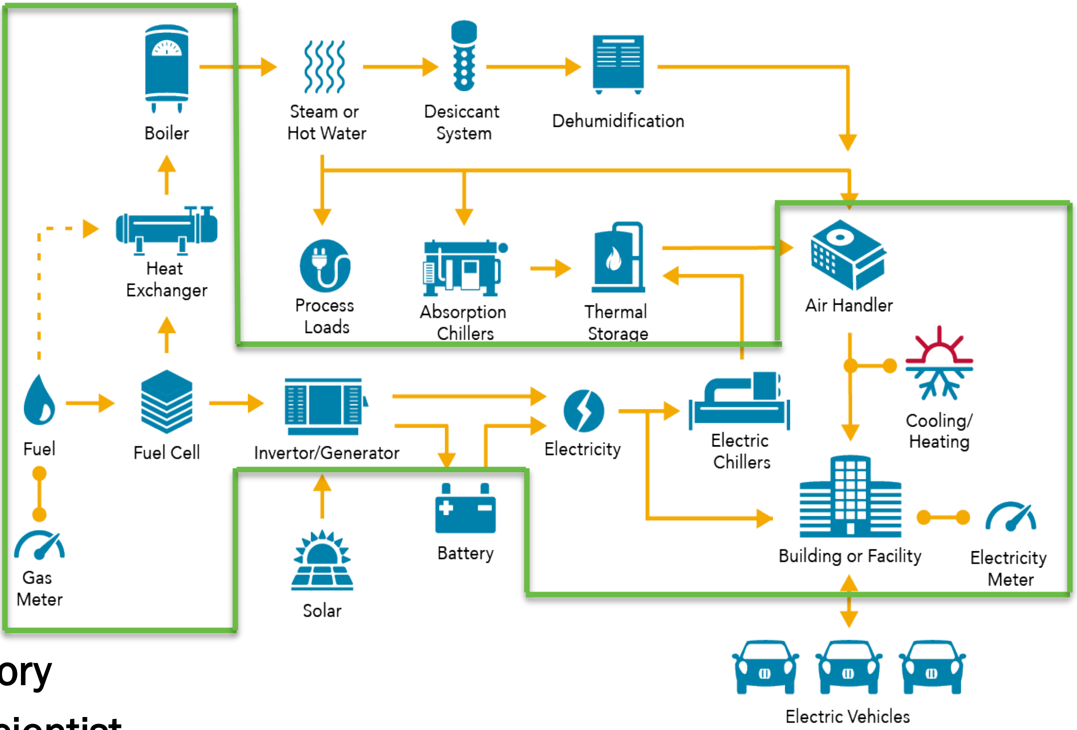
U.S. DEPARTMENT OF
ENERGY
Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

# Economic Dispatch:
# VOLTTRON™ Controller for Energy Systems



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# Project Summary

## Timeline:

Start date: March 2016

Planned end date: March 2019

Key Milestones

1. Testing of algorithms with offline data complete; 6/30/2017
2. Integration of all algorithms with VOLTTRON™ complete; 3/31/2018
3. Field validation and documentation of results complete; 3/31/2019

## Budget:

**Total Project $ to Date:**

- DOE: $2.25M
- Cost Share: NA

**Total Project $:**

- DOE: $2.25M
- Cost Share: $0

## Key Partners:

| |
|---|
| Arizona State University (ASU) |
| Washington State University (WSU) |
| Frontier Energy |

## Project Outcome:

- Maximum return-on-investment of combined cooling-heating and power systems
- VOLTTRON-compatible real-time control algorithms packaged as a fully functional toolkit
- Supervisory control and generalized economic dispatch developed with inclusion of short-term weather and load forecasting, management of short-term imbalance between local generation and demand and performance monitoring and fault detection, and diagnostics and automated continuous commissioning
- Contribute to Building Technology Office, Grid Modernization Laboratory Consortium and Grid Modernization Initiative goals – optimizing transaction-based controls between buildings and grid

