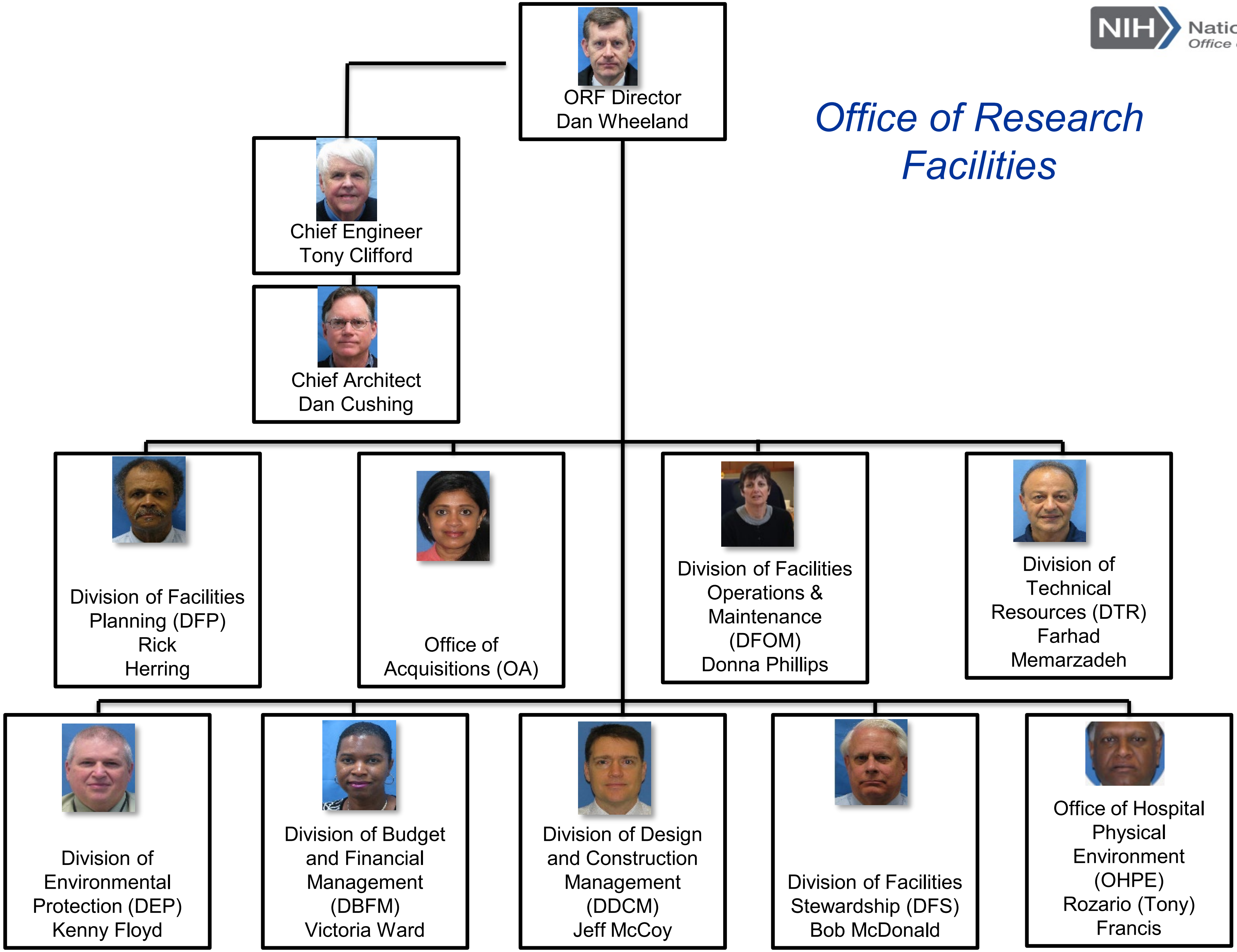

CUP Organizational Structure

Utility Systems Design and Technical Service Branch (HNAM967) Main Phone: 301-594-7123		
Haghjou, Marty	Branch Chief	301-402-7811
Abdelsalam, Amir	Mechanical Engineer	301-594-0118
Bear, Brenda*	Divsion of Technical Resources	301-881-3500
Bhuiyan, Abdul, PhD, PE	Supervisory General Engineer - Branch Chief USDTSB, DTR	301-451-4954
Blatzheim, Michael*	Division of Technical Resources	703-533-0039
Egan, John J.	Project Officer	301-451-6361
Fratangelo, John	General Engineer	301-451-1949
Lassise, Kevin*	Division of Technical Resources	301-881-5120
Lee, Shawn, PE	Electrical Engineer	301-402-3765
Luccese, Joseph*	Division of Technical Resources	717-814-5498
Muise, Ryan*	Divsion of Technical Resources	703-533-0039
Oberholzer, Raymond*	Division of Technical Resources	240-543-5724
Smalls, Wayne P.	Electrical Engineer	301-402-8135
Viering, Arthur*	Division of Technical Resources	301-339-5480
Wodka, Brian*	Division of Technical Resources	410-576-0505
Utilities Engineering Branch (HNAM965) Main Phone: 301-443-5680		
Guan, Don, PhD, PE	Branch Chief	301-443-5585
Battick, Kevin*	Division of Technical Resources	703-932-5261
Brugh, Timothy*	Division of Technical Resources	574-339-7310
Clifford, Brian	General Engineer	301-435-7335
Corey, Kayla		301-451-4469
Hu, Ping	Maximo Data Support	301-451-4478
Huang, Alex	Mechanical Engineer	301-451-1328
John, Brendan*		631-338-5338
Sreenivasan, Ram		301-443-5585
Tao, Ye*	Division of Technical Resources	269-982-2414
Torkashvan, Kayvan	General Engineer	
Yang, Andrew		240-204-1210
Utilities Generation Branch (HNAM964) Main Phone: 301-451-4478 Fax: 301-402-0401		
Nieves, Joseph D.	Branch Chief	301-451-4478
Warren, Sharon	Program Assistant	301-451-4469
Bentley, Bob		301-451-4995
Cooley, Robert		301-451-4469
Deng, Curtis	Student Trainee (Admin Support)	301-402-0375
Fox, Johnnie	Central Utility Plant Operation (Leader)	301-451-4493
Gordon, Joseph	Division of Technical Resources	301-429-1533
Gumapas, Leo, PE	Environmental Compliance Officer	301-832-4320
Hill, Terrance	Boiler Plant Operator	301-496-9040
Hughes, Casey*	Administrative Assistant - Technician - Clerk	301-827-6505
Lyon, Chris *		301-451-1188
Ma, Haitao	Engineer civil, mechanical	301-594-1124
Madden, Brian*	Division of Technical Resources	301-451-9398
Oormazdi, Armin		301-451-3998
Ramcharan, Shivan*	Purchaser, Inventory Control	301-451-4576
Ramcharan, Tiffany	Student Trainee (Admin Support)	301-402-0375
Showe, James		301-451-4494
Thomas, Ahmon	High Voltage Electrician	301-451-4469
Velazquez-Cruz, Daniel		
Wisehart, Eric	Maximo Administrator	301-402-0375

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CUP Organizational Structure (Continued)

Central Utility Plant Operation & Maintenance		
Mayberry, Donald	Chief (CUP) Operation and Maintenance	301-451-3593
Sadler, Dax	Mechanical Maintenance Supervisor	301-451-1188
Brewer, Anthony	Maintenance Mechanic (Boiler Leader)	301-451-4475
Cannon, Paul E.	Maintenance Mechanic	301-451-1188
Clark, Jamie	Maintenance Mechanic	301-451-1188
Duong, Cuong	Maintenance Mechanic	301-451-1188
Harrod, Anthony	Maintenance Mechanic	301-451-3593
Hawkins, Darrell	Maintenance Mechanic (Chill Leader)	301-451-1188
Martin, James M.	Maintenance Mechanic	301-451-4475
Messer, Timothy	Maintenance Mechanic	301-451-1188
Cogeneration Plant Operation Main Phone: 301-402-5522		
Prideaux, Michael*	(CRO) Control Room Operator	301-402-5522
Weibert, Scott*	Plant Manager	301-402-5522
CUP Operation & Maintenance (Shift A)		
England, Milton	Boiler Plant Operator (Supervisor)	301-451-4489
Pickens, Benjamin C.	Boiler Plant Operator (Leader)	301-451-4489
CUP Operation & Maintenance (Shift B)		
Jones, Brian	Boiler Plant Operator (Supervisor)	301-451-4493
CUP Operation & Maintenance (Shift C)		
Reid, Darius	Boiler Plant Operator (Supervisor)	301-451-4492
Washington, Edward	Boiler Plant Operator (Leader)	301-451-4494
Cooke, Kelvin E.	Central Utility Plant Operation	301-451-4475
Fuqua, Larry A.	Boiler Plant Operator Supervisor	301-451-3593
Utilities Control & Instrumentation Section Main Phone: 240-507-3290		
Vergara, Andres	Chief Utilities Control and Instrumentation Section	301-451-3527
Belcher, John	Instrument Lab (Supervisor)	301-451-4476
Armstrong, Joseph	High Voltage Electrician	301-451-3527
Asano, Tiyo	Division of Technical Resources	301-451-3527
Foye, Glenwood	High Voltage Electrician (Leader)	301-496-2719
Gomes, Andrew, PhD	Physical Scientist	301-435-2107
Hooks, Nicholas		301-451-4469
Huffman, Kevin	High Voltage Electrician	301-451-4487
Lawrence, Thomas M.	Instrument Technician	301-451-4488
Meyer, David	Program Support, Asset Manager	301-451-2454
Mundy, James	High Voltage Electrician	301-451-4488
Pajardo, Joseph	High Voltage Electrician	301-451-3527
Taluckder, Mohammed	Shift Electrician	301-451-4488
Tolbert, Brandon	Electrical Supervisor	301-496-2719
Wagner, Brandon D.	Instrument Technician	301-451-3527
Young, William	Facility Operations and Maintenance staff	301-451-4487

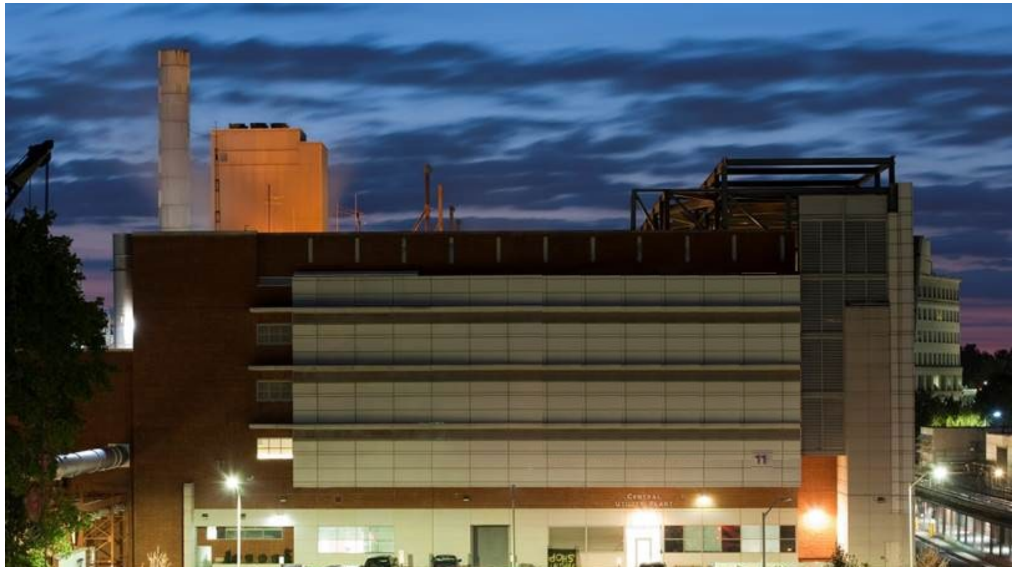
CUP Organizational Structure (Continued)

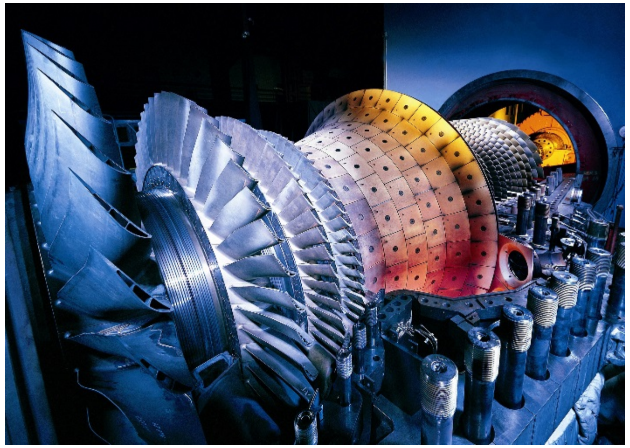
Utilities Distribution Branch (HNAM966) Main Phone: 301-402-2848		
Moses, Daniel, PE	Branch Chief	301-402-2848
Biser Jr. Donald	General Engineer	301-443-8124
Daniels, Michael	Electrical Engineer	301-402-5593
Goughnour, Mark	Engineering Technician	301-443-1567
Leas, Douglas	Engineering Technician	301-451-4473
Rand, Presley	Engineering Technician	301-451-4479
Rendall, Frederick	Maintenance Mechanic	301-451-4469
Sudek, George	Engineering Technician	301-594-0677
Tran, William	General Engineer	301-480-9872

* indicates Contractor or Consultant

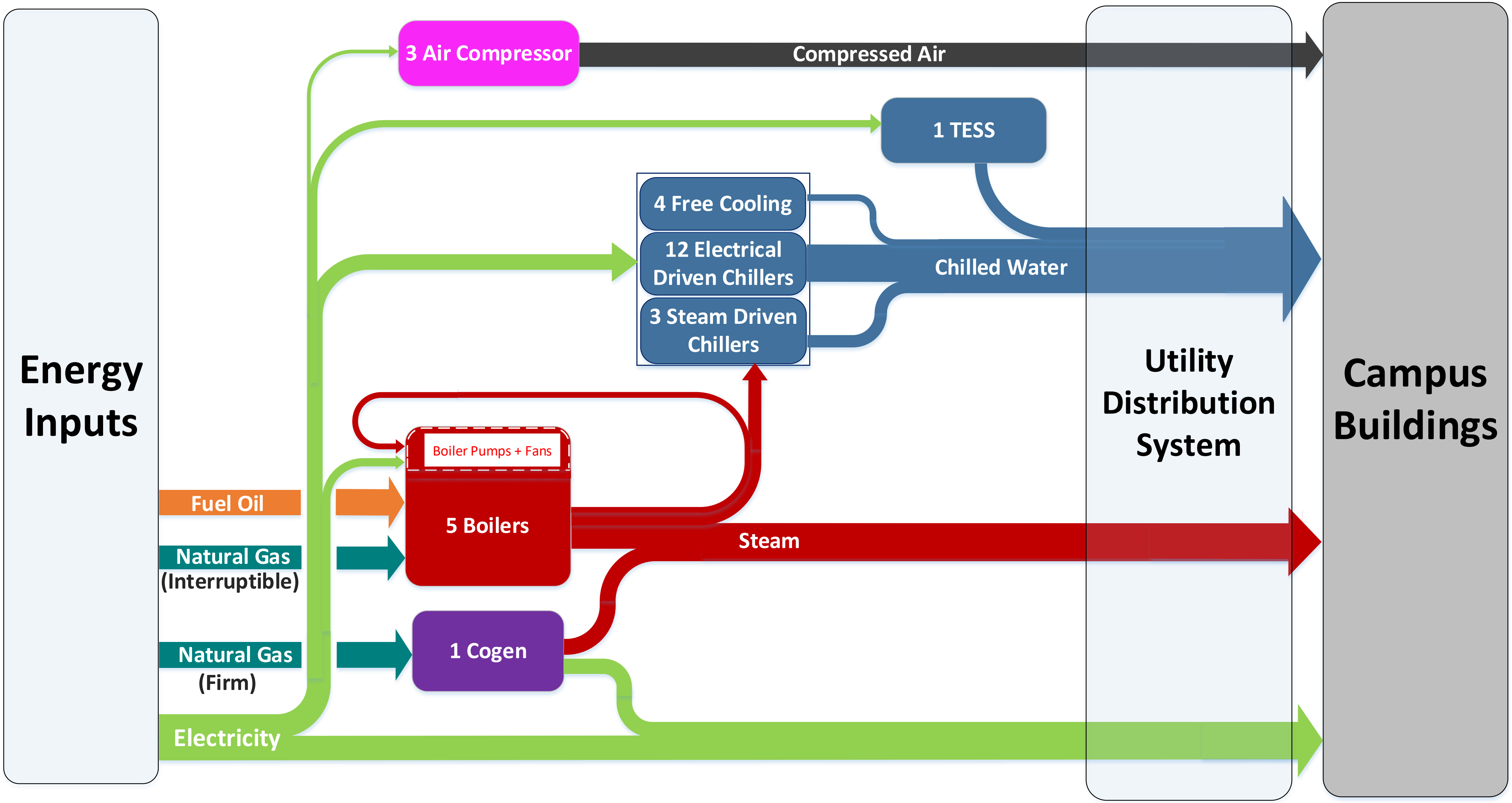
NIH Central Utility Plant (CUP) Overview

