End to End Chilled Water Optimization
Merck West Point, PA Site

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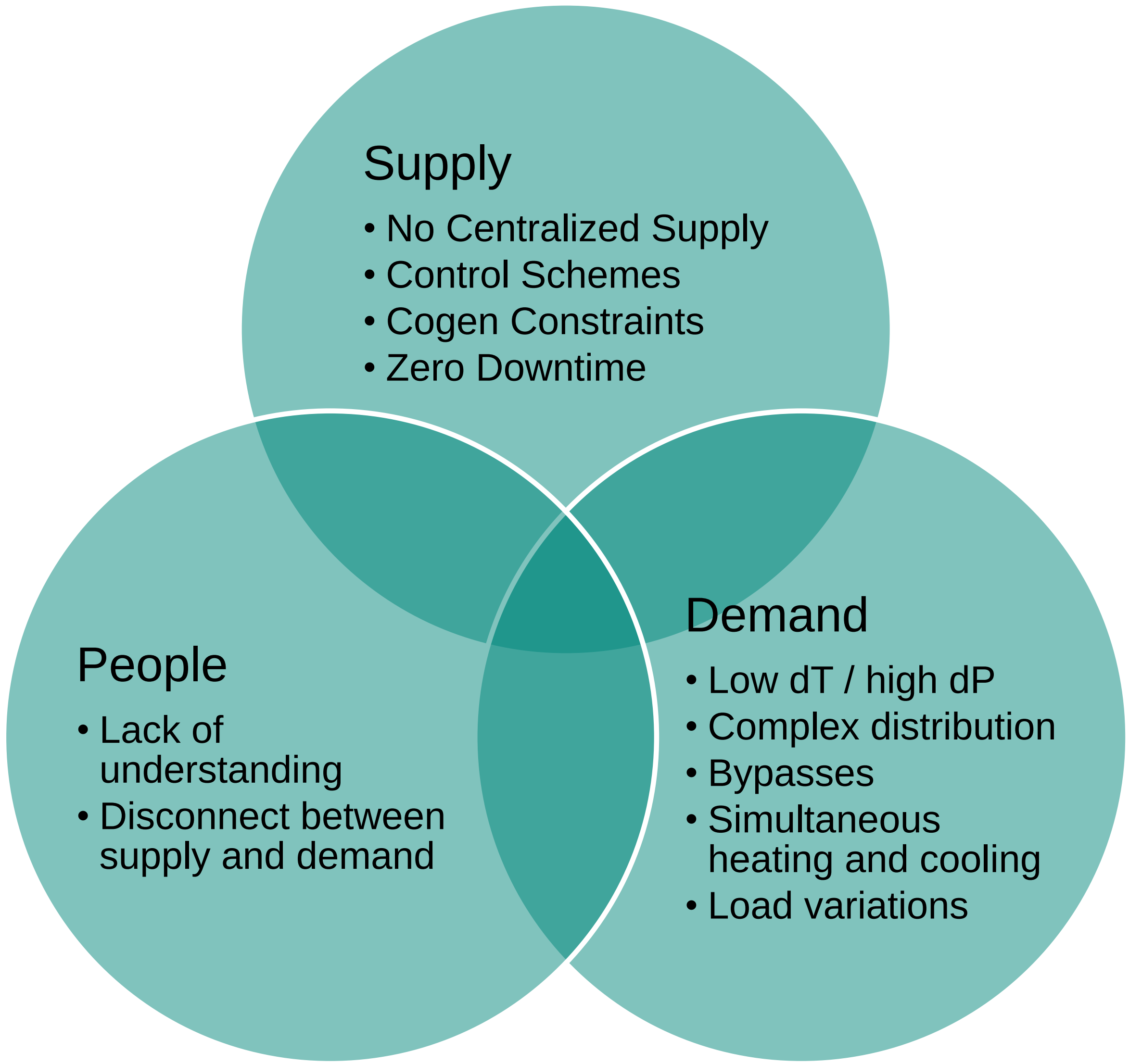
Site Background

- 500 Acre Mixed Use Manufacturing, Research, and Administration Site
  - 60+ buildings ranging in age from 1950s to 2000s
  - 6.1MM sq ft under roof
- Over 62,000 tons of installed chilled water capacity
  - 7 Plants – 43 chillers – 209 pieces of equipment
  - ~ 50/50 steam turbine and electric chillers
  - > 25 miles of distribution piping
- Unique cooling demands as a result of research and manufacturing
  - Significant variations in cooling demand from summer to winter