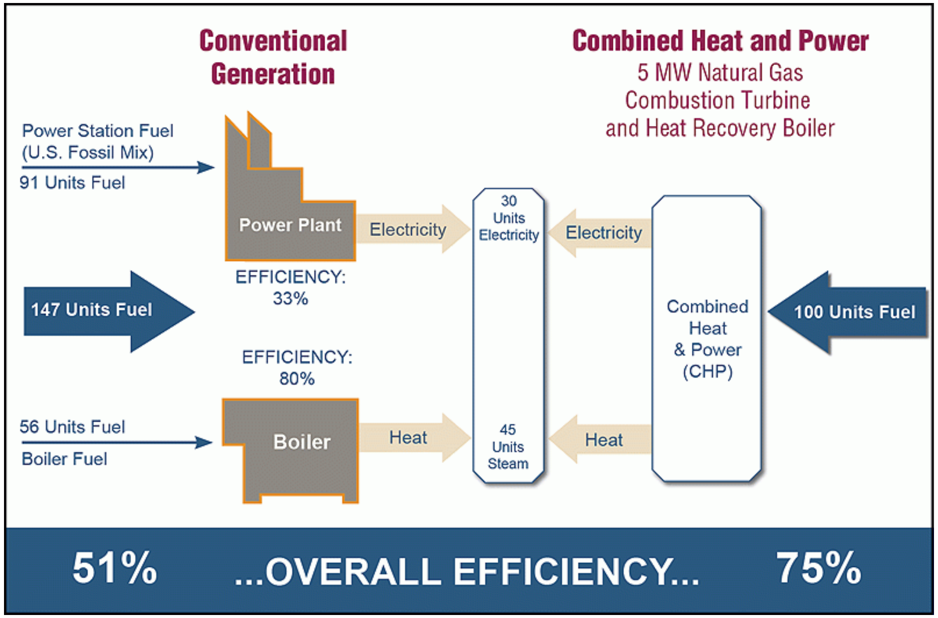
# Team

- **PNNL**: Lead
  - Key team members: Srinivas Katipamula, PI, Nick Fernandez, Di Wu, Kyle Monson and Mike Roup
- **ASU**:
  - PI, Dr. Reddy, has written a textbook that covers this general subject matter
- **WSU**:
  - PI, Dr. McLarty, was a primary developer of the DG-BEAT, CCHP design tool
- **Frontier Energy**:
  - PI, Hugh Henderson, has significant experience in field validation of CCHP technologies

# Challenge

- Today, economic benefit from building-integrated **combined cooling, heating and power** (CCHP) systems is often **not fully realized** because of lack of integrated dispatch and control solution
  - Technical potential for <1MW CCHP systems is 38GW*

- Distributed renewable energy generation is increasing and operation of heating, ventilation, and air conditioning system is lacking



https://www.epa.gov/chp/chp-benefits

*US Department of Energy, Combined Heat and Power (CHP) Technical Potential in the United States, March 2016

- To operate such complex systems in an “optimal” manner, **building operators** need real-time control systems based on price signals, monitored performance data, inverse models (accurate physics-based or empirical) and risk preferences
  - Such a capability will allow building operators/owners to make sound, practical and cost-effective decisions under uncertainty
- Low-cost control solutions that can handle highly dynamic nature of thermal and electric loads and time-varying energy prices in building applications **do not yet exist**

# Approach: Overcoming Barriers to Building-Integrated CCHP Systems

- Develop and validate:
  - A controller that dispatches power and thermal energy, where energy is produced and consumed at the lowest cost achievable while reliably meeting building needs—enabling "optimal economic dispatch"
  - A set of algorithms packaged as a toolkit:
    - supervisory control and economic dispatch
    - forecasting of short-term weather and loads
    - management of short-term imbalance between local generation and demand
    - performance monitoring
    - AFDD
- Testing, integration, and validation using open source VOLTTRON transactive energy reference platform

*Supply-side generation, such as fuel cells, and demand-side technologies, such as HVAC systems, can be brought together to serve as combined cooling, heat, and power systems.*