- One of the largest CUPs under one roof
  - Provides campus with chilled water, steam, electricity, and compressed air
- CUP Components
  - Twelve 5,000 Ton capacity chillers
  - 7.9 million gal CHW thermal storage tank
  - 5 million gal Industrial Water System
  - Five gas/ diesel dual fuel fired boilers
    - 800 KPPH, 980 KPPH with Cogen
- Cogeneration Power Plant
  - One of the largest US government Cogen plants
  - 23 MW, 180KPPH steam (40% of campus demand)

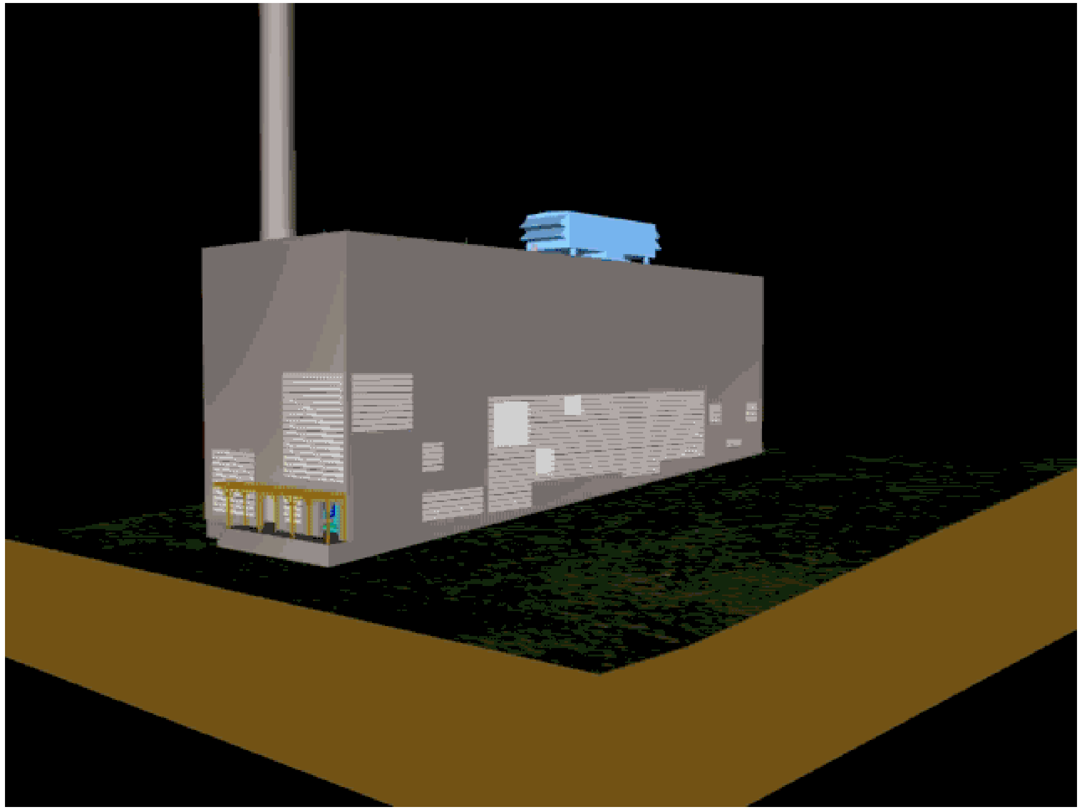




Multiple Energy Sources and Equipment Configuration Options



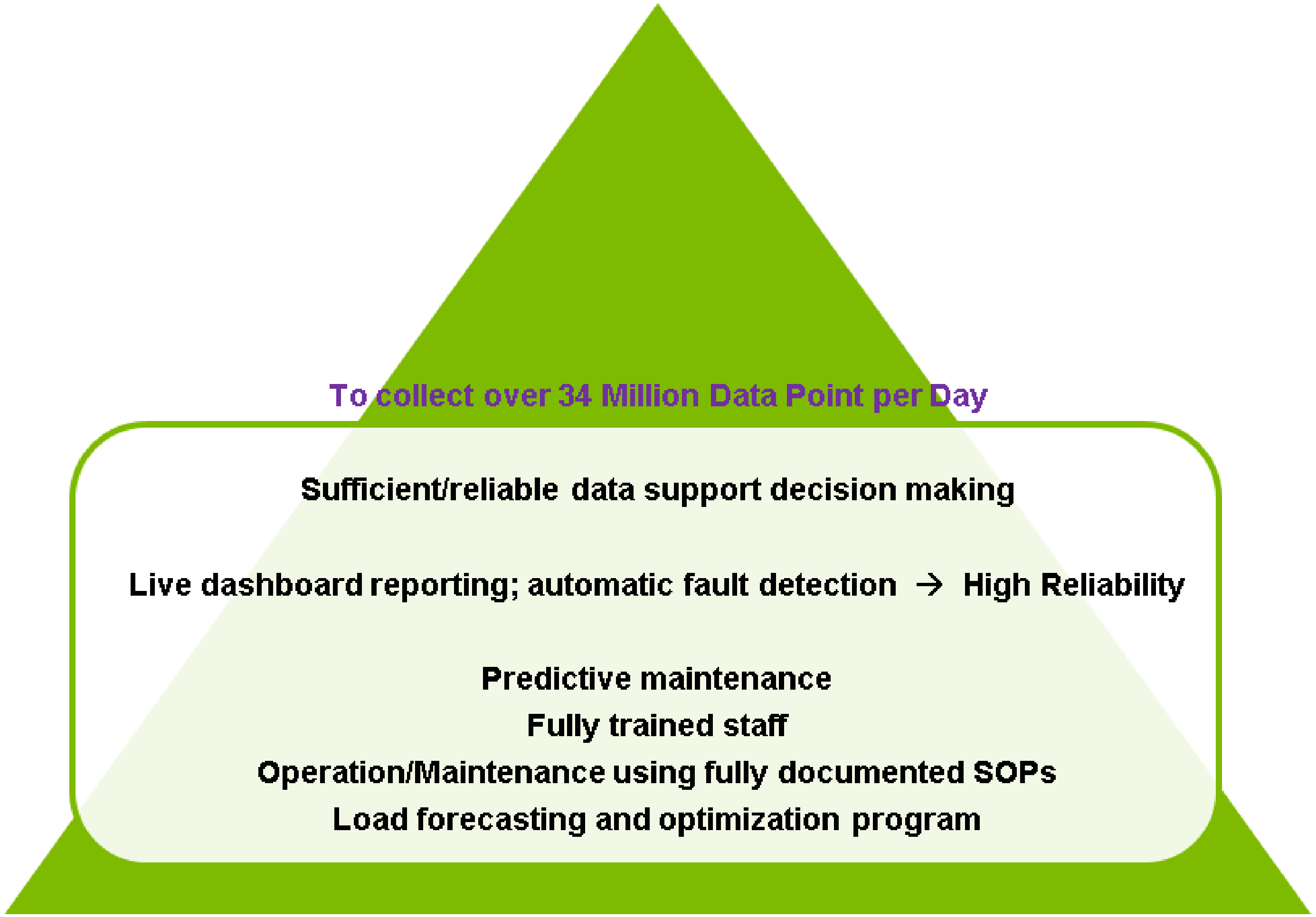
Cogeneration Plant



Cogeneration Plant Benefits

- One of Lowest Emission Cogen in the world!!
- ~ $12 Million Per Year Savings in Energy
- Cogeneration Energy Savings is Equivalent to Energy Usage of ~ 5,000 typical homes
- Reduce CO_2 Emissions Equivalent to Emissions from 10,000 typical cars.

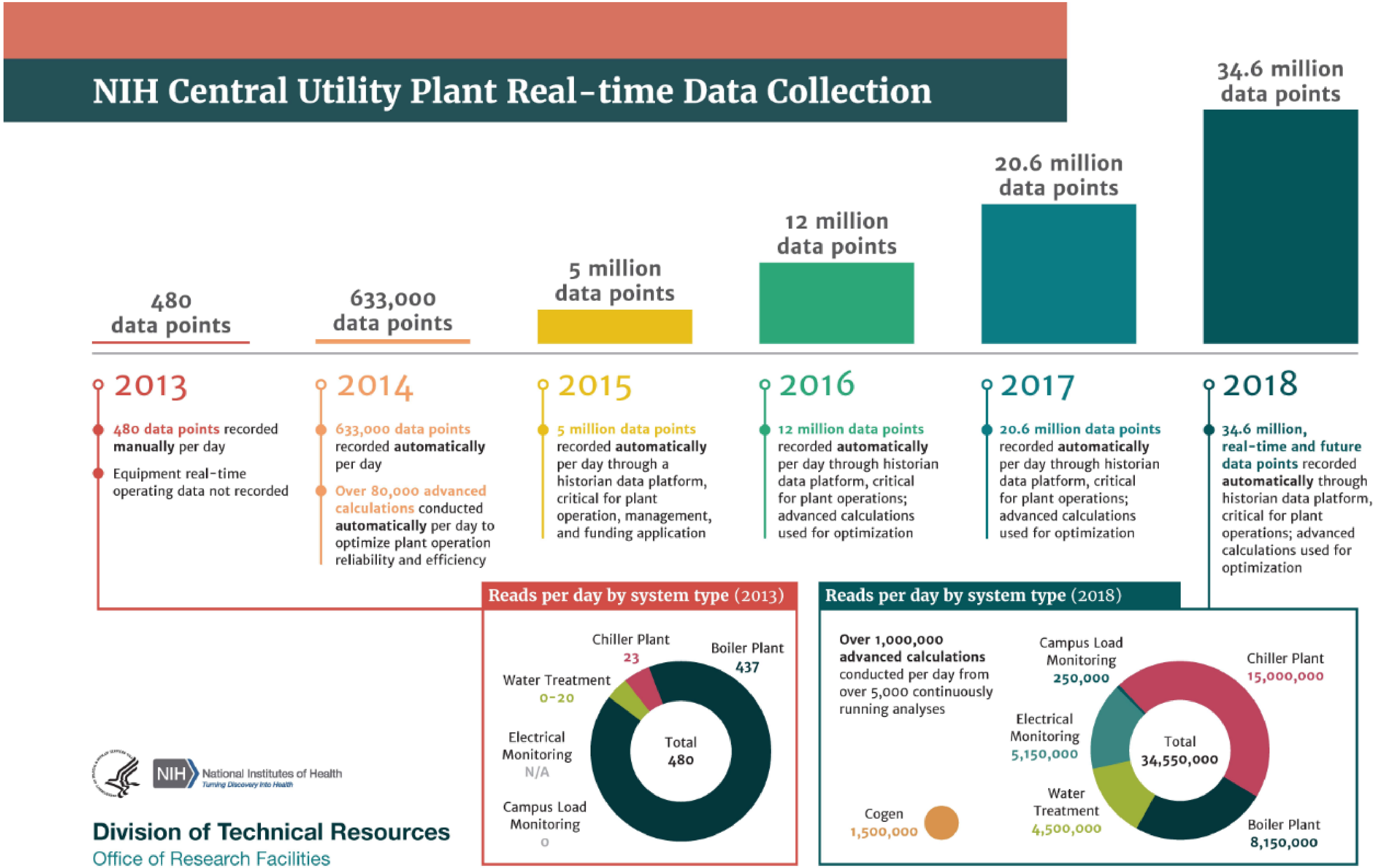
Data Platform Leads Operational Paradigm Shift



You can't manage what you can't measure!

Data is the foundation for operating the plant safely, reliably, efficiently and as cost effectively as possible.