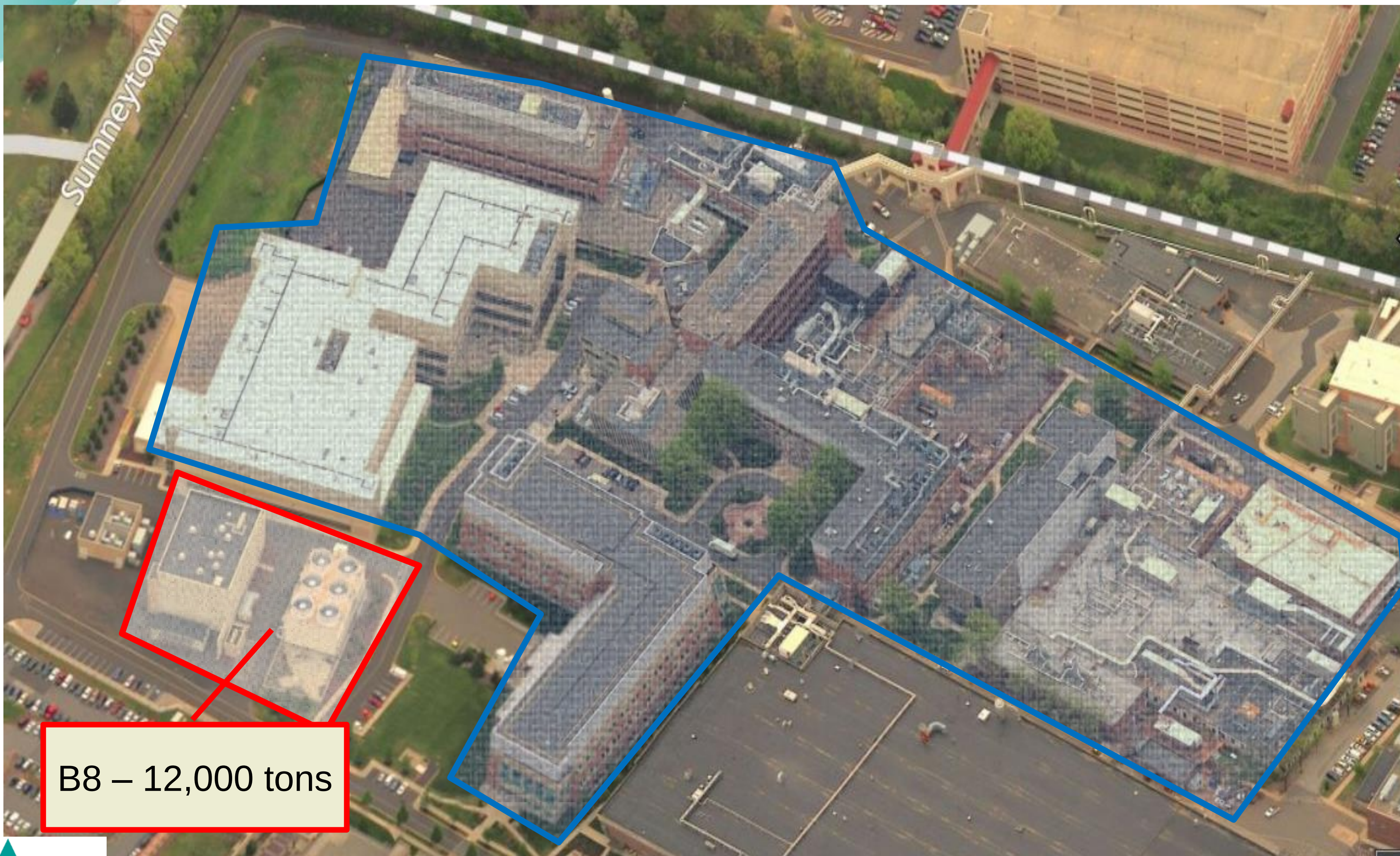
Systemic Chilled Water Challenges

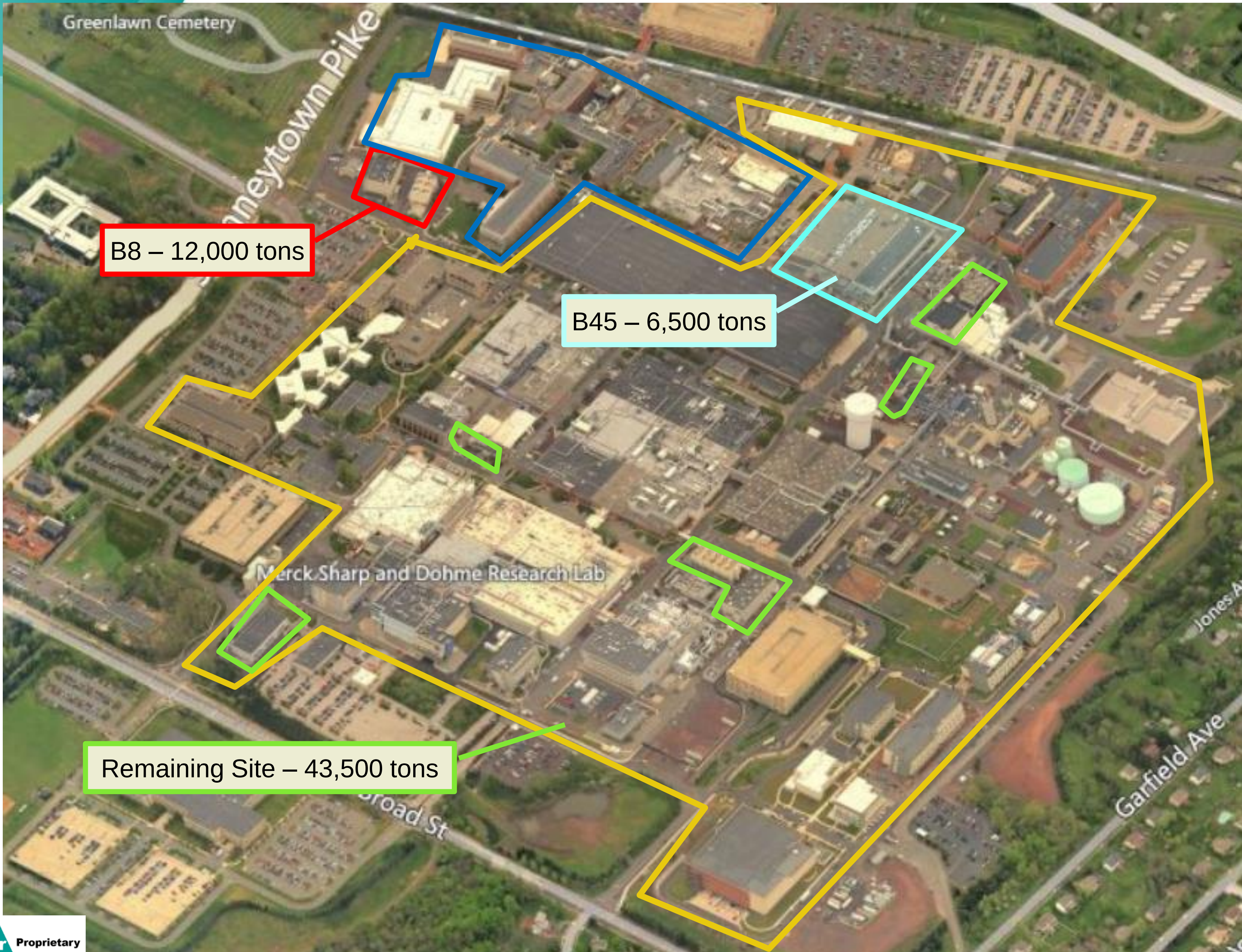


End to End Optimization Goals

- Focused "end to end" optimization of chilled water to maximize the existing plant assets and improve building performance
  - Ensure reliable supply and efficient operation
  - Utilize our existing assets smarter = eliminate waste
  - Drive down utility cost and the need for additional capital assets
  - More Available Assets = Master plan flexibility
- Establish a process as a template for the next zone of the chilled water network optimization

End to End Optimization Scope





Proprietary

End to End Optimization - Approach

Supply

- Focus on B8 plant that serves a pilot plant, multiple research and administration buildings
  - 12,000 tons – 1 electric, 5 steam turbine chillers

People

- Focus on training and awareness of chilled water system

Demand

- Focus on resolving issues in the piping system and within the user buildings by a variety of methods

End to End Optimization – Key Activities

Supply

- B8 Chiller Plant Optimization Capital Project
- Termis Solution

People

- Pilot Plant Utility Alliance
- Training of Building Managers and Mechanics
- Education for Design Engineers

Demand

- Metering HMI
- BAS Interrogation
- Brute Force Walkdowns

Supply – Optimizing CHW Generation

- Plants use four fuel sources
  - Cogen Electric
  - Cogen Steam
  - Grid Electric
  - Boiler Steam
- Systems with multiple fuel sources but be optimized on common energy units or more preferably $.
  - All upstream system efficiencies and pricing must be understood

Supply – Optimizing CHW Generation

- All optimization is non-proprietary.
- Multivariable equations with adjustable coefficients
  - Number of Pumps
    - Equation Constants
      - A: 3.60746000000
      - B: 0.00014121000
      - C: -0.00856000000
      - D: -0.00000000297
      - E: 0.00002655000
      - F: -0.00000007695
  - CWST
    - Equation Constants
      - A: 15
      - B: 4.5
      - C: 0.78

	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000	6,500	7,000	7,500	8,000	8,500	9,000	9,500	10,000	10,500	11,000	11,500	12,000	12,500	13,000	13,500	14,000	14,500
350	3.92	3.98	4.03	4.08	4.13	4.18	4.23	4.27	4.32	4.36	4.40	4.44	4.48	4.52	4.55	4.59	4.62	4.65	4.68	4.71	4.74	4.76	4.79	4.81	4.83	4.85	4.87	4.88	4.90
340	3.82	3.88	3.93	3.98	4.04	4.08	4.13	4.18	4.22	4.27	4.31	4.35	4.39	4.43	4.46	4.50	4.53	4.56	4.59	4.62	4.65	4.67	4.70	4.72	4.74	4.76	4.78	4.80	4.81
330	3.73	3.79	3.84	3.89	3.94	3.99	4.04	4.09	4.14	4.18	4.22	4.26	4.30	4.34	4.38	4.41	4.44	4.48	4.51	4.54	4.56	4.59	4.61	4.64	4.66	4.68	4.70	4.71	4.73
320	3.64	3.70	3.76	3.81	3.86	3.91	3.96	4.01	4.05	4.10	4.14	4.18	4.22	4.26	4.29	4.33	4.36	4.40	4.43	4.46	4.48	4.51	4.54	4.56	4.58	4.60	4.62	4.64	4.65
310	3.56	3.62	3.67	3.73	3.78	3.83	3.88	3.93	3.97	4.02	4.06	4.10	4.14	4.18	4.22	4.25	4.29	4.32	4.35	4.38	4.41	4.44	4.46	4.49	4.51	4.53	4.55	4.57	4.58
300	3.49	3.54	3.60	3.65	3.71	3.76	3.81	3.85	3.90	3.95	3.99	4.03	4.07	4.11	4.15	4.18	4.22	4.25	4.28	4.31	4.34	4.37	4.39	4.42	4.44	4.46	4.48	4.50	4.52
290	3.42	3.47	3.53	3.58	3.64	3.69	3.74	3.79	3.83	3.88	3.92	3.96	4.01	4.04	4.08	4.12	4.15	4.19	4.22	4.25	4.28	4.31	4.33	4.36	4.38	4.40	4.42	4.44	4.46
280	3.35	3.41	3.46	3.52	3.57	3.62	3.67	3.72	3.77	3.82	3.86	3.90	3.94	3.98	4.02	4.06	4.09	4.13	4.16	4.19	4.22	4.25	4.28	4.30	4.32	4.35	4.37	4.39	4.40
270	3.29	3.35	3.41	3.46	3.51	3.57	3.62	3.67	3.71	3.76	3.80	3.85	3.89	3.93	3.97	4.01	4.04	4.08	4.11	4.14	4.17	4.20	4.22	4.25	4.27	4.30	4.32	4.34	4.35
260	3.24	3.29	3.35	3.41	3.46	3.51	3.56	3.61	3.66	3.71	3.75	3.80	3.84	3.88	3.92	3.96	3.99	4.03	4.06	4.09	4.12	4.15	4.18	4.20	4.23	4.25	4.27	4.29	4.31
250	3.19	3.25	3.30	3.36	3.41	3.47	3.52	3.57	3.62	3.66	3.71	3.75	3.79	3.84	3.87	3.91	3.95	3.98	4.02	4.05	4.08	4.11	4.14	4.16	4.19	4.21	4.23	4.25	4.27
240	3.14	3.20	3.26	3.32	3.37	3.42	3.48	3.53	3.57	3.62	3.67	3.71	3.75	3.80	3.84	3.87	3.91	3.95	3.98	4.01	4.04	4.07	4.10	4.13	4.15	4.18	4.20	4.22	4.24
230	3.10	3.16	3.22	3.28	3.33	3.39	3.44	3.49	3.54	3.59	3.63	3.68	3.72	3.76	3.80	3.84	3.88	3.91	3.95	3.98	4.01	4.04	4.07	4.10	4.12	4.15	4.17	4.19	4.21
220	3.07	3.13	3.19	3.25	3.30	3.36	3.41	3.46	3.51	3.56	3.60	3.65	3.69	3.73	3.77	3.81	3.85	3.89	3.92	3.96	3.99	4.02	4.05	4.07	4.10	4.12	4.15	4.17	4.19
210	3.04	3.10	3.16	3.22	3.27	3.33	3.38	3.43	3.48	3.53	3.58	3.62	3.67	3.71	3.75	3.79	3.83	3.87	3.90	3.93	3.97	4.00	4.03	4.05	4.08	4.10	4.13	4.15	4.17