Evolving Use of Data

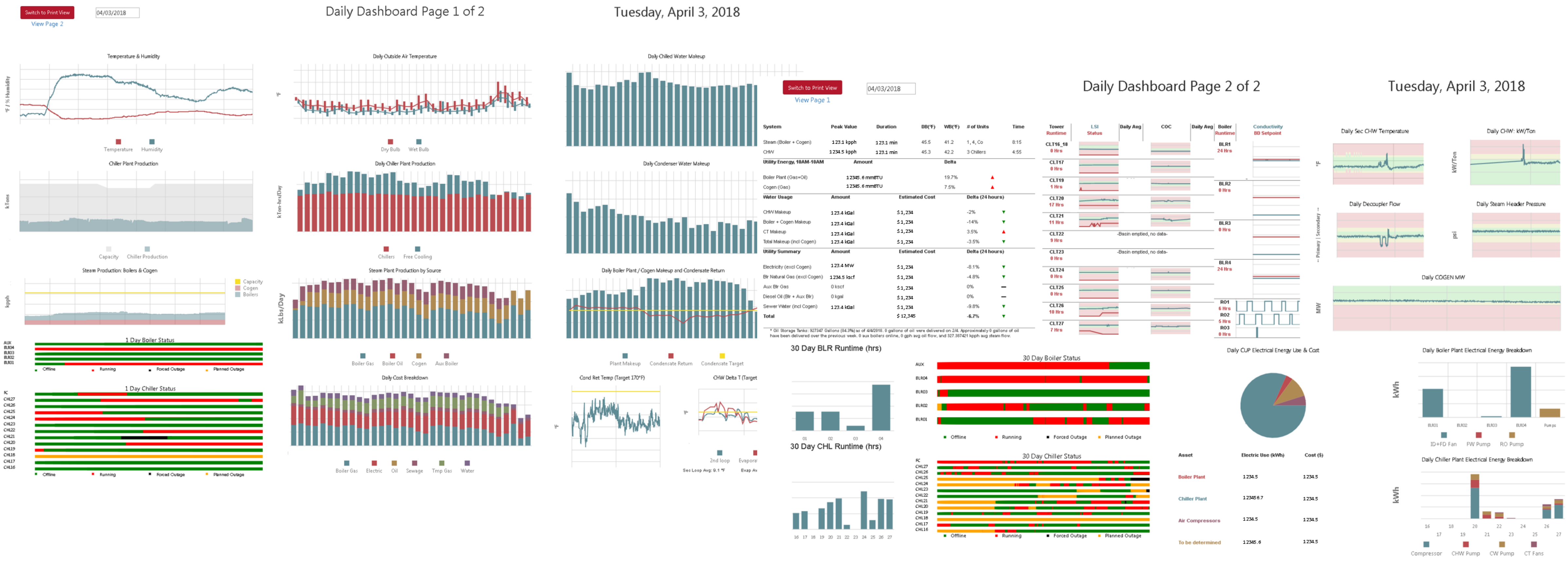


National Institutes of Health
Turning Discovery Into Health

Division of Technical Resources
Office of Research Facilities

Web-based Executive Level Summaries and Reporting

High level, executive daily performance data accessible with 1 click



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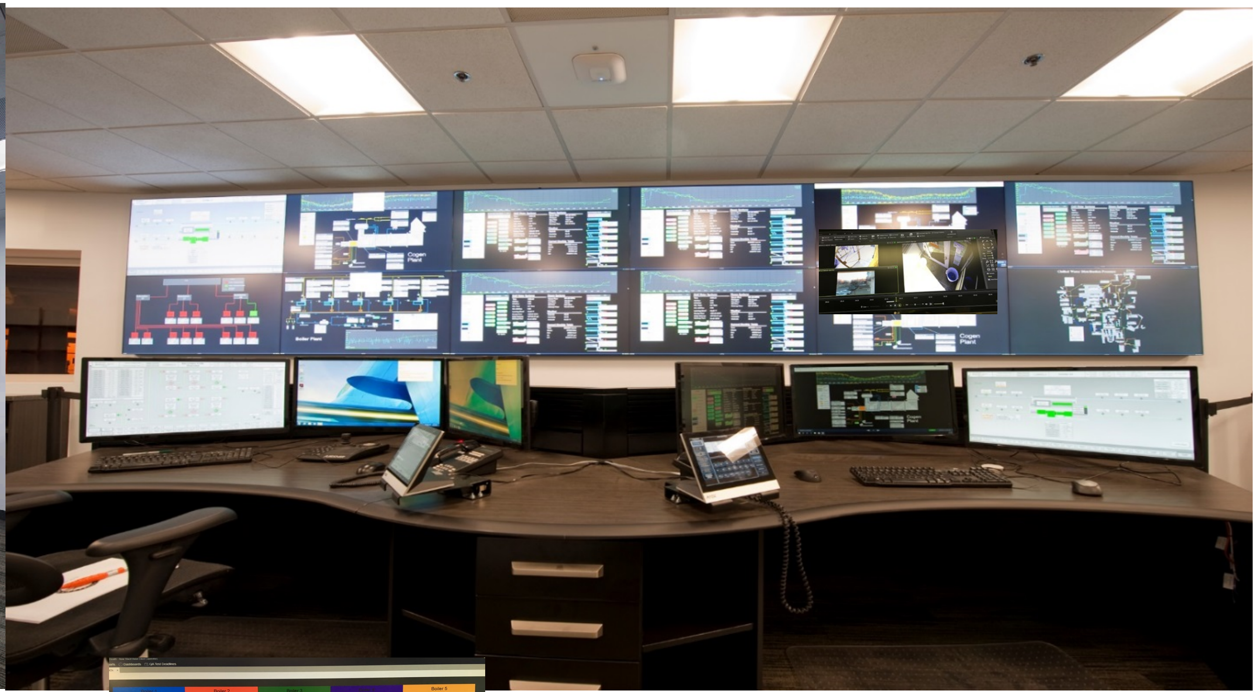
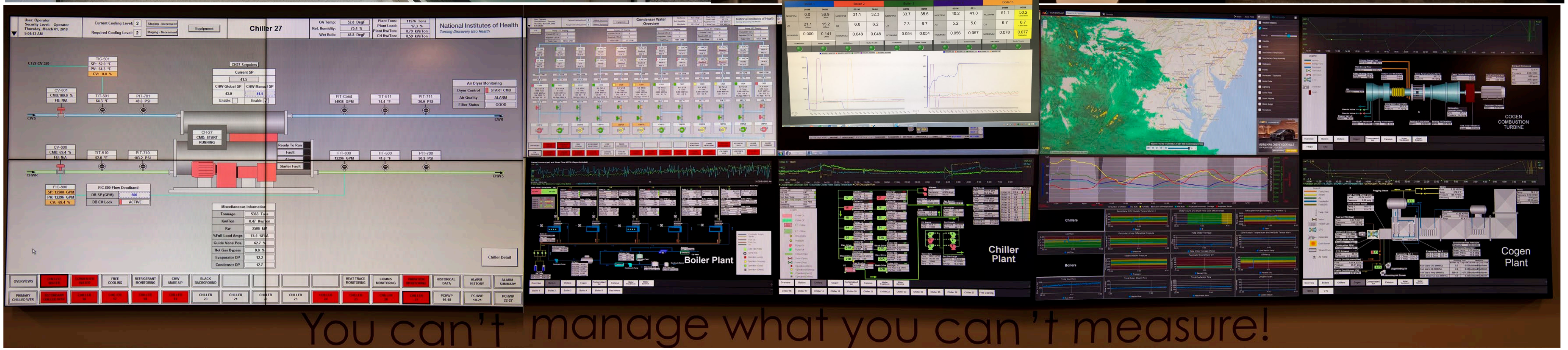
Data Platform Powers the CUP Control Room





Actionable Operational Intelligence & Fault Detection

Data Platform provides operators **actionable** intelligence, in-time Root Cause Analysis, and Shift performance

The formulae for building state of the art biomedical research facilities.

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Operation 96 Hour Event Log

Start Time	Duration	System	Description	Recommendation	Current Reading	Event Link
4/2/2018 101:00:22 PM	Active Event	Chiller_Plant/Chl27/Operations	Chiller Load HiHi Alarm (>105%)	Chiller Load Above HiHi Alarm (>105%)	Load: 0%	Click Here
4/6/2018 2:18:21 PM	52 minutes	Chiller_Plant/Chl24/Operations	Chl_Load_HiHi	Chiller Load Above HiHi Alarm (>105%)	Load: 64.1%	Click Here
4/5/2018 101:57:43 PM	Active Event	Chiller_Plant/Chl17/Operations	Chiller Load HiHi Alarm (>105%)	Chiller Load Above HiHi Alarm (>105%)	Load: 0%	Click Here
4/3/2018 102:18:36 PM	Active Event	Chiller_Plant/Chl21/Operations	Chiller Load Lo Warning (<65%)	Chiller Load Below LoLo Alarm (<60%)	Load: 0%	Click Here
4/4/2018 100:09:22 AM	Active Event	Chiller_Plant/Chl27/Operations	Chiller Load HiHi Alarm (>105%)	Chiller Load Above HiHi Alarm (>105%)	Load: 0%	Click Here
4/4/2018 100:02:36 PM	Active Event	Chiller_Plant/Chl20/Operations	Chiller Load HiHi Alarm (>105%)	Chiller Load Above HiHi Alarm (>105%)	Load: 0%	Click Here
4/6/2018 2:15:52 PM	54 minutes	Chiller_Plant/Chl25/Operations	Chl_Load_HiHi	Chiller Load Above HiHi Alarm (>105%)	Load: 69.5%	Click Here
4/6/2018 2:13:36 PM	56 minutes	Chiller_Plant/Chl21/Operations	Chl_Load_Lo	Chiller Load Below LoLo Alarm (<60%)	Load: 0%	Click Here
4/6/2018 8:25:51 AM	5 hours	Chiller_Plant/Chl24/Operations	Chl_Load_HiHi	Chiller Load	Load: 64.1%	Click Here
4/6/2018 6:00:52 AM	8 hours	Chiller_Plant/Chl25/Operations	Chl_Load_HiHi	Chiller Load	Load: 69.5%	Click Here
				Chiller Load Above HiHi		

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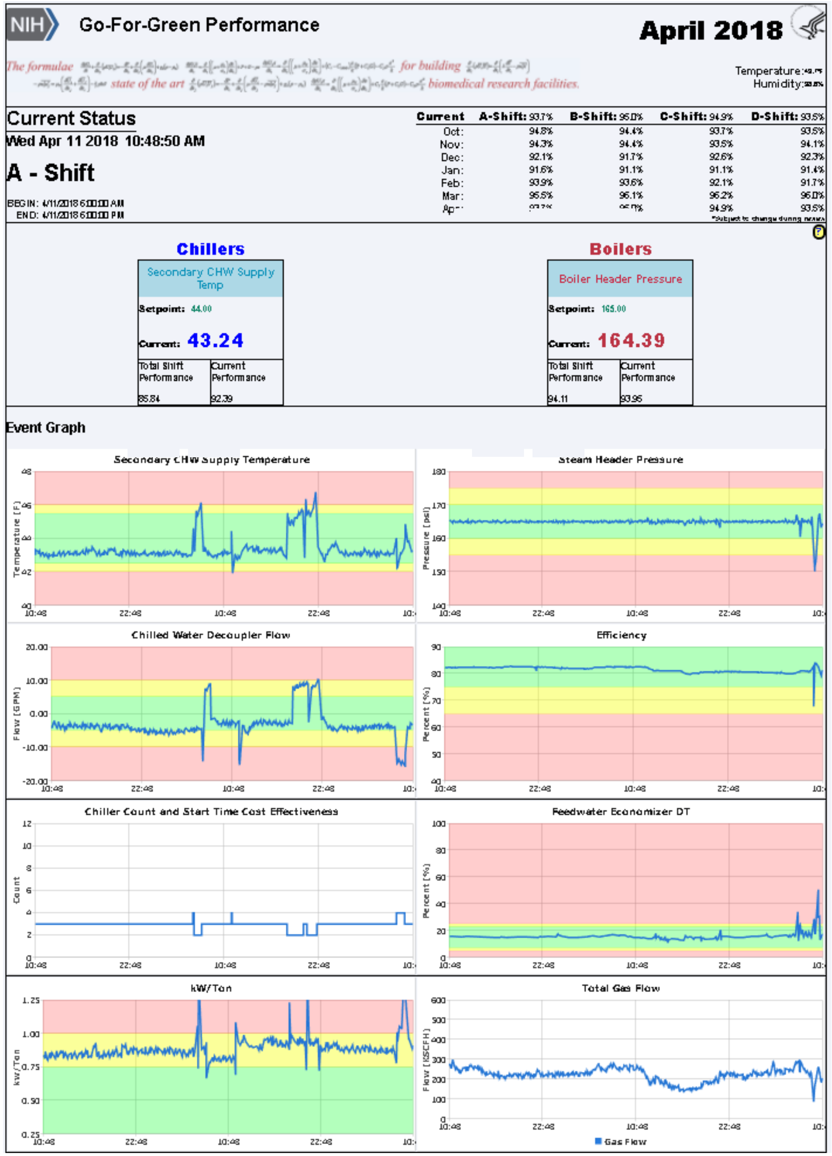
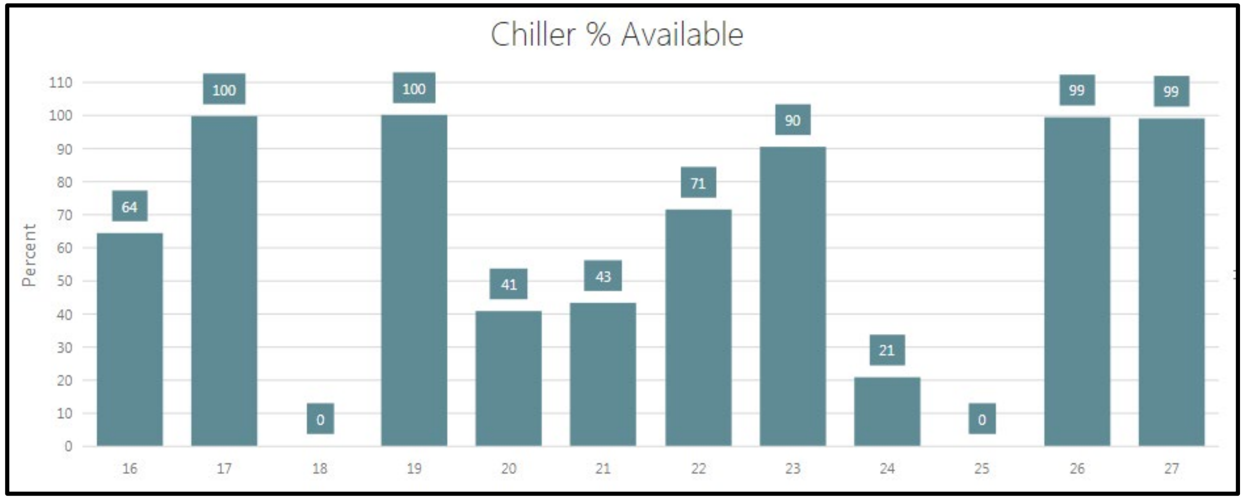
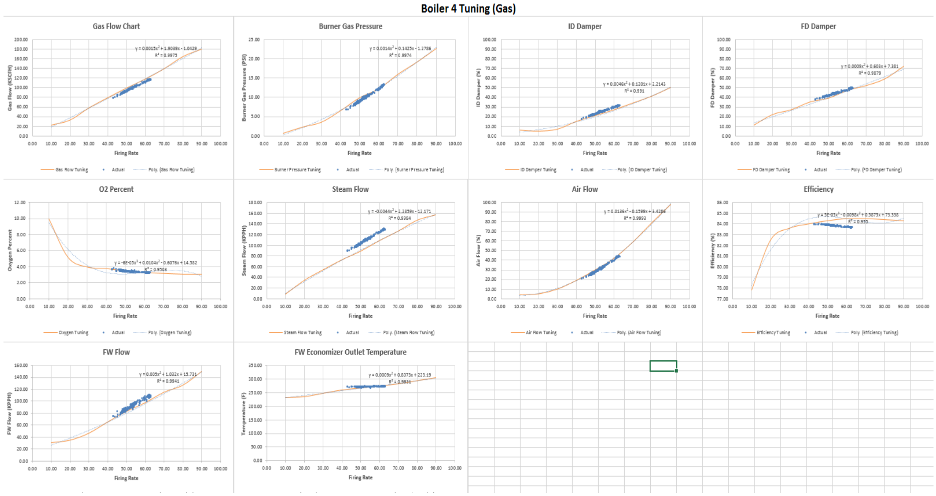
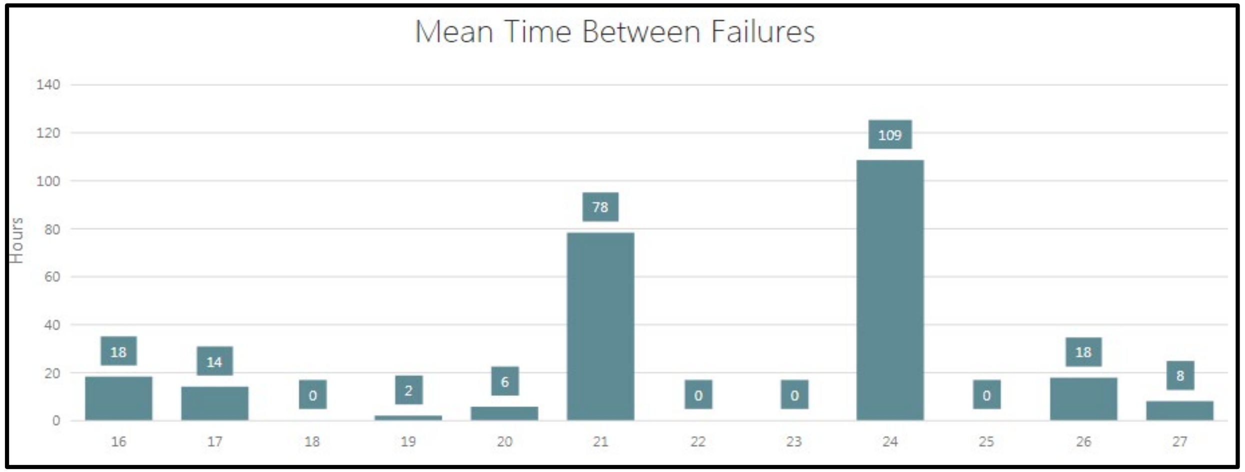
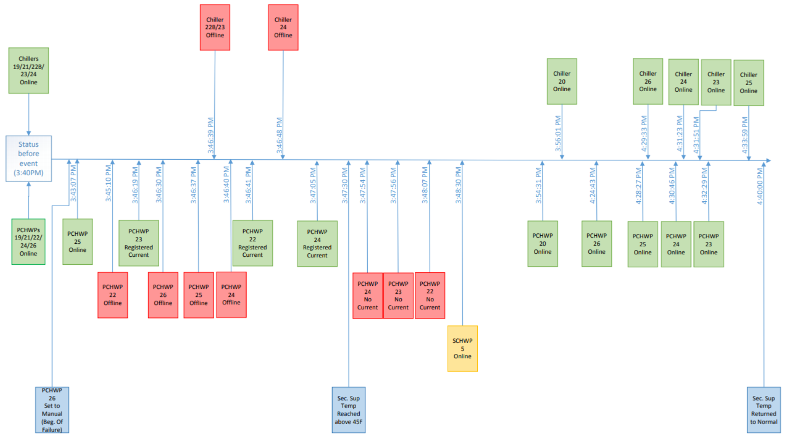