200	3.02	3.08	3.14	3.20	3.25	3.31	3.36	3.41	3.46	3.51	3.56	3.61	3.65	3.69	3.73	3.77	3.81	3.85	3.88	3.92	3.95	3.98	4.01	4.04	4.07	4.09	4.12	4.14	4.16
190	3.00	3.06	3.12	3.18	3.24	3.29	3.35	3.40	3.45	3.50	3.55	3.59	3.64	3.68	3.72	3.76	3.80	3.84	3.87	3.91	3.94	3.97	4.00	4.03	4.06	4.08	4.11	4.13	4.15
180	2.99	3.05	3.11	3.17	3.23	3.28	3.34	3.39	3.44	3.49	3.54	3.58	3.63	3.67	3.72	3.76	3.79	3.83	3.87	3.90	3.94	3.97	4.00	4.03	4.06	4.08	4.11	4.13	4.15
170	2.98	3.04	3.11	3.16	3.22	3.28	3.33	3.38	3.44	3.49	3.53	3.58	3.63	3.67	3.71	3.75	3.79	3.83	3.87	3.90	3.94	3.97	4.00	4.03	4.06	4.08	4.11	4.13	4.15
160	2.98	3.04	3.10	3.16	3.22	3.28	3.33	3.39	3.44	3.49	3.54	3.58	3.63	3.67	3.72	3.76	3.80	3.84	3.87	3.91	3.94	3.98	4.01	4.04	4.06	4.09	4.12	4.14	4.16
150	2.98	3.05	3.11	3.17	3.23	3.28	3.34	3.39	3.44	3.49	3.54	3.59	3.64	3.68	3.73	3.77	3.81	3.85	3.88	3.92	3.96	3.99	4.02	4.05	4.08	4.10	4.13	4.15	4.18
140	2.99	3.06	3.12	3.18	3.24	3.29	3.35	3.40	3.46	3.51	3.56	3.61	3.65	3.70	3.74	3.78	3.82	3.86	3.90	3.94	3.97	4.01	4.04	4.07	4.10	4.12	4.15	4.17	4.20
130	3.01	3.07	3.13	3.19	3.25	3.31	3.37	3.42	3.47	3.53	3.58	3.62	3.67	3.72	3.76	3.80	3.84	3.88	3.92	3.96	3.99	4.03	4.06	4.09	4.12	4.15	4.17	4.20	4.22
120	3.03	3.09	3.15	3.21	3.27	3.33	3.39	3.44	3.50	3.55	3.60	3.65	3.70	3.74	3.79	3.83	3.87	3.91	3.95	3.99	4.02	4.06	4.09	4.12	4.15	4.18	4.20	4.23	4.25
110	3.05	3.12	3.18	3.24	3.30	3.36	3.42	3.47	3.52	3.58	3.63	3.68	3.72	3.77	3.82	3.86	3.90	3.94	3.98	4.02	4.05	4.09	4.12	4.15	4.18	4.21	4.24	4.26	4.29
100	3.08	3.15	3.21	3.27	3.33	3.39	3.45	3.50	3.56	3.61	3.66	3.71	3.76	3.81	3.85	3.90	3.94	3.98	4.02	4.06	4.09	4.13	4.16	4.19	4.22	4.25	4.28	4.30	4.33
90	3.12	3.18	3.25	3.31	3.37	3.43	3.49	3.54	3.60	3.65	3.70	3.75	3.80	3.85	3.89	3.94	3.98	4.02	4.06	4.10	4.13	4.17	4.20	4.24	4.27	4.30	4.32	4.35	4.38
80	3.16	3.22	3.29	3.35	3.41	3.47	3.53	3.59	3.64	3.69	3.75	3.80	3.85	3.89	3.94	3.98	4.03	4.07	4.11	4.15	4.18	4.22	4.25	4.29	4.32	4.35	4.37	4.40	4.43
70	3.21	3.27	3.34	3.40	3.46	3.52	3.58	3.63	3.69	3.74	3.80	3.85	3.90	3.94	3.99	4.03	4.08	4.12	4.16	4.20	4.24	4.27	4.31	4.34	4.37	4.40	4.43	4.46	4.48
60	3.26	3.32	3.39	3.45	3.51	3.57	3.63	3.69	3.74	3.80	3.85	3.90	3.95	4.00	4.05	4.09	4.14	4.18	4.22	4.26	4.30	4.33	4.37	4.40	4.43	4.46	4.49	4.52	4.55
50	3.31	3.38	3.45	3.51	3.57	3.63	3.69	3.75	3.80	3.86	3.91	3.96	4.01	4.06	4.11	4.15	4.20	4.24	4.28	4.32	4.36	4.40	4.43	4.47	4.50	4.53	4.56	4.59	4.61
40	3.38	3.44	3.51	3.57	3.63	3.70	3.75	3.81	3.87	3.92	3.98	4.03	4.08	4.13	4.18	4.22	4.27	4.31	4.35	4.39	4.43	4.47	4.50	4.54	4.57	4.60	4.63	4.66	4.69

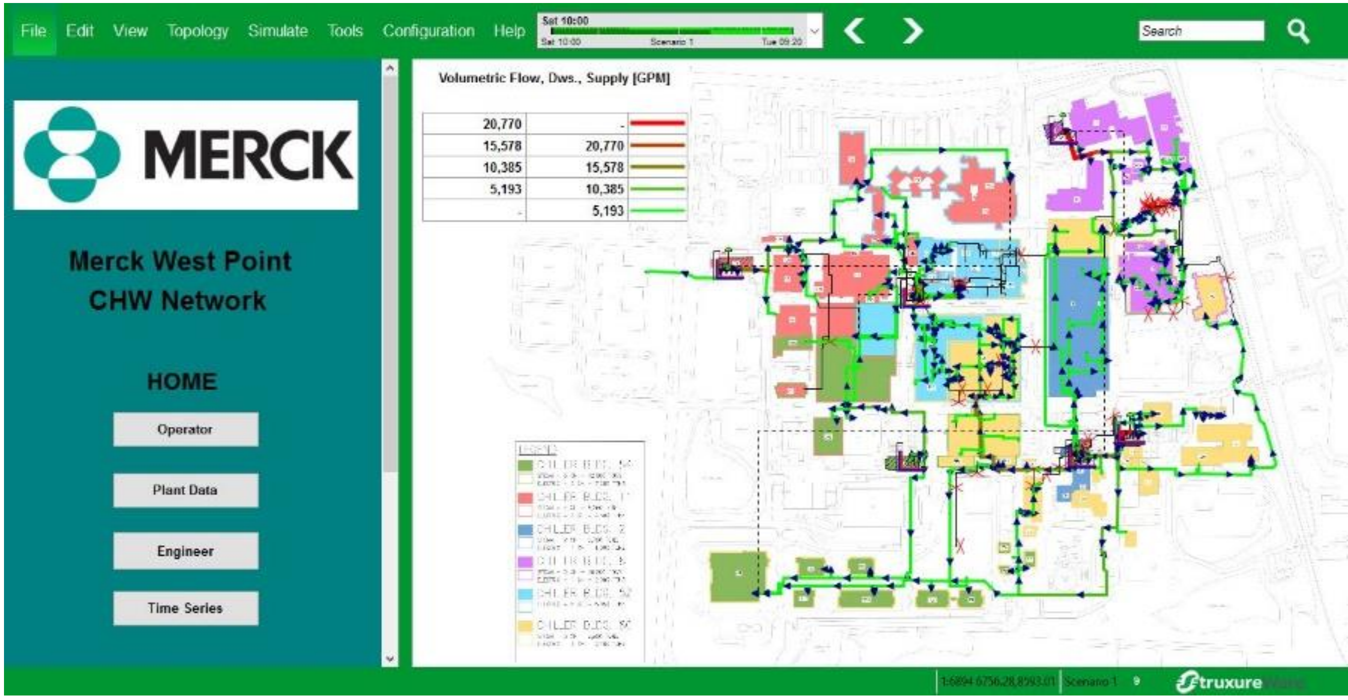
	0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%	105%	110%	115%	120%	125%	130%	135%	140%
80	77.40	77.63	77.85	78.08	78.30	78.53	78.75	78.98	79.20	79.43	79.65	79.88	80.10	80.33	80.55	80.78	81.00	81.23	81.45	81.68	81.90	82.13	82.35	82.58	82.80	83.03	83.25	83.48	83.70
78	75.84	76.07	76.29	76.52	76.74	76.97	77.19	77.42	77.64	77.87	78.09	78.32	78.54	78.77	78.99	79.22	79.44	79.67	79.89	80.12	80.34	80.57	80.79	81.02	81.24	81.47	81.69	81.92	82.14
76	74.28	74.51	74.73	74.96	75.18	75.41	75.63	75.86	76.08	76.31	76.53	76.76	76.98	77.21	77.43	77.66	77.88	78.11	78.33	78.56	78.78	79.01	79.23	79.46	79.68	79.91	80.13	80.36	80.58
74	72.72	72.95	73.17	73.40	73.62	73.85	74.07	74.30	74.52	74.75	74.97	75.20	75.42	75.65	75.87	76.10	76.32	76.55	76.77	77.00	77.22	77.45	77.67	77.90	78.12	78.35	78.57	78.80	79.02
72	71.16	71.39	71.61	71.84	72.06	72.29	72.51	72.74	72.96	73.19	73.41	73.64	73.86	74.09	74.31	74.54	74.76	74.99	75.21	75.44	75.66	75.89	76.11	76.34	76.56	76.79	77.01	77.24	77.46
70	69.60	69.83	70.05	70.28	70.50	70.73	70.95	71.18	71.40	71.63	71.85	72.08	72.30	72.53	72.75	72.98	73.20	73.43	73.65	73.88	74.10	74.33	74.55	74.78	75.00	75.23	75.45	75.68	75.90
68	68.04	68.27	68.49	68.72	68.94	69.17	69.39	69.62	69.84	70.07	70.29	70.52	70.74	70.97	71.19	71.42	71.64	71.87	72.09	72.32	72.54	72.77	72.99	73.22	73.44	73.67	73.89	74.12	74.34
66	66.48	66.71	66.93	67.16	67.38	67.61	67.83	68.06	68.28	68.51	68.73	68.96	69.18	69.41	69.63	69.86	70.08	70.31	70.53	70.76	70.98	71.21	71.43	71.66	71.88	72.11	72.33	72.56	72.78
64	64.92	65.15	65.37	65.60	65.82	66.05	66.27	66.50	66.72	66.95	67.17	67.40	67.62	67.85	68.07	68.30	68.52	68.75	68.97	69.20	69.42	69.65	69.87	70.10	70.32	70.55	70.77	71.00	71.22
62	63.36	63.59	63.81	64.04	64.26	64.49	64.71	64.94	65.16	65.39	65.61	65.84	66.06	66.29	66.51	66.74	66.96	67.19	67.41	67.64	67.86	68.09	68.31	68.54	68.76	68.99	69.21	69.44	69.66
60	61.80	62.03	62.25	62.48	62.70	62.93	63.15	63.38	63.60	63.83	64.05	64.28	64.50	64.73	64.95	65.18	65.40	65.63	65.85	66.08	66.30	66.53	66.75	66.98	67.20	67.43	67.65	67.88	68.10
58	60.24	60.47	60.69	60.92	61.14	61.37	61.59	61.82	62.04	62.27	62.49	62.72	62.94	63.17	63.39	63.62	63.84	64.07	64.29	64.52	64.74	64.97	65.19	65.42	65.64	65.87	66.09	66.32	66.54
56	58.68	58.91	59.13	59.36	59.58	59.81	60.03	60.26	60.48	60.71	60.93	61.16	61.38	61.61	61.83	62.06	62.28	62.51	62.73	62.96	63.18	63.41	63.63	63.86	64.08	64.31	64.53	64.76	64.98
54	57.12	57.35	57.57	57.80	58.02	58.25	58.47	58.70	58.92	59.15	59.37	59.60	59.82	60.05	60.27	60.50	60.72	60.95	61.17	61.40	61.62	61.85	62.07	62.30	62.52	62.75	62.97	63.20	63.42
52	55.56	55.79	56.01	56.24	56.46	56.69	56.91	57.14	57.36	57.59	57.81	58.04	58.26	58.49	58.71	58.94	59.16	59.39	59.61	59.84	60.06	60.29	60.51	60.74	60.96	61.19	61.41	61.64	61.86
50	54.00	54.23	54.45	54.68	54.90	55.13	55.35	55.58	55.80	56.03	56.25	56.48	56.70	56.93	57.15	57.38	57.60	57.83	58.05	58.28	58.50	58.73	58.95	59.18	59.40	59.63	59.85	60.08	60.30
48	52.44	52.67	52.89	53.12	53.34	53.57	53.79	54.02	54.24	54.47	54.69	54.92	55.14	55.37	55.59	55.82	56.04	56.27	56.49	56.72	56.94	57.17	57.39	57.62	57.84	58.07	58.29	58.52	58.74
46	50.88	51.11	51.33	51.56	51.78	52.01	52.23	52.46	52.68	52.91	53.13	53.36	53.58	53.81	54.03	54.26	54.48	54.71	54.93	55.16	55.38	55.61	55.83	56.06	56.28	56.51	56.73	56.96	57.18
44	50.00	50.00	50.00	50.00	50.22	50.45	50.67	50.90	51.12	51.35	51.57	51.80	52.02	52.25	52.47	52.70	52.92	53.15	53.37	53.60	53.82	54.05	54.27	54.50	54.72	54.95	55.17	55.40	55.62
42	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.01	50.24	50.46	50.69	50.91	51.14	51.36	51.59	51.81	52.04	52.26	52.49	52.71	52.94	53.16	53.39	53.61	53.84	54.06
40	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.03	50.25	50.48	50.70	50.93	51.15	51.38	51.60	51.83	52.05	52.28	52.50
38	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.04	50.27	50.49	50.72	50.94
36	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
34	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
32	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
30	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
28	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
26	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
24	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
22	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
20	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
18	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00