Reliability-Centered Maintenance Program

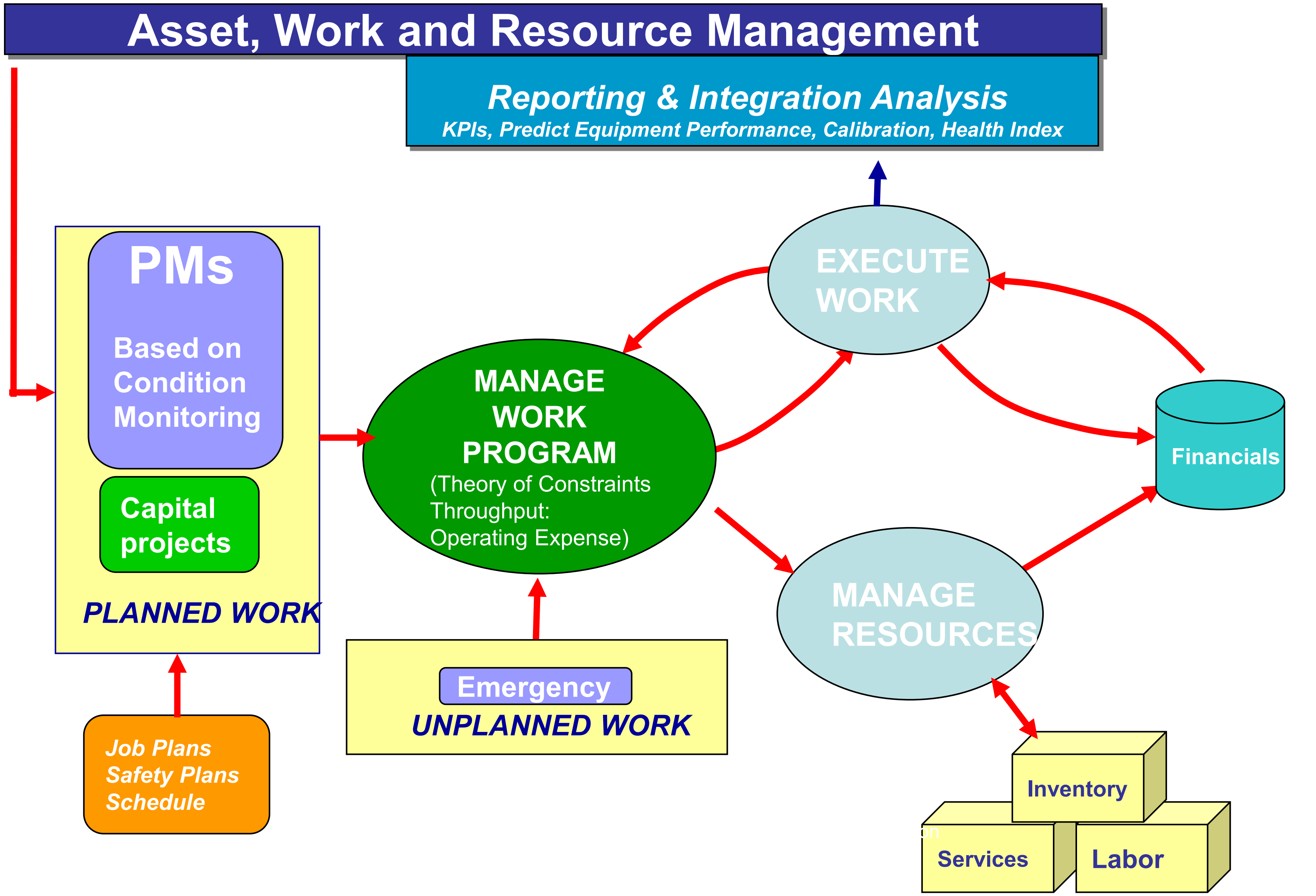








Vision for Maximo and Reliability-Centered Maintenance Program

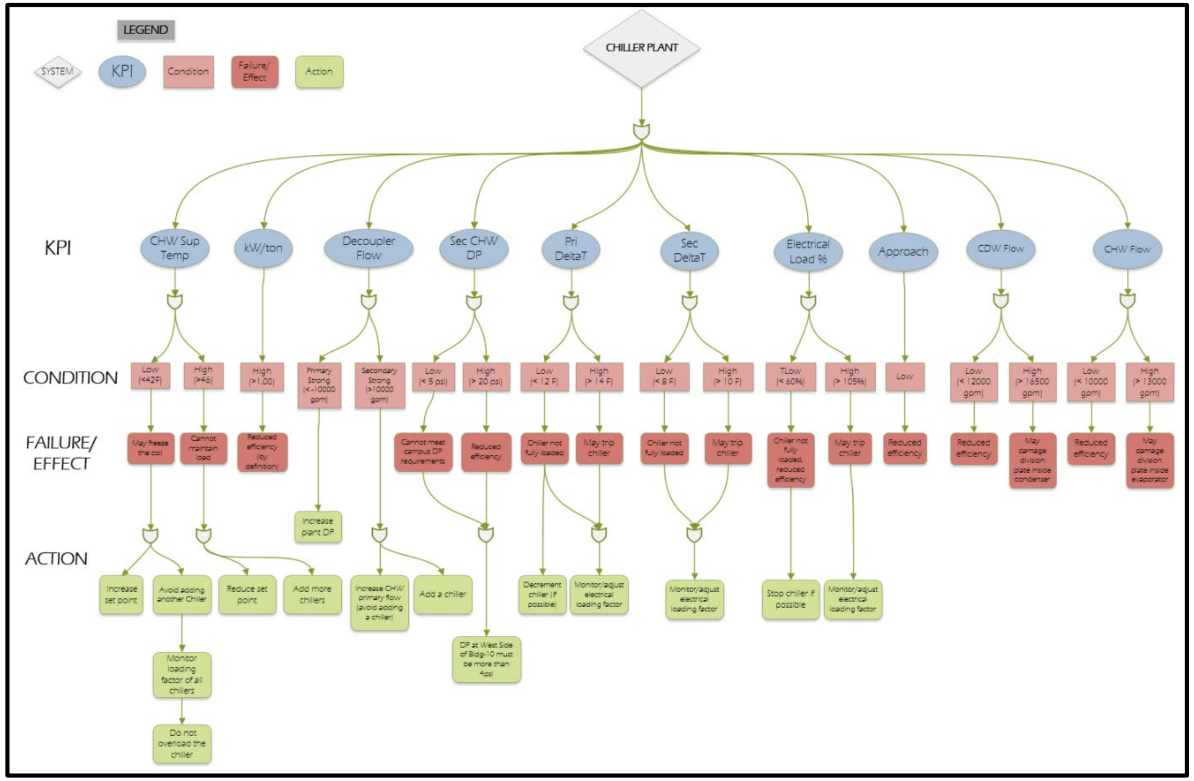


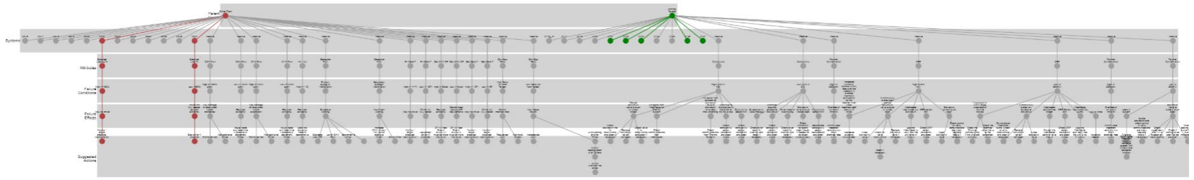
Moving Assets Management Forward!
Major 6 Elements

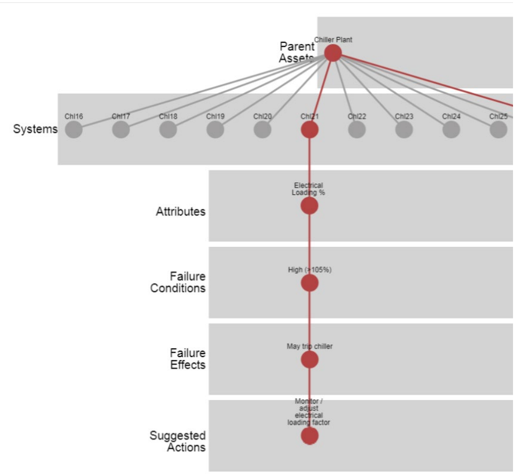
1. Digitization of all major assets using Internet of Things (IoT)
2. Distributed Database - No single point of failure
   - Users will not interfere with each other when accessing / manipulating data
   - Every node is an "administrator"
   - Speed—Files are retrieved from nearest location
   - If one site fails-system can still run
   - Need to work on synchronization of multiple database
3. Transparent data and none corruptible
4. Authentication- Trend analysis and crowdsourcing on assets conditions
5. Audit – Performance is transparent and verified
6. Benchmarking

Reliability-Centered Maintenance Program
Operational KPIs and Automatic Early Fault Detection

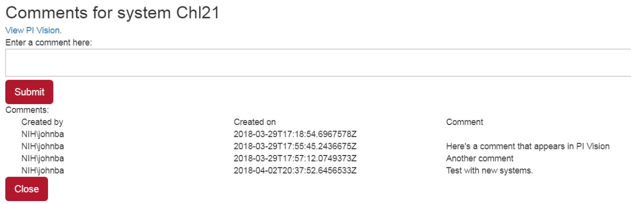
- **Data should flag the issues - our website can identify the dynamic events and potential problems for Operators and Engineers to respond and review**







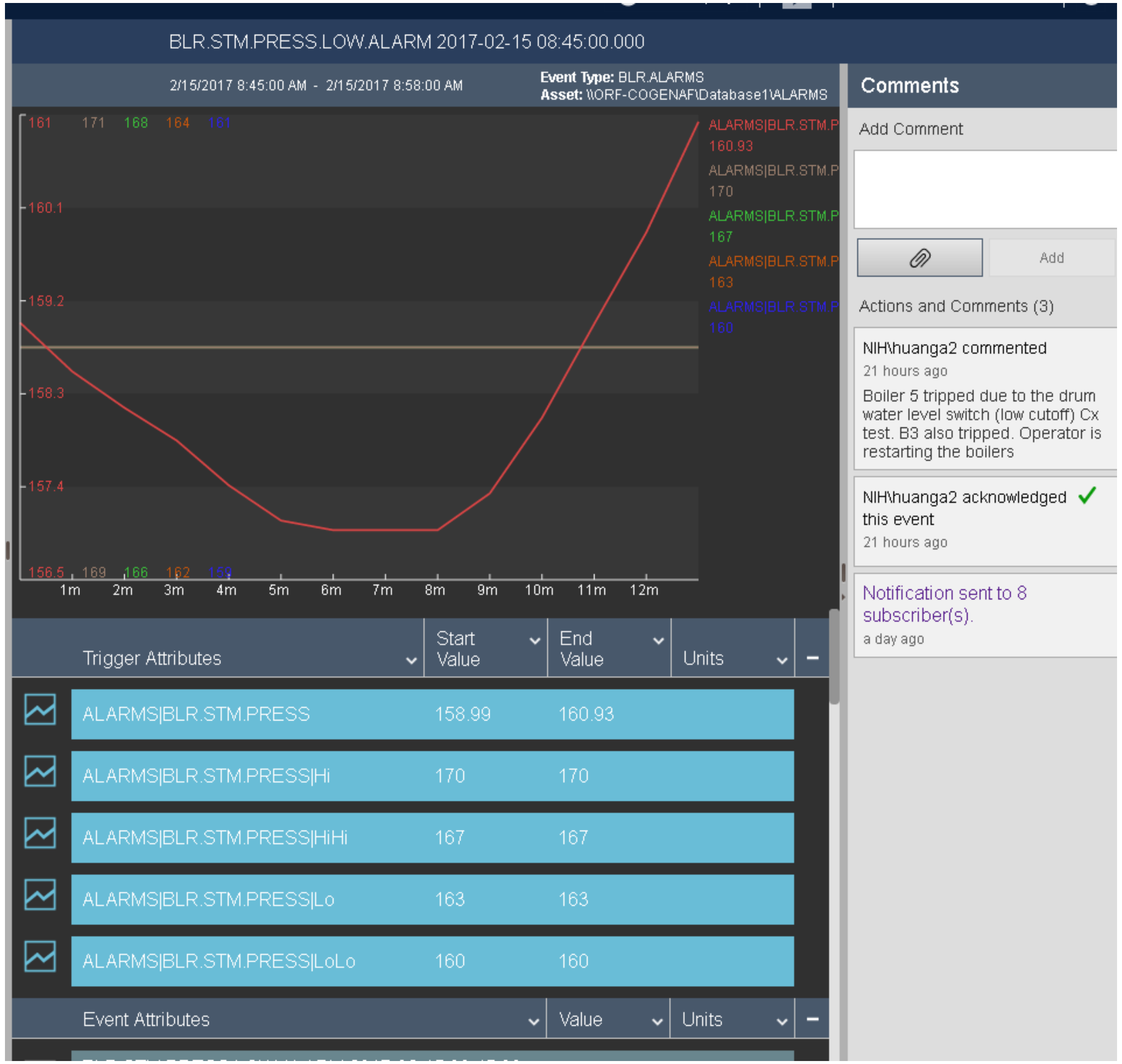
Incident review

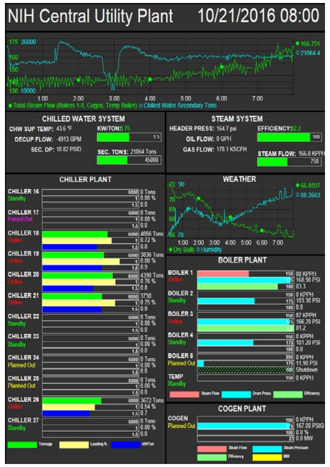


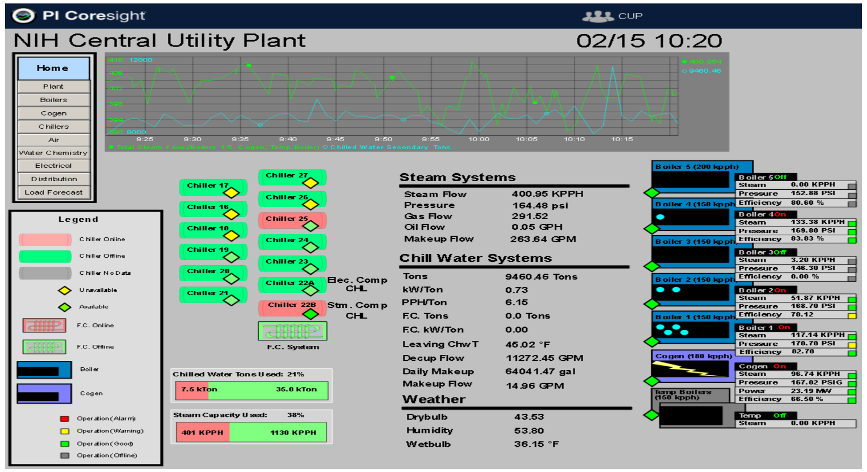
Calibration Program

- To avoid GIGO, Calibration and online cross platform validation improve the data quality
- Allows for visual reporting and status checks on calibration program
- Strides are being made on error propagation and more rigorous standards