- Data from PI is run through machine learning and constants can be updated as frequently as desired

Supply – Optimizing CHW Distribution

Distribution Optimization with Termis

- Macro Distribution Decisions and Planning
- Potential Elimination of Chiller Plant B52
- Interconnection of all plants
- Plant Dispatch

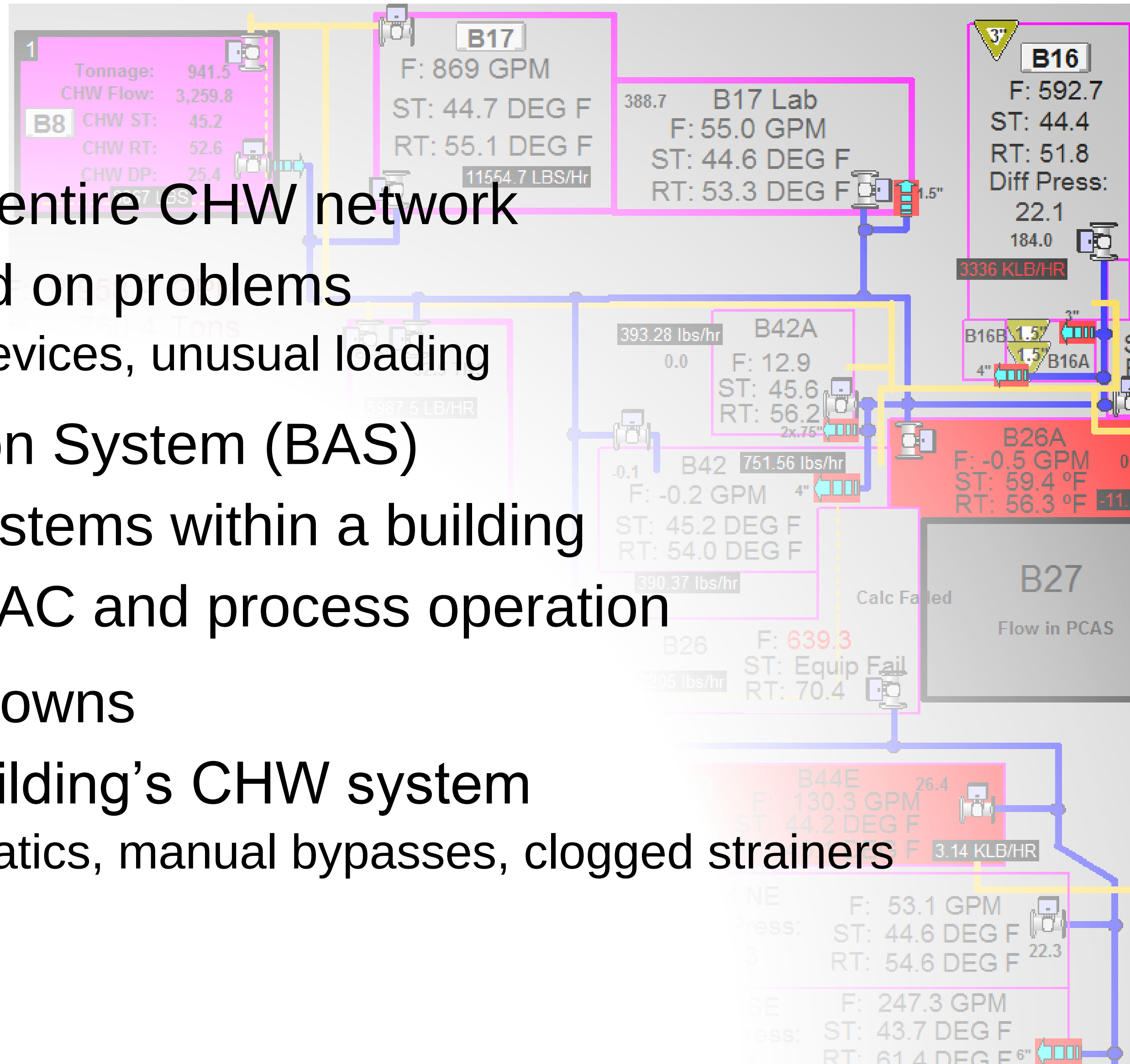


Demand – Optimizing Customer Usage

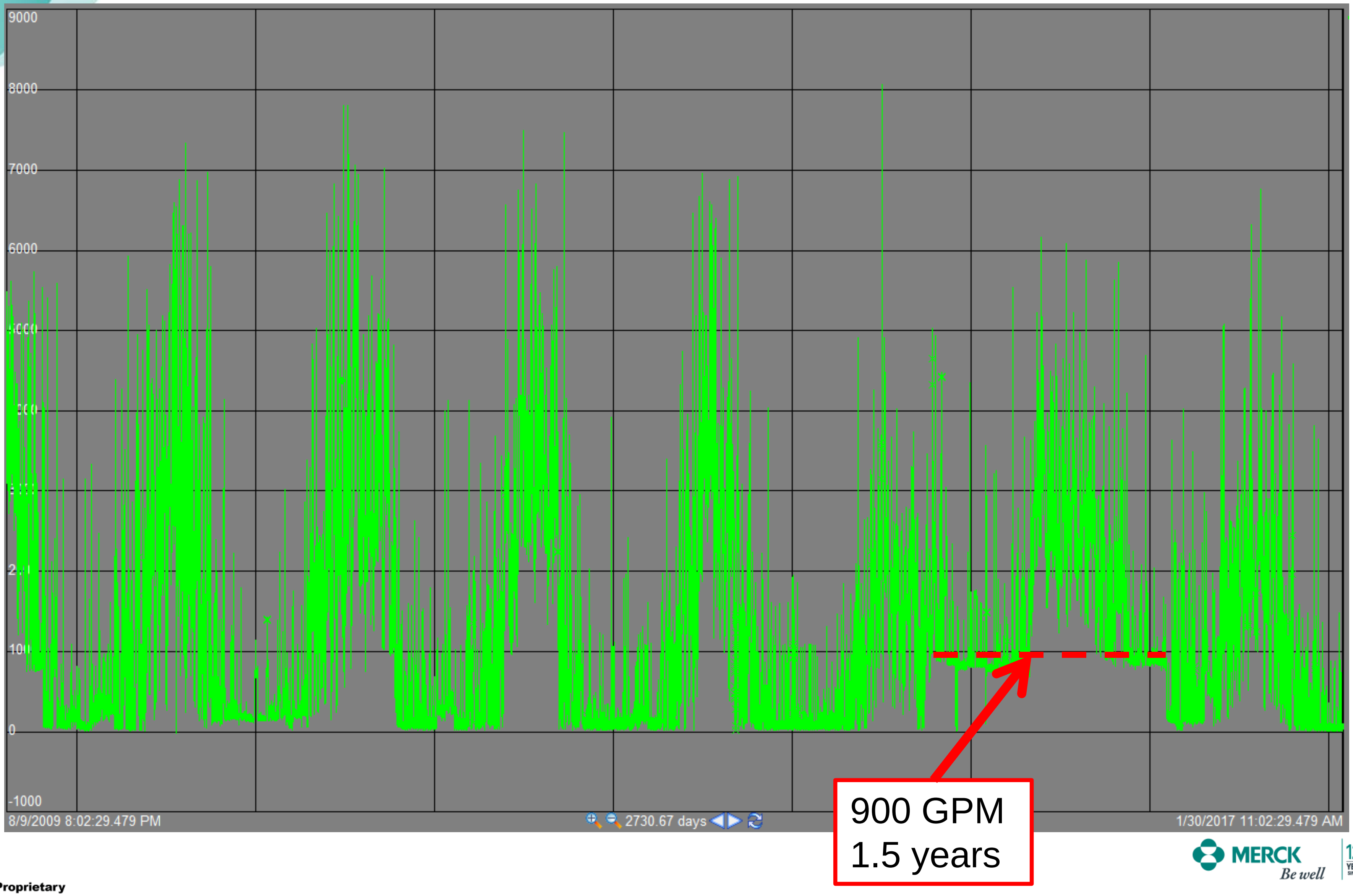
- Policing our utility customers
  - Equipment overrun caused by low delta T
    - High flow + Low load = Poor COP
    - Isolate unloaded CHW flow
      - 3-way valves, bypasses, OOS equipment
- Big data at our disposal
  - 450 CHW instruments
  - >4,000 calculated tags
    - Tonnage, dT, dP, totalization, cost
  - Need a filter to help locate problems only
- Creation of a new HMI

Demand – Data Driven Investigations

- Processbook HMI
  - Holistic view of entire CHW network
  - Visually focused on problems
    - dT, dP, failed devices, unusual loading
- Building Automation System (BAS)
  - CHW control systems within a building
  - Focused on HVAC and process operation
- Brute Force Walkdowns
  - “Health” of a building’s CHW system
    - Leaking pneumatics, manual bypasses, clogged strainers



Case Study: B14 Low dT Investigation



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MERCK
Be well
125 YEARS

Case Study: B14 Low dT Investigation

- Chilled Water ΔT
  - ΔT is the temperature difference between supply and return water flowing through a building
    - This temperature is a very good indicator for malfunctioning valves that are not maintaining adequate flow
  - Typically this temperature is ~10°F by design throughout the year
  - B14's average ΔT was about 4°F!
- The Culprit: AHU 7
  - February 2016 AHU 7 was found to be off with its CHW control valve wide open due to a design flaw
    - This valve was allowing roughly 800 GPM through the AHU for 1.5 years or about 600,000,000 gallons

Demand – The Metering Problem

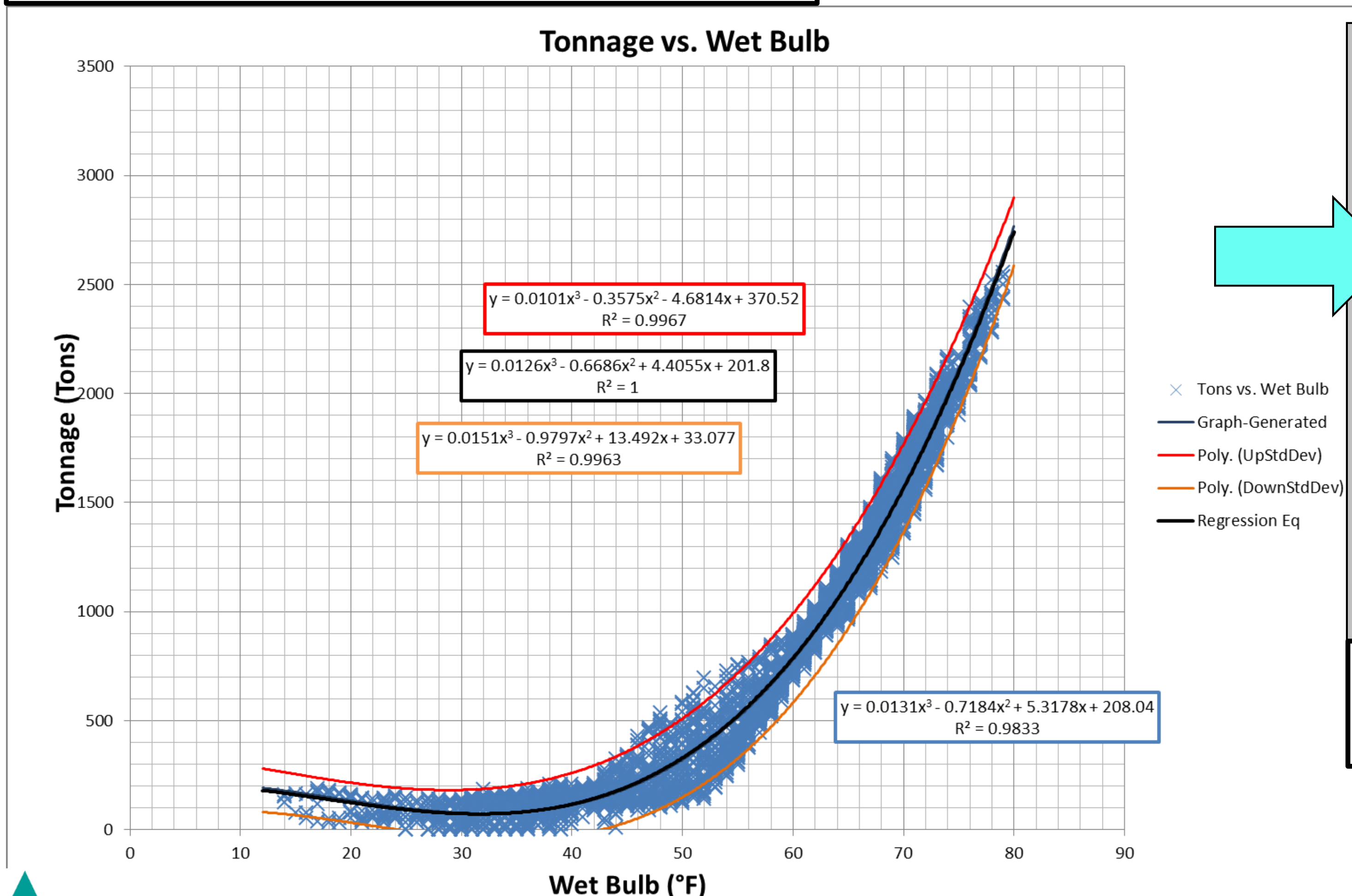
- Building load regressions
  - How has the building behaved in the past?
    - Dependency on weather conditions
- Error detection equation

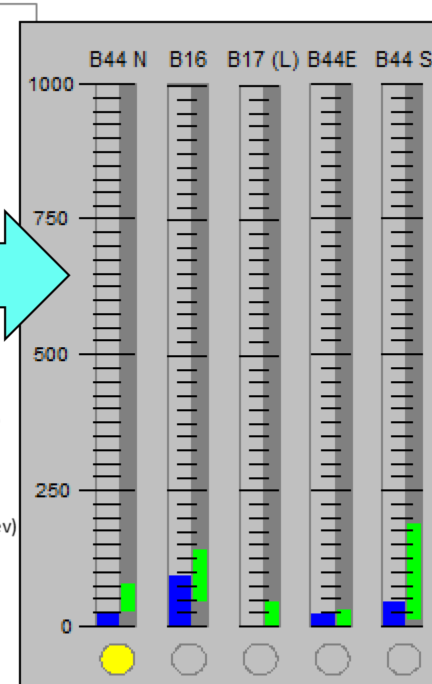
$$PI\ \exp = \frac{(0.01681 * WB^3 - 1.59587 * WB^2 + 47.20835 * WB - 451.85376) - (B14\ tonnage)}{(0.003 * WB^3 - 0.51214 * WB^2 + 18.4556 * WB - 291.935)} + 10$$

  - Derived from PI historian data using PI Datalink
    - Custom built report automatically creates PI expressions
  - Detects unusual load conditions based on OA wet bulb temp
- Translation to HMI
  - Must be illustrated graphically to have use
  - Gives user clear indication of need to act

Demand – Creating Active Regressions

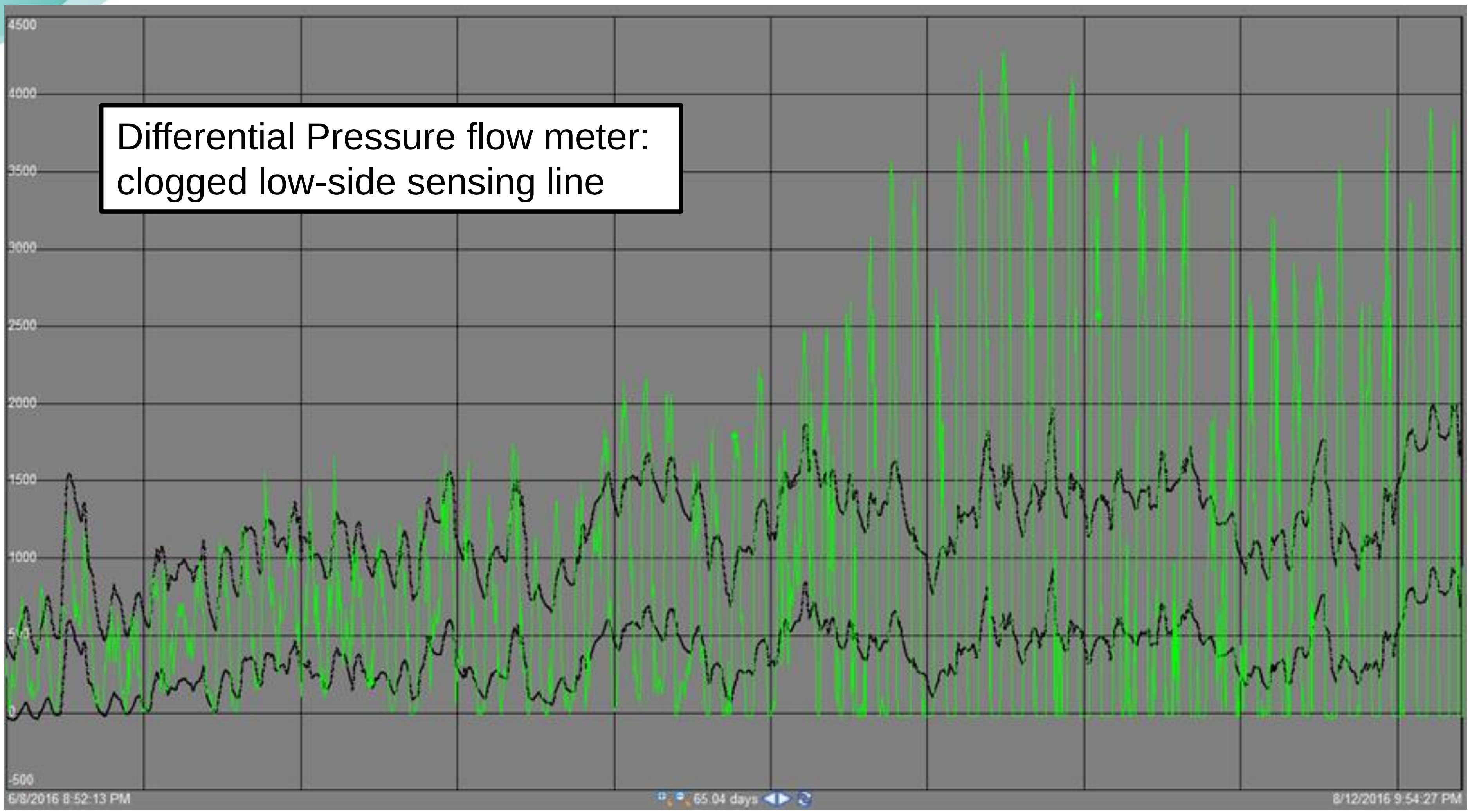
Building tonnage behavior (PI Datalink)