Alarm/Operation Notification and Mobility

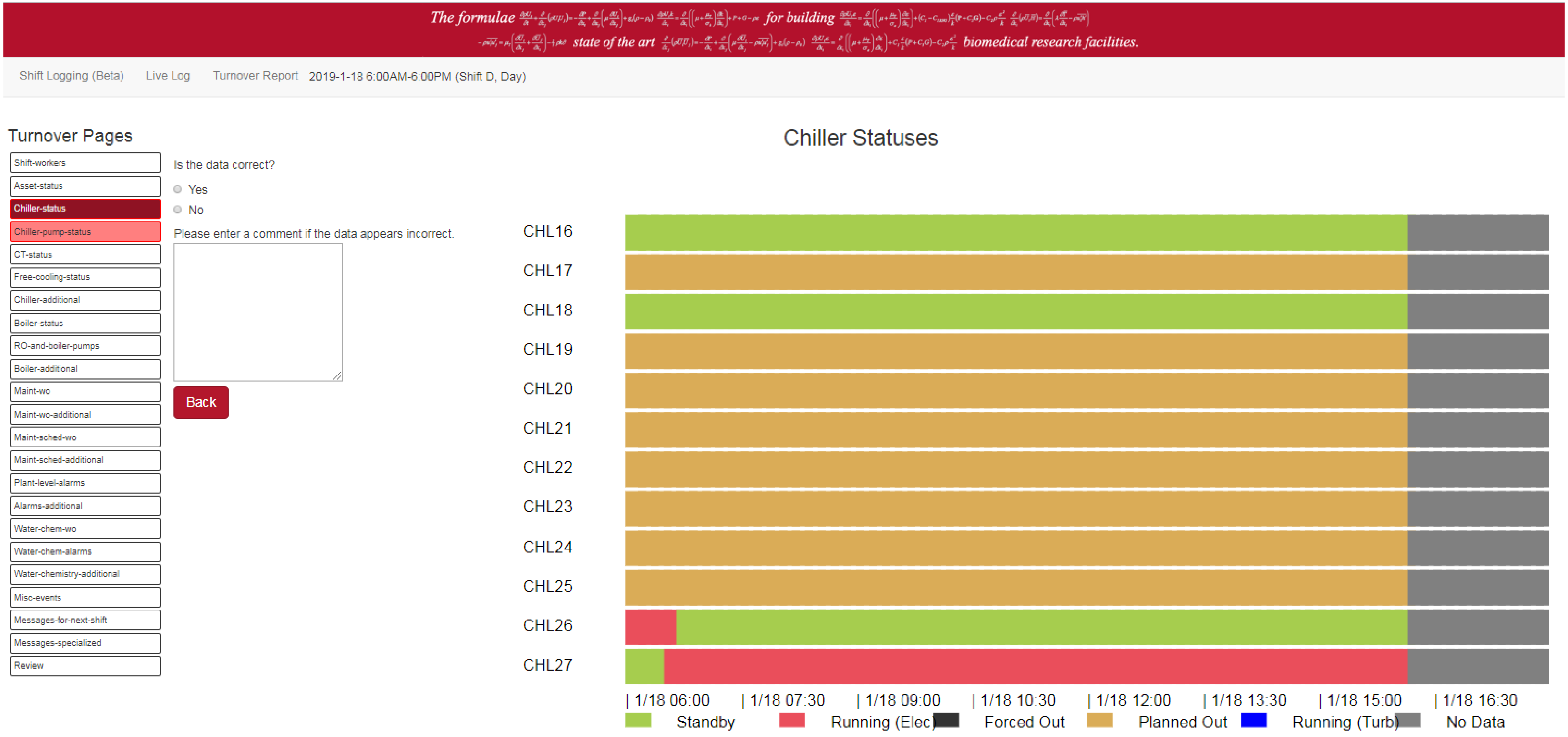






Digitization of Plant Operations - Operator Shift Turnover Website

Asset status, work orders closed and submitted, alarms, live log, message to the next shift



Digitization of Plant Operations

Boiler Round Data

Boiler Feed Water Round

Description	Value	Units	% compliance
Conductivity Daily Rounds	22.75	uS/cm	
pH Daily Rounds	9.51		40
02 Concentration DailyRounds	3.3	ppb	100
Hardness Daily Rounds	0	ppm	100

Steam Condensate Return Round

Description	Value	Units	% compliance
CRC Amine Daily Round	4.36	ppm	

Soft Water Round

Description	Value	Units	% compliance
Hardness Daily Rounds	0	ppm	100

EB Round

Description	Value	Units	% compliance
Feed ORP Round Data	360	mV	
Inlet Water Conductivity RoundData	990	uS/cm	
Outlet Conductivity Round Data	9.95	uS/cm	80
PermeateORP Round Data	252	mV	
RO Filter Pressure Drop		psi	

RO 1 Round

Description	Value	Units	% compliance
Inlet Hardness Daily Round	0		100
Inlet ORP Daily Rounds	283	mV	60
RO filter pressure drop			
Outlet Conductivity Daily R	6	uS/cm	100
Outlet pH Daily Rounds	9.36		80
Inlet pH Daily Rounds	9.07		60

RO 2 Round

Description	Value	Units	% compliance
Inlet Hardness Daily Round	0		100
Outlet ORP Daily Rounds	160	mV	
RO filter pressure drop			
Outlet Conductivity Daily Rounds	7.1	uS/c	100
Outlet pH Daily Rounds	8.44		70
Inlet pH Daily Rounds	9.23		60

Boiler 1-5 Conductivity Live

Description	uS/cm	% compliance
Boiler 1 Conudctivity	2244.91	100
Boiler 2 Conductivity	2306.99	100
Boiler 3 Conductivity	2329.95	100
Boiler 4 Conductivity	2314.99	100
Boiler 5 Conductivity	2178.71	100

Boiler 1 Rounds

Description	Ppm	% compliance
Palk Daily Rounds	350	90
Polymer Daily Rounds	322	100
Sulfite Daily Rounds	150	0

Boiler 2 Rounds

Description	PPM	% compliance
Palk DAily Rounds	200	70
Polymer Daily Rounds	147	50
Sulfite Daily Rounds	80	30

Boiler 3 Rounds

Description	Ppm	% compliance
Palk DAily Rounds	350	90
Polymer Daily Rounds	496	100
Sulfite Daily Rounds	160	0

Boiler 4 Rounds

Description	Ppm	% compliance
Palk DAily Rounds	350	100
Polymer Daily Rounds	418	100
Sulfite Daily Rounds	180	0

Boiler 5 Rounds

Description	Ppm	% compliance
Palk DAily Rounds	400	70
Polymer Daily Rounds	428	90
Sulfite Daily Rounds	200	10

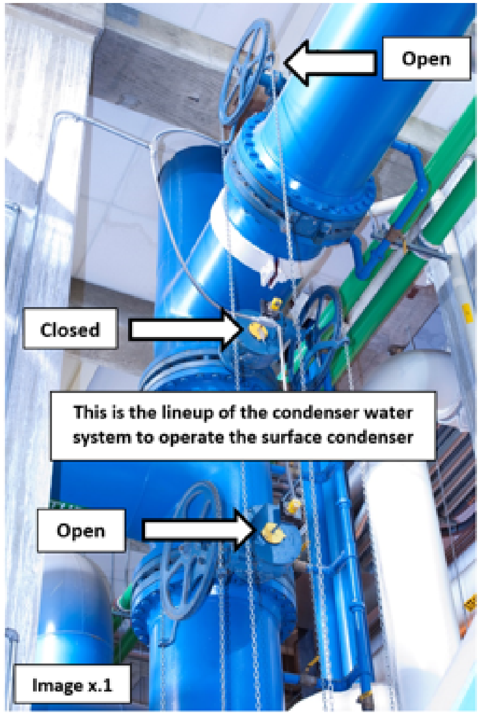
Digitization of Plant Operations – Steam Turbine Readiness Checklist

Chiller 22/ 23

Operator

Ensure that the three condenser and surface condenser isolation valves are **properly lined up**

The surface condenser water inlet valve (SCIV-22) and the surface condenser outlet valve (SCOV-22) should be **Open,** and the condenser outlet valve (COV-22) from the chiller condenser should be **Closed.**



Operator

Ensure that the chiller and condenser barrels have been properly vented.

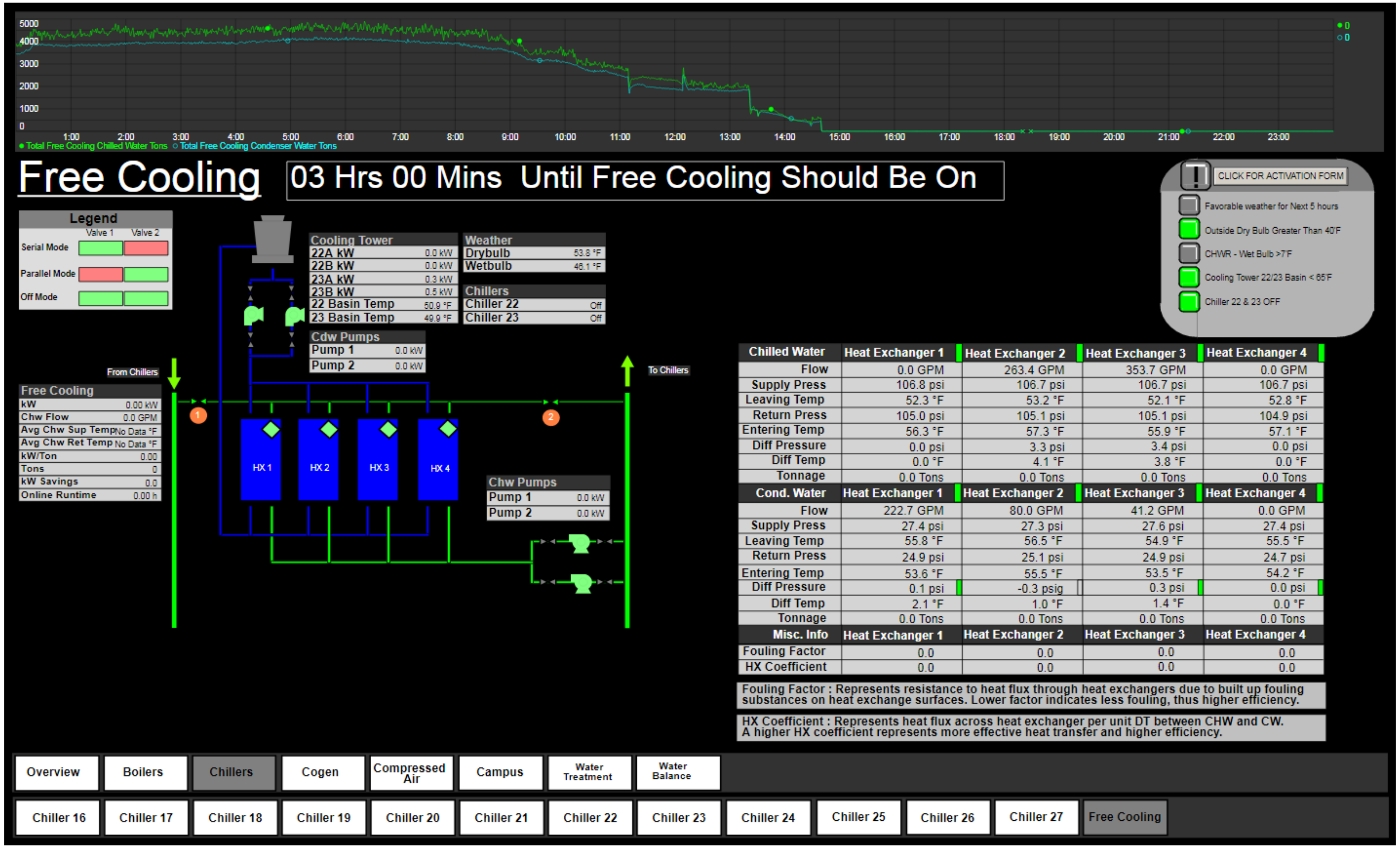
Operator

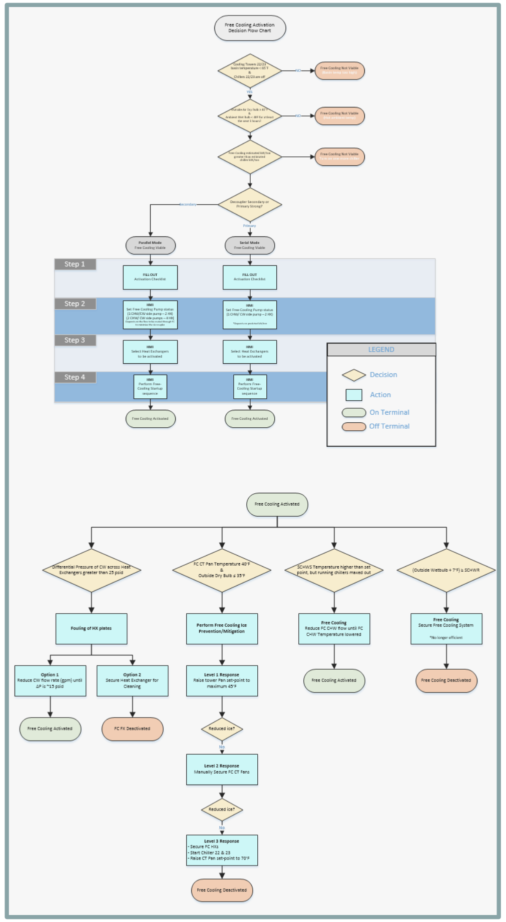
Ensure that the emergency stop button is **pulled out.**

CT roof level | Chiller 22/ 23 | Chiller MCC | Surface condenser

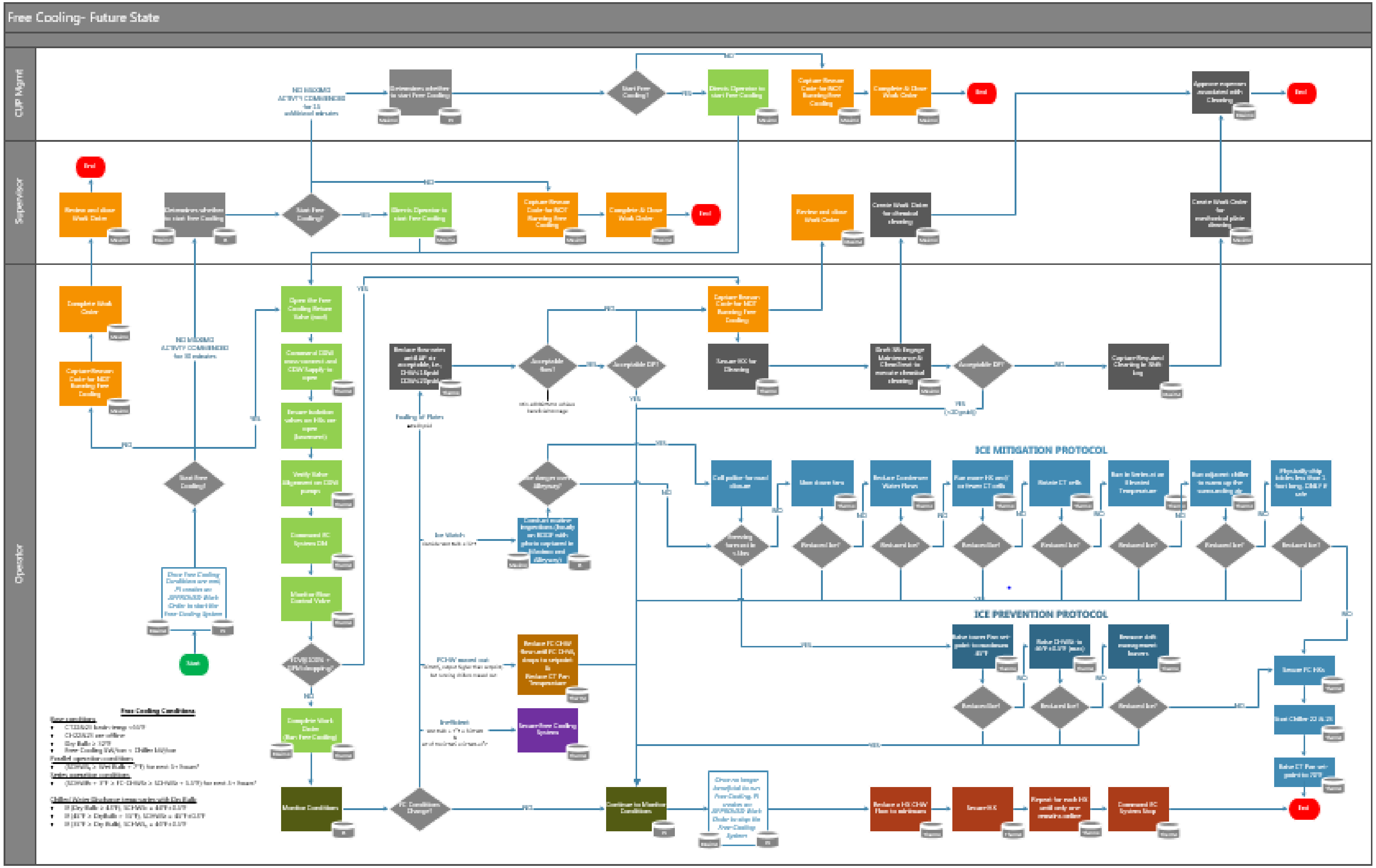
Plant Operations – Free Cooling

- The Weather Forecaster model gives Plant Operators 12 hours advance notice of **when** to operate the Free Cooling system based on anticipated ambient conditions and projected campus chilled water loads.



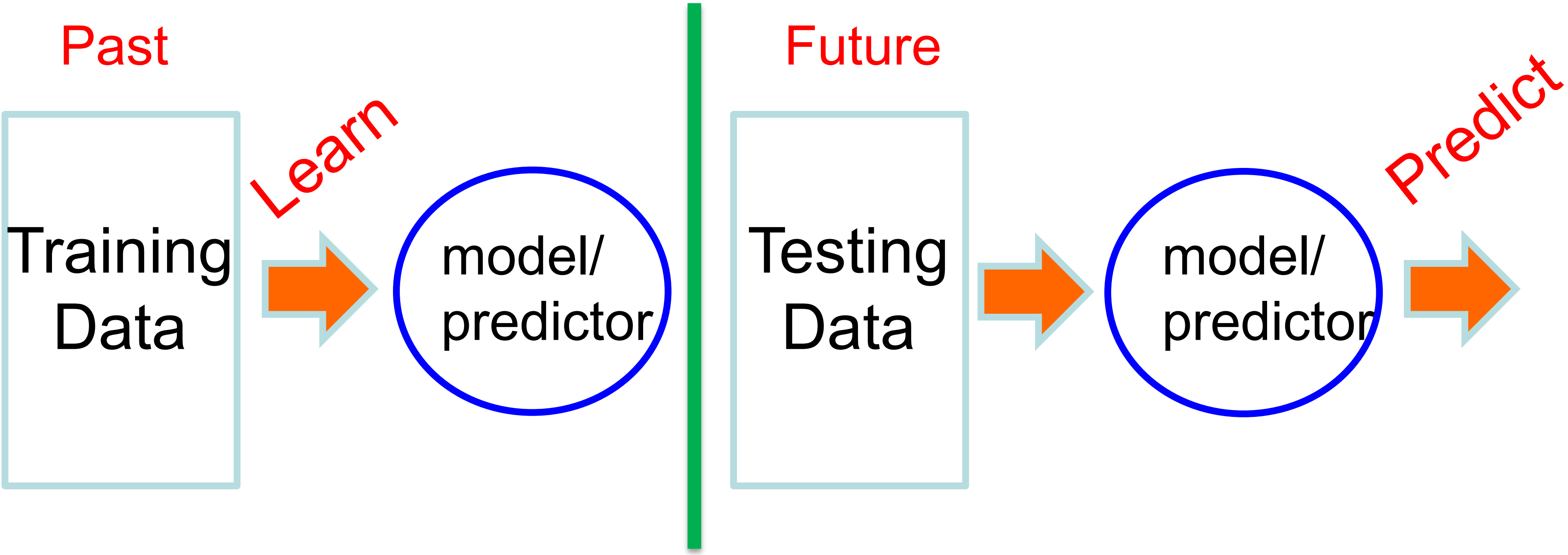


Optimize Processes/Operation with Lean Six Sigma

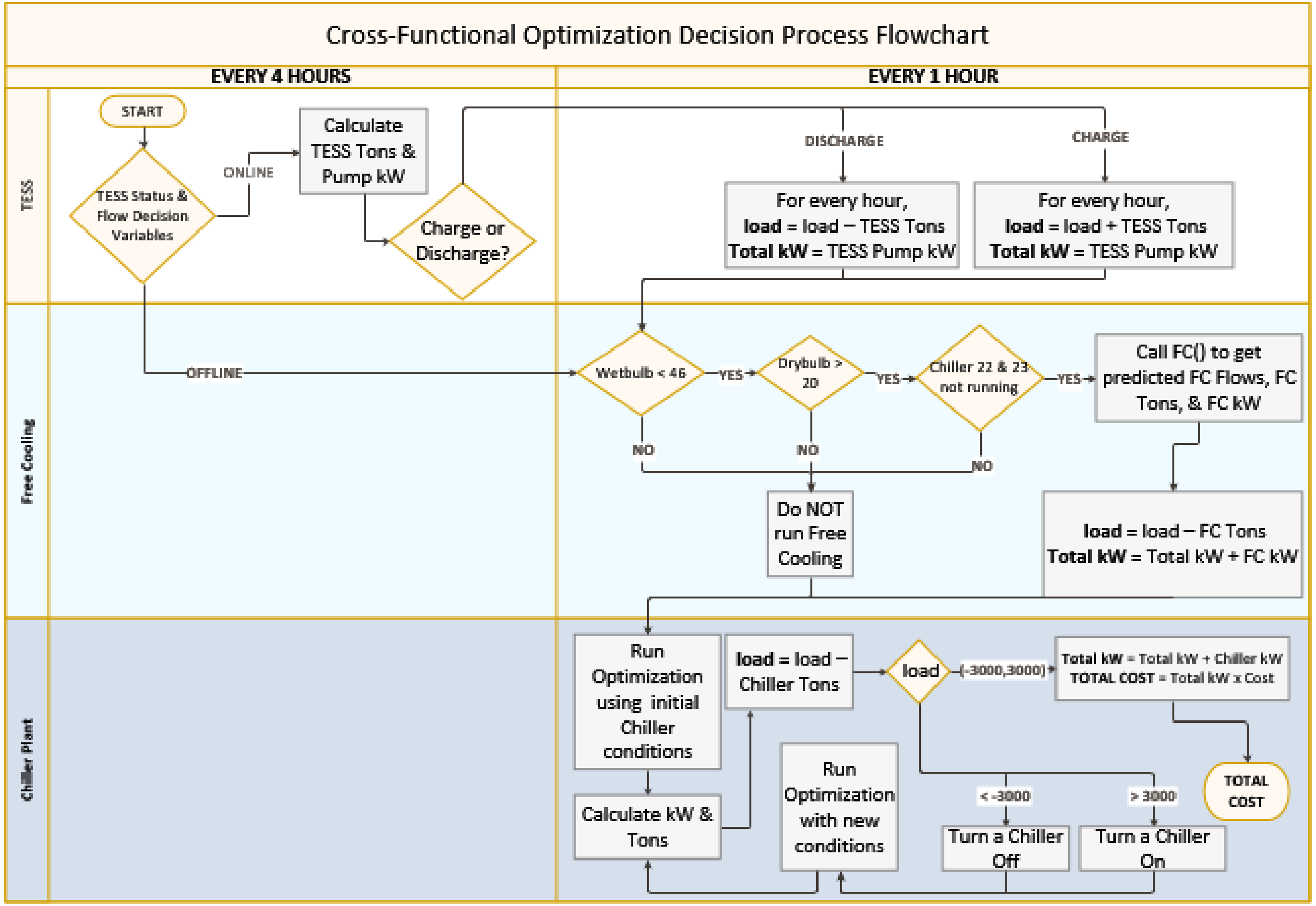


Application Supervised Machine Learning (ML)

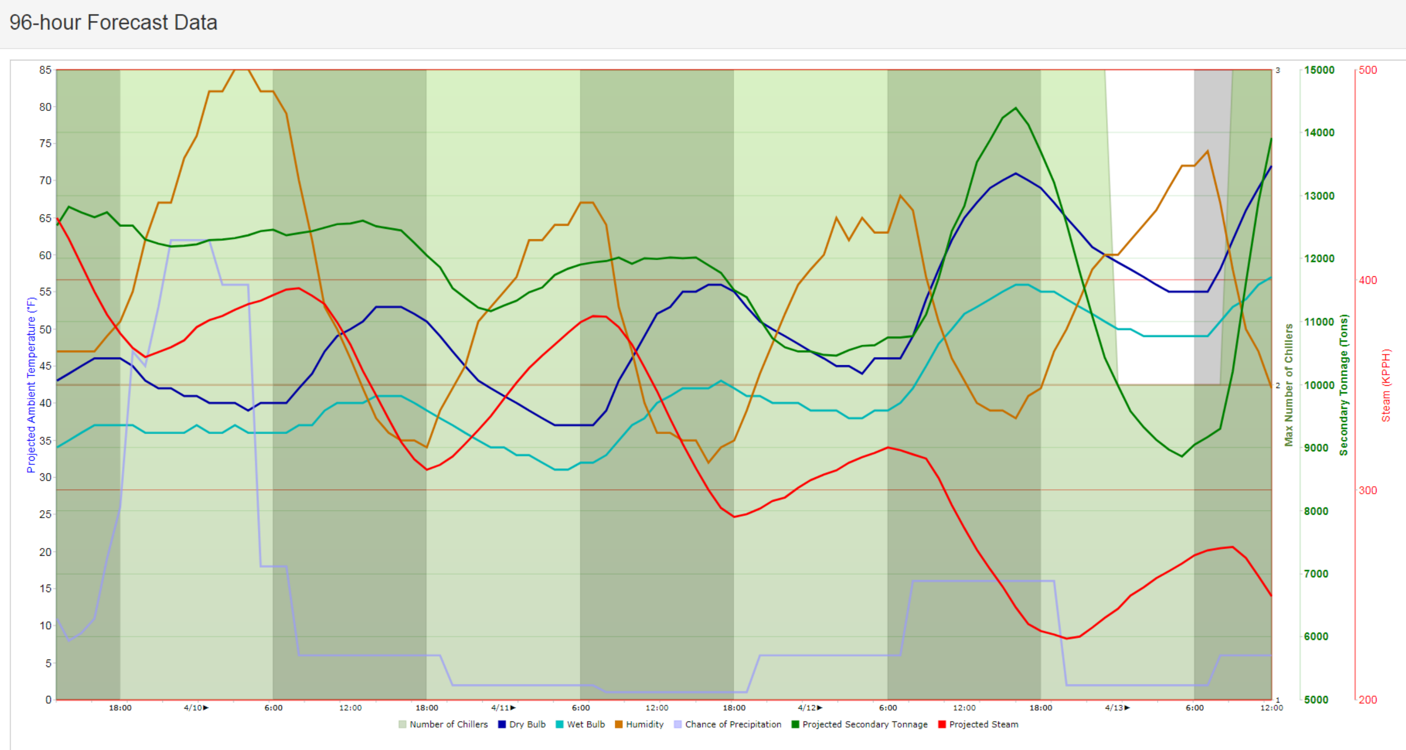
- We use ML probability to make decisions or predictions with a reasonable degree of certainty.

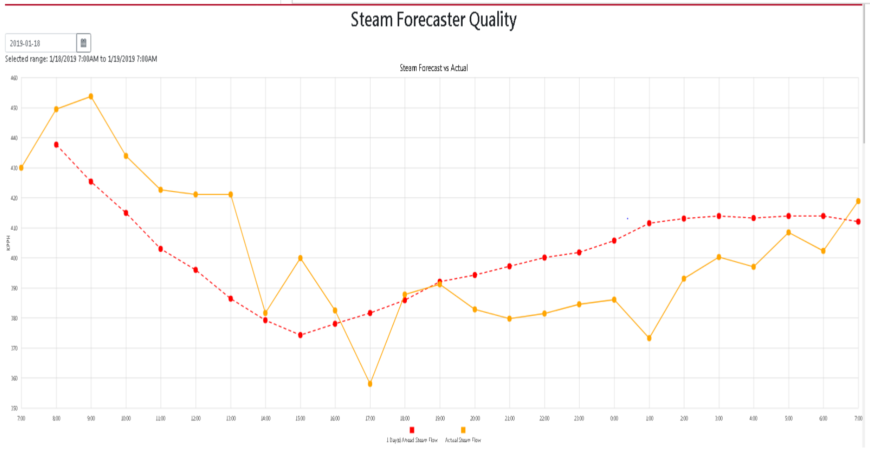


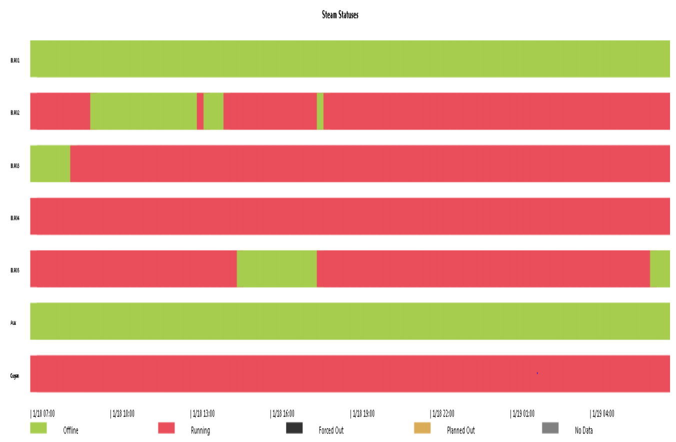
Optimization Using Machine Learning - Mixed Integer Non-Linear Optimization