Real-time HMI (PI Processbook)

Demand – Error Detection in Action



People

- Pilot Plant Utility Alliance
  - Identified as the largest consumer of chilled water (among other utilities)
    - Cross functional team established with strong building leadership to improve efficiency
- Training of Demand Side Owners and Mechanics
  - Supply side driven effort to train the building managers and their mechanics as to the impact of inefficient use of chilled water
- Education For Design Engineers
  - Central utilities involved in early design decisions
  - Established a notification process for using CHW

End to End Optimization – Results Summary

B08 Optimization Results
(Pre Machine Learning)

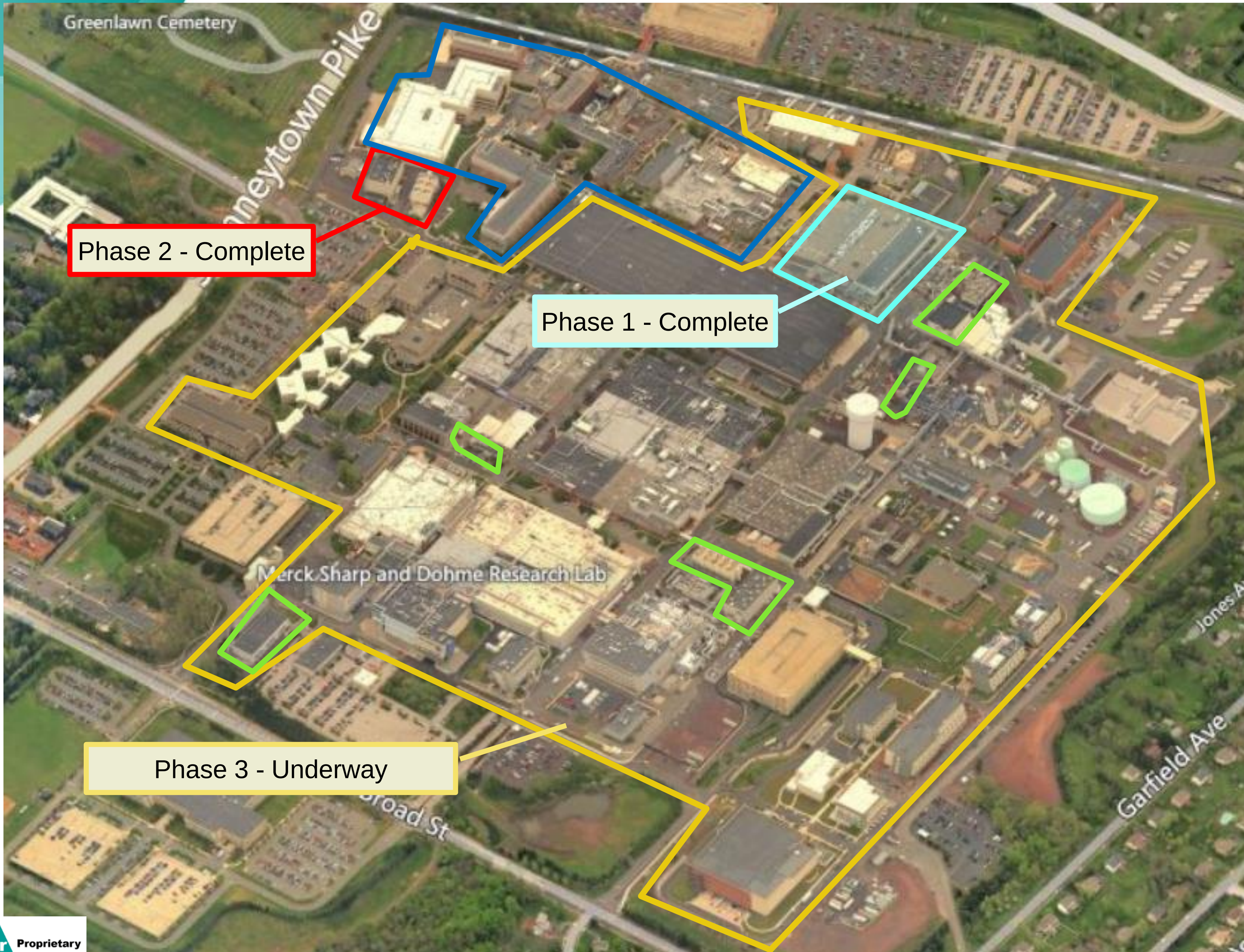
	Pre-Optimization		Post Optimization			Savings	
	7/1/2013	7/1/2016	7/5/2016	11/15/2016			
Steam Chiller Average lb/Ton		11.10		9.40	lb/Ton	15%	%
Elec Chiller Average kW/Ton		0.76		0.63	kW/Ton	17%	%
CHW Pump Average kW/Ton		0.114		0.057	kW/Ton	50%	%
CW Pump Average kW/Ton		0.174		0.128	kW/Ton	26%	%
CT Fan Average kW/Ton		0.068		0.054	kW/Ton	20%	%

Lessons Learned

- GENERAL
  - No silver bullet solution – customizable approach for each situation
    - Complex relationships between supply and demand exist
- SUPPLY
  - Chiller plant optimization without demand side optimization is short sighted
    - Machine learning and network distribution optimization is the current focus
- DEMAND
  - Metering is key!
    - Need to have eyes on the system at all time
    - Being able to quantify low delta T and converting it a meaningful metric
  - Fresh eyes are needed for field walkdowns
- PEOPLE
  - Training and re-training is key
    - Speak demand side language (criticality, risk, compliance)

Next Steps

- SUPPLY
  - Future Optimization
    - Optimizing the balance of the plant CHW systems over the next 3 years
  - Termis calibration and utilization for operational improvements and site master planning
- DEMAND
  - Metering
    - Significant investment in metering of buildings
- PEOPLE
  - Continuing to promote connection between chilled water optimization and overall system reliability
    - Speaking production and research language



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Thank You / Questions?