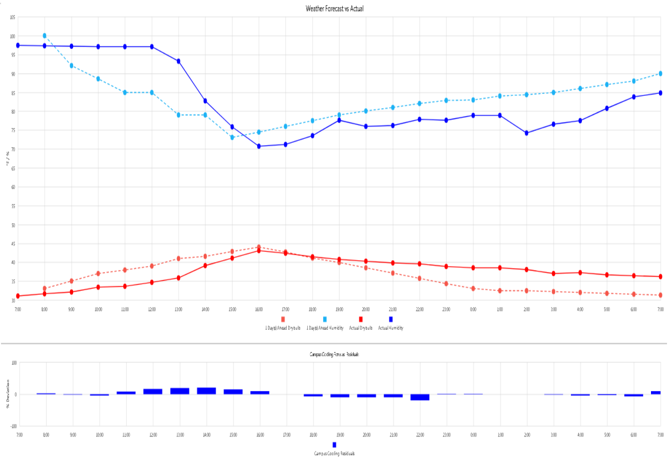


Artificial Neural Network Based Load Forecaster and Error Analysis









Plant Optimization

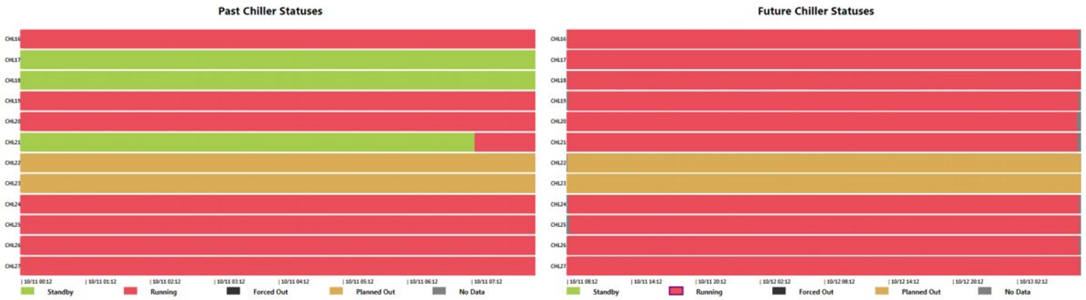
Constraints:

- Chiller/Boiler run time and availability
- Natural gas prices
- Electrical feeder load balance
- Limits of the individual chiller /free cooling capacity, flow, temp, etc.
- TES tank status and capacity
- Load Forecasting and Energy Balance
- PJM Electricity Price
    - *PJM Interconnection is a regional transmission organization (RTO) that coordinates the movement of wholesale electricity in all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia.*

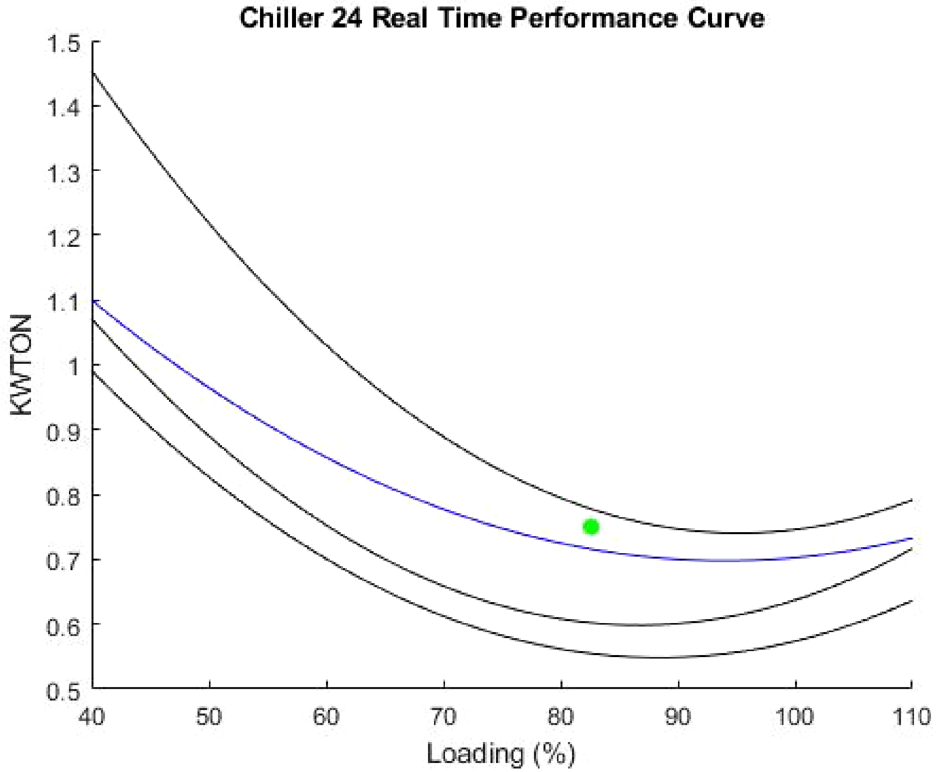
Decision Variables:

- The chiller condenser evaporator flow, temp
- The load distribution among the chillers
- Free cooling flow, number of heat exchangers
- TES charge / discharge dispatch decision and flow

Asset Availability Website



Optimization Animation



Prescriptive Analytics by Machine Learning
Chiller Plant Optimization & Operation Recommendations

The objective: Minimize the total equivalent cost

The constraints:

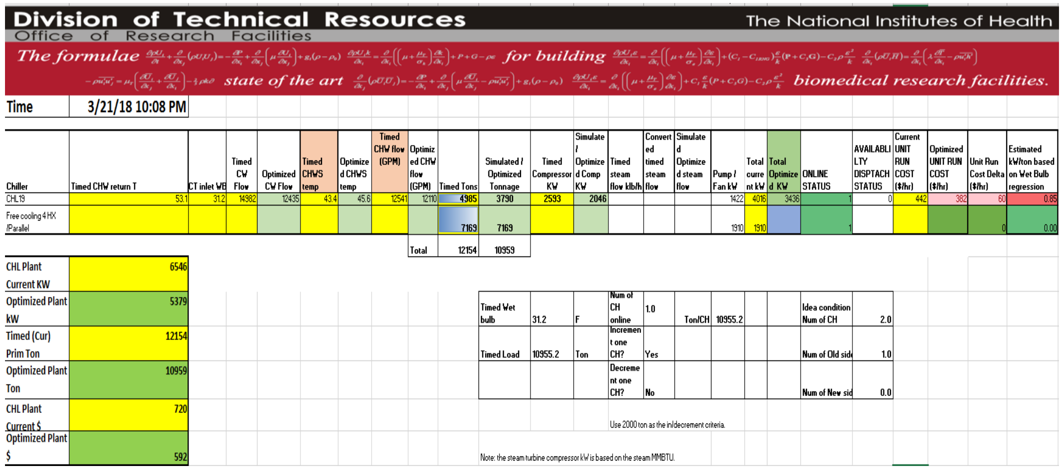
- Chiller run time and availability
- Limits of the individual chiller /free cooling capacity, flow, temp
- Load Forecasting and Energy Balance
- Future PJM Electricity Price

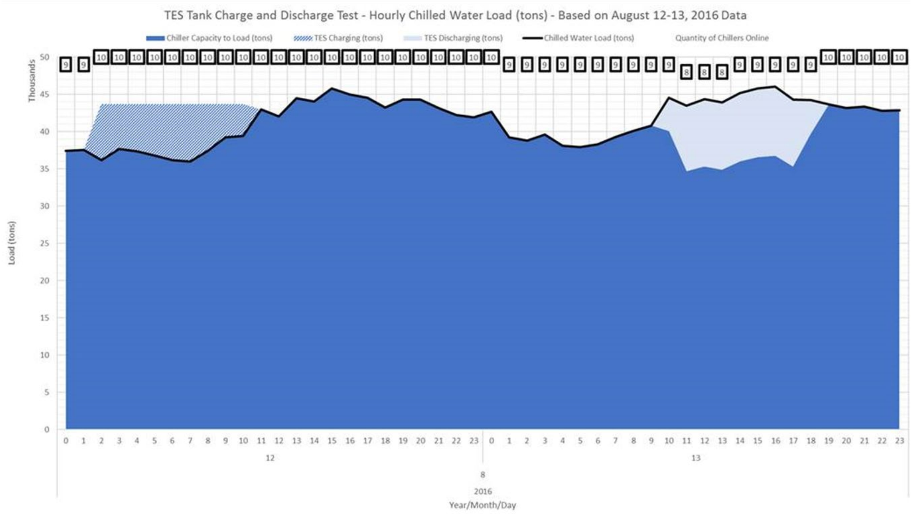
The variables:

- The chiller condenser evaporator flow, temp
- The load distribution among the chillers

Typical Suggestions:

- Run minimum number of chillers, shift more load to the more efficient chillers or the steam turbine chiller, run more cooling tower cells to reduce the tower return temp, or increase the chilled water supply temp.

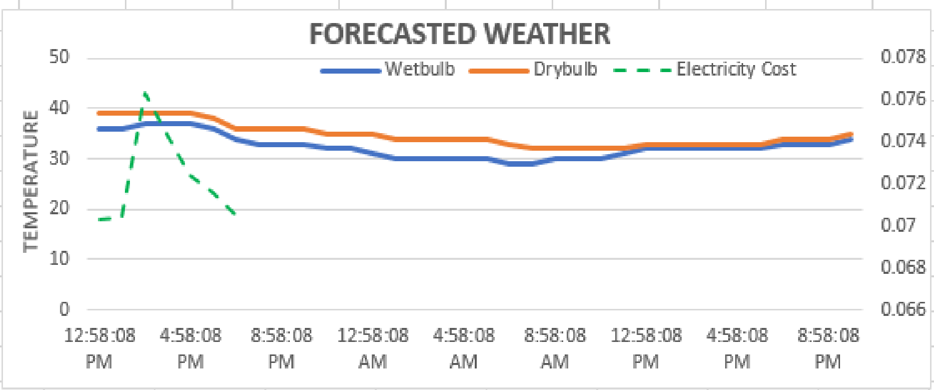


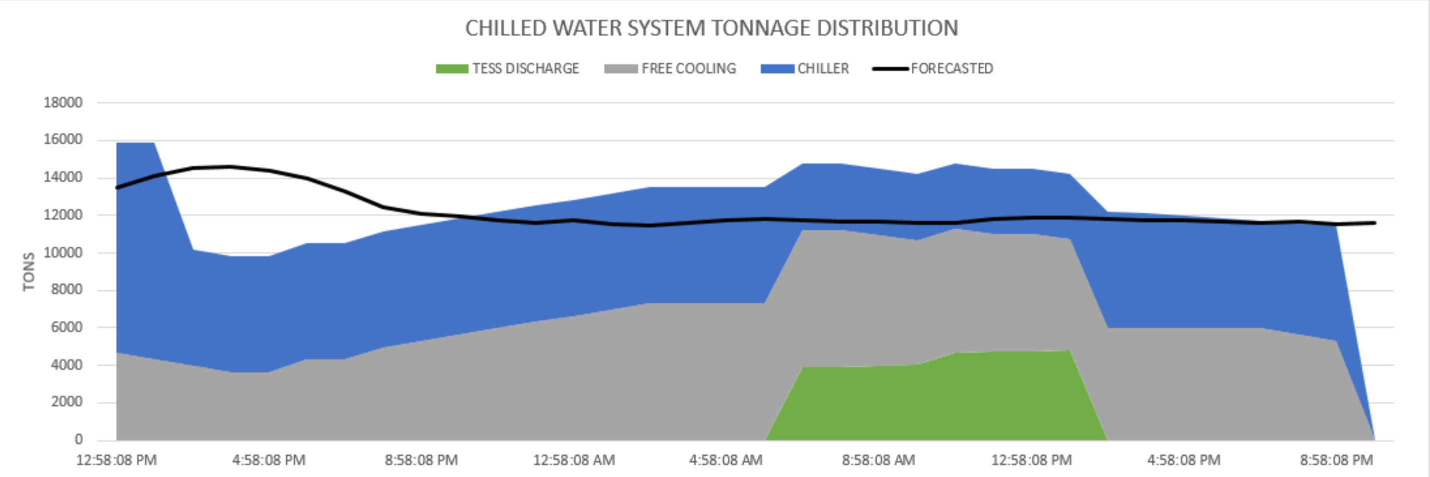


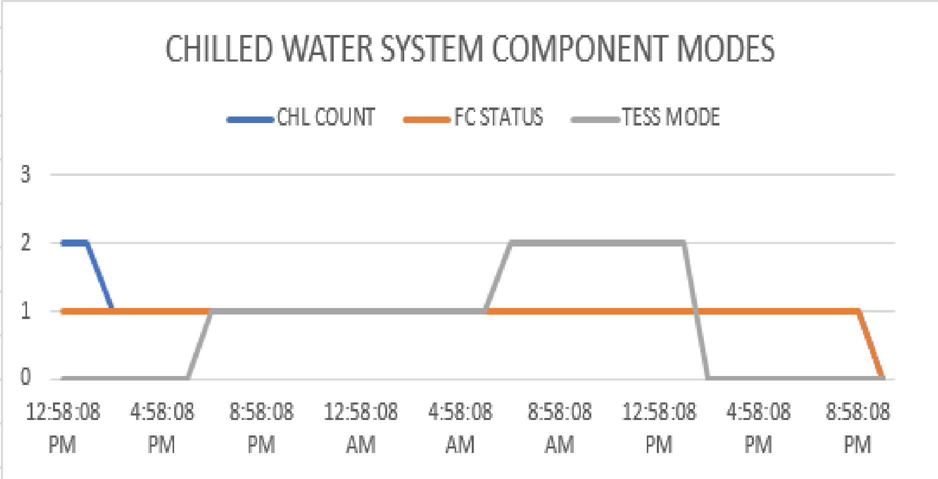
Optimization Results and Recommendations

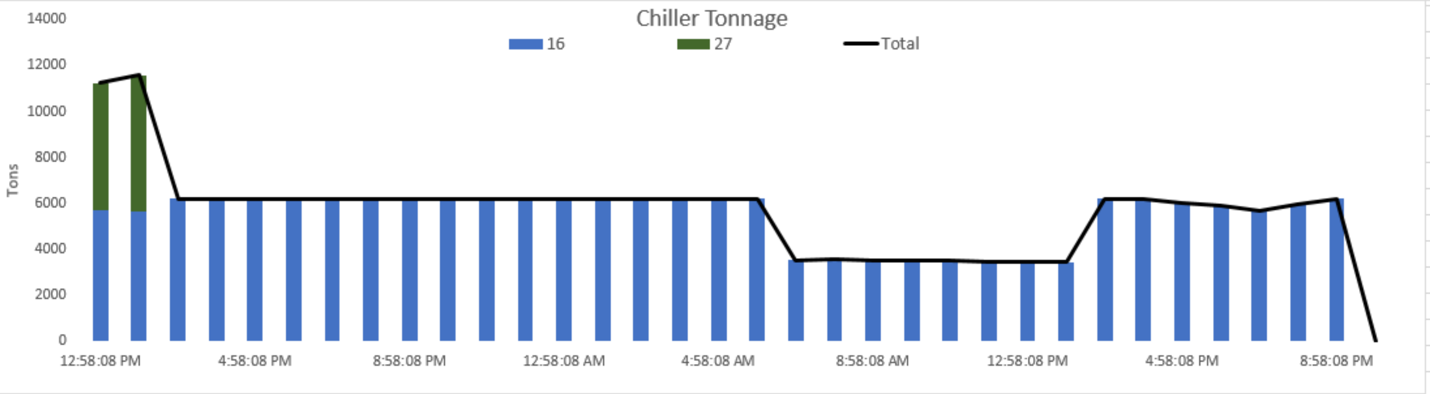
Typical Suggestions:

- Run minimum number of chillers, shift more load to the more efficient chillers or the steam turbine chiller, run more cooling tower cells to reduce the tower return temp, or increase the chilled water supply temp.









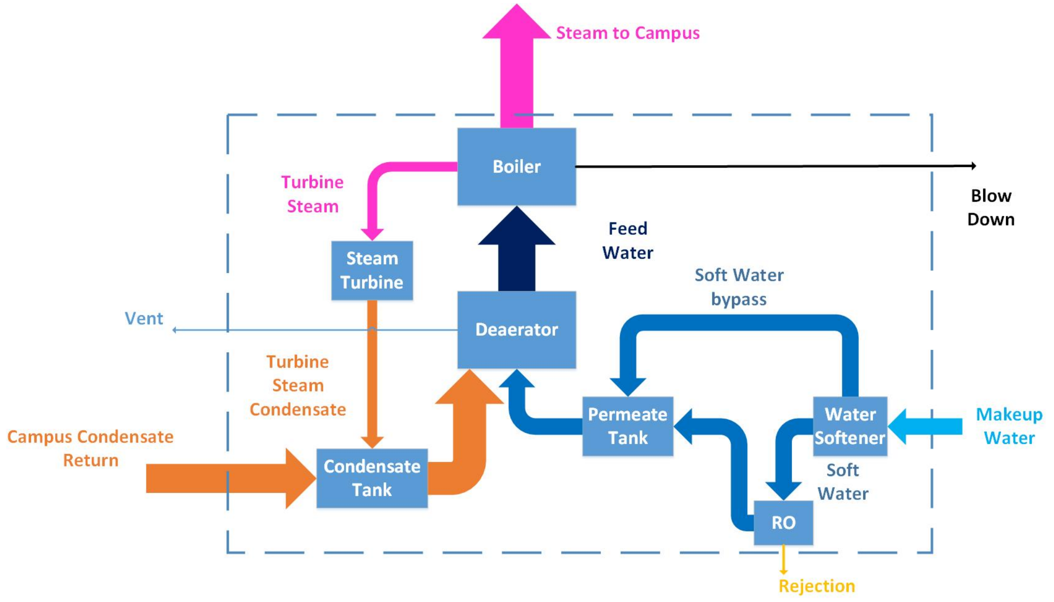
Data Quality Management

Data Generation

DQ Dimensions		Metric functions
Accuracy		$Acc = (Ncv / N)$
Completeness		$Comp = (Nmv / N)$
Consistency		$Cons = (Nvrc / N)$
Ncv	*Number of correct values*	
Nmv	*Number of missing values*	
Nvrc	*Number of values that respects the constraints*	
N	*Total number of values (rows) of the sample Dataset*	

Online statistic scan
Identify the incorrect and missing data
Clean and update the data
Calibrate and maintain the sensors
Fix the data / interface communication errors
Error propagation and metrological standards

Data Utilization

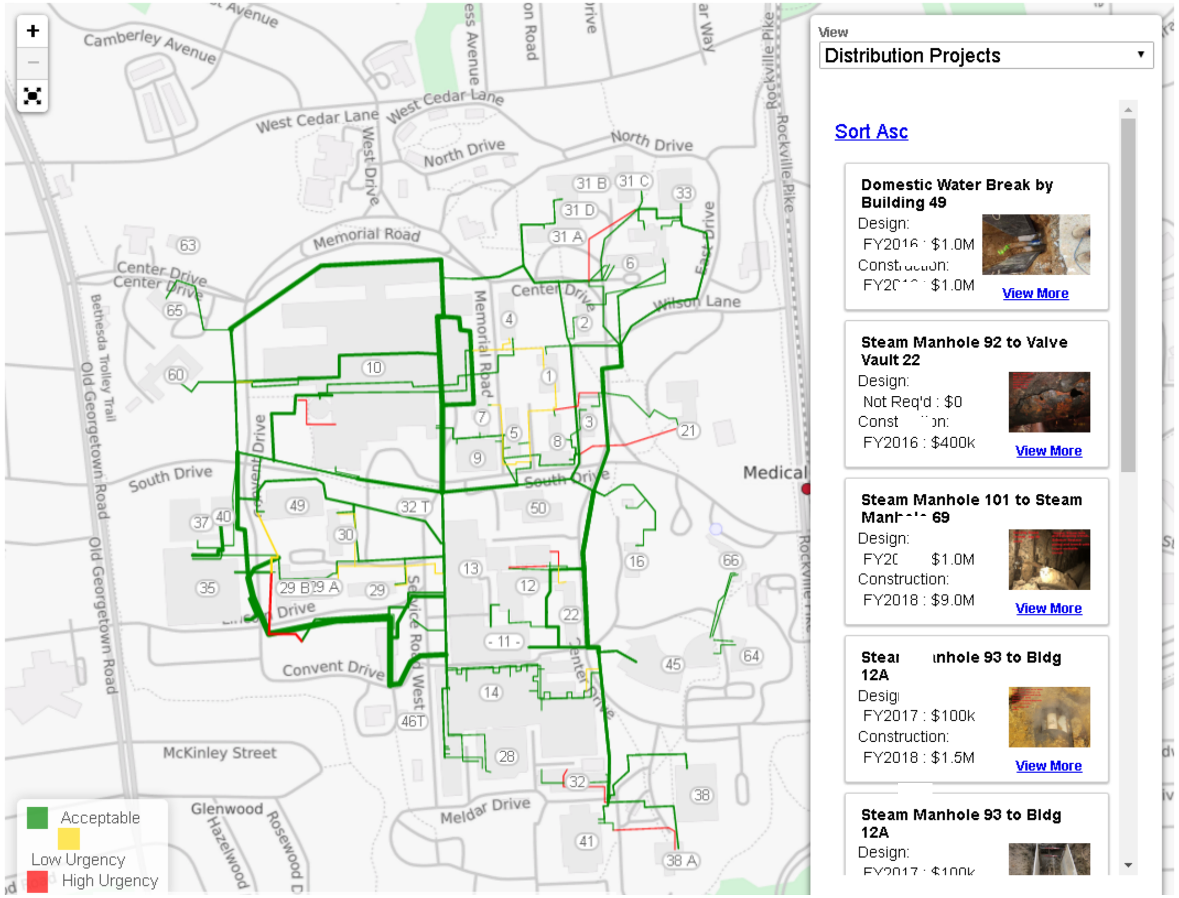


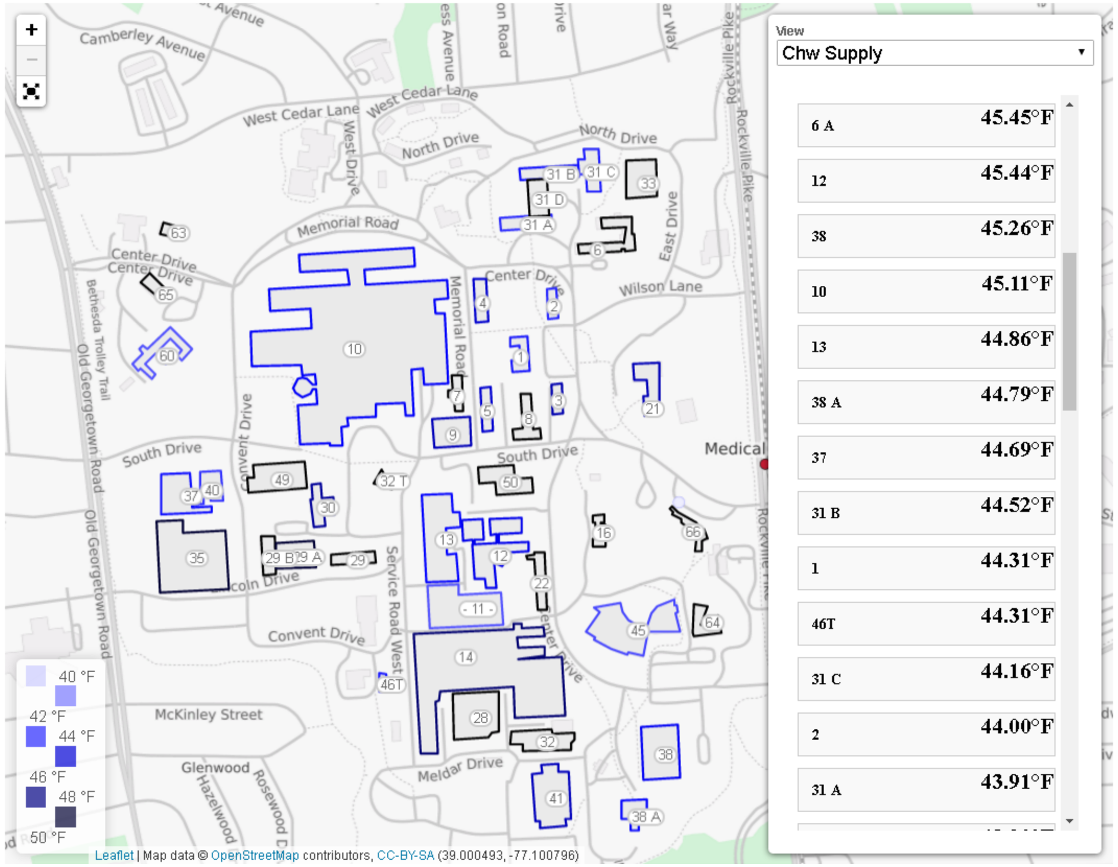
Calculation Handbook and Change Management SOP
Daily / Monthly Dashboard Review SOP
Machine baseline and health check
Energy / mass/ cost balance and cross disciplinary check
Text message & emails notifications

Real-time Data Quality Dashboard

Using GIS for Visualizing Campus Building Automation System Data

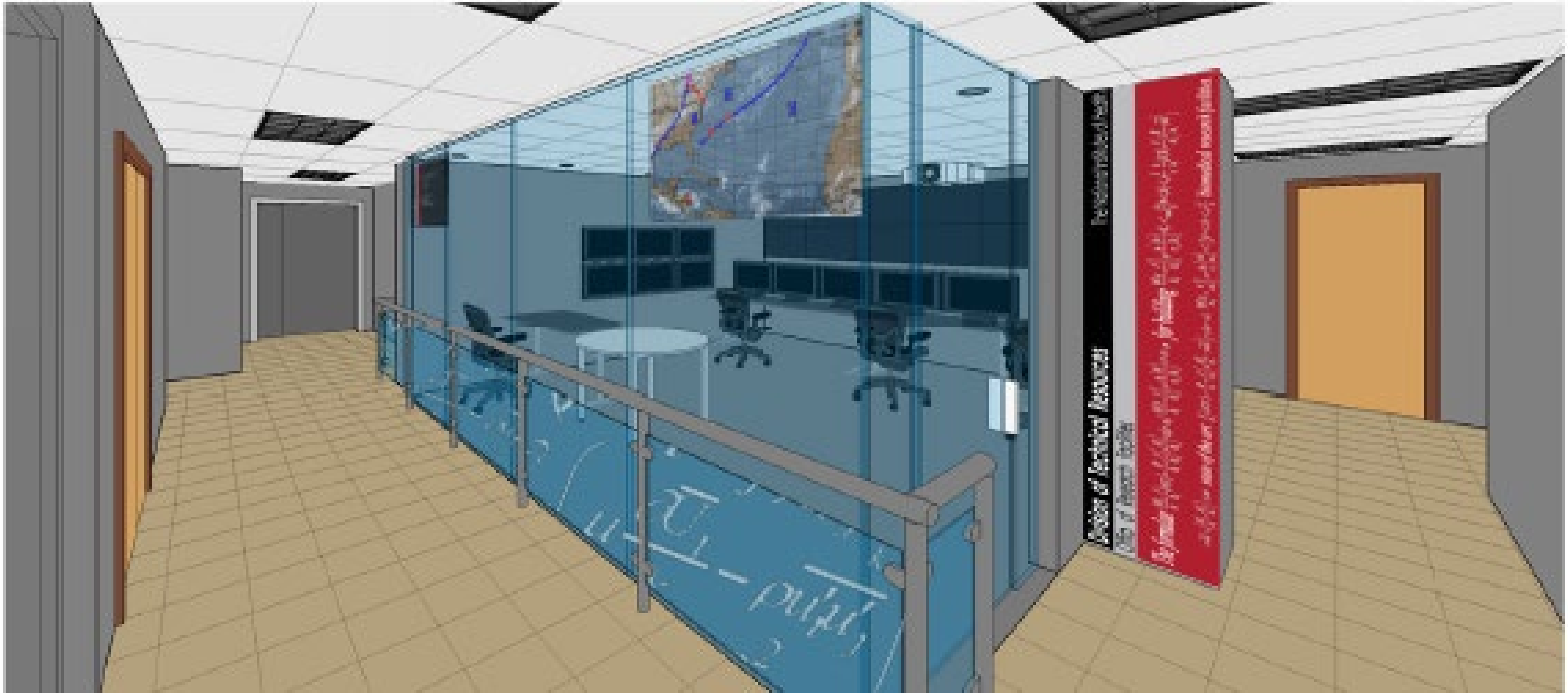
Integrate real-time data with open-source GIS to visualize real-time utility distribution information





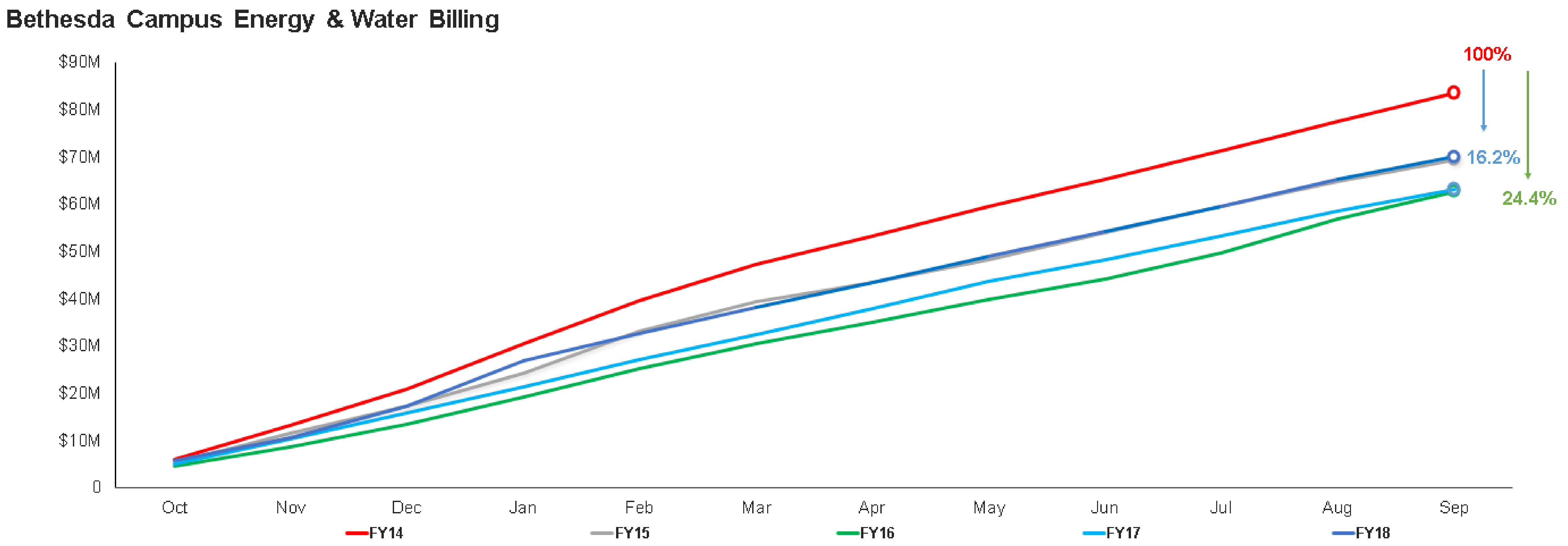
CUP Simulator

Operator training on normal and emergency scenarios, situation playback, evaluate innovative control strategy and optimize the process



Tangible Results – Financial

Millions of dollars saved despite increased utility costs & demand!



Tangible Results - Reliability

- Since FY14, no loss of control, no need for early dismissal of office buildings
- No impacts to patient safety or patient comfort
- No impacts to cGMP space – temperature, humidity, differential pressures and air change rates
- No impacts to research animals
- No impacts to biospecimens stored in ultralow temperature freezers
- Scientists able to focus on science, vice distractions associated with building issues