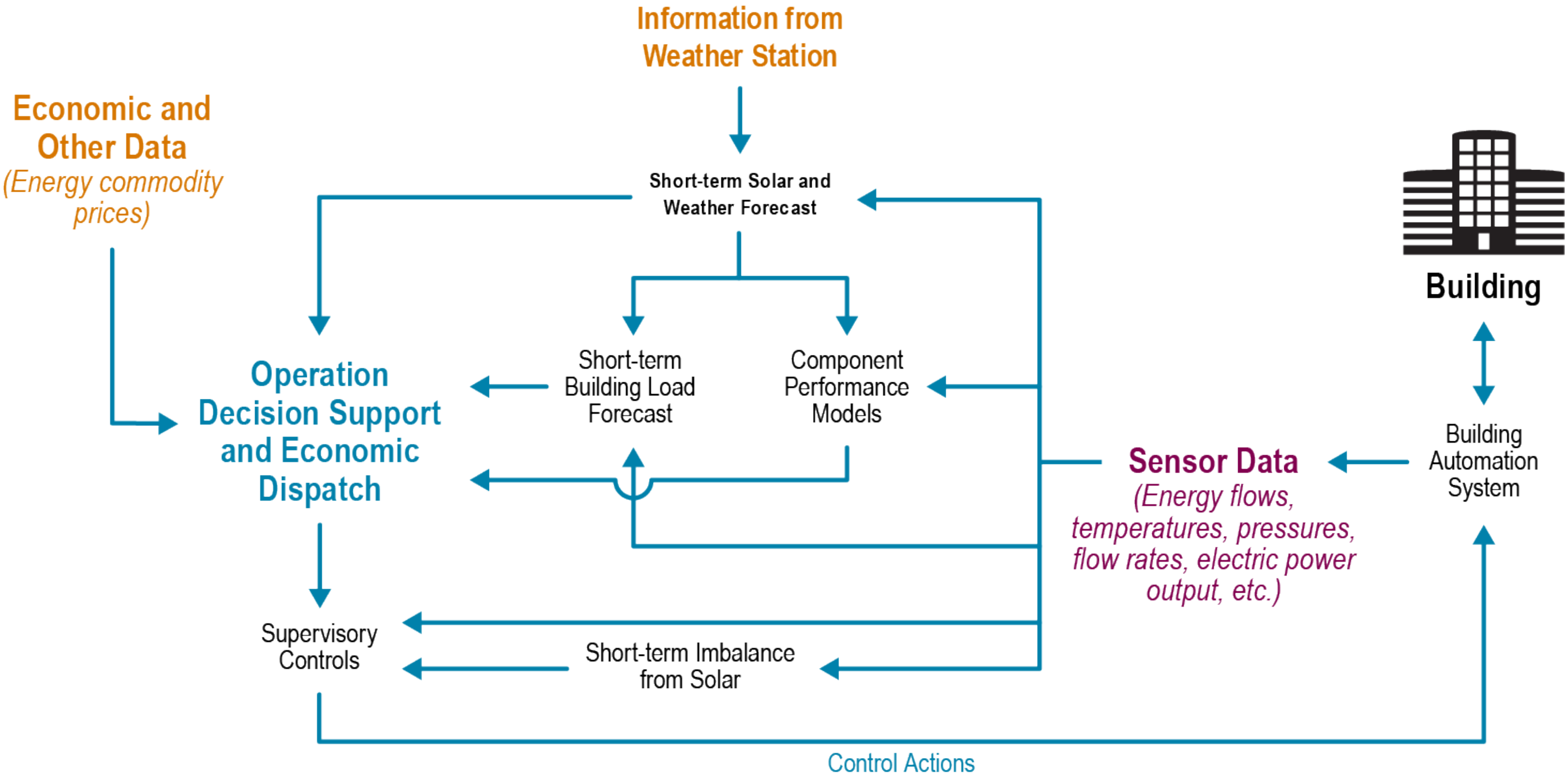
*The controller and associated algorithms will be tested, integrated and validated on the VOLTTRON platform.*

# Approach (cont.)

- Development of Models:
  - Weather forecast models to predict solar irradiation to better manage and integrate onsite solar PV
  - Inverse empirical models for forecasting electric and thermal loads
  - Performance models for prime movers, heat recovery heat exchangers, absorption and vapor compression chillers, boilers, and other HVAC equipment
- Development of Algorithms:
  - Combining component models, developing generalized economic dispatch and supervisory control algorithms for day-ahead and shorter-term operations
  - AFDD for ensuring performance
- Testing and Validation:
  - Algorithms coded in Python programming using open-source libraries and deployed on the VOLTTRON platform-hosted controller

The economic dispatch and supervisory control software will be deployed on the versatile and secure VOLTTRON™ distributed control platform, hosted on a low-cost (<$200) hardware and integrated with the existing building automation system

# Approach: Economic Dispatch Process



Information from Weather Station

Economic and Other Data

*(Energy commodity prices)*

Short-term Solar and Weather Forecast

Building

Short-term Building Load Forecast

Component Performance Models

Operation Decision Support and Economic Dispatch

Building Automation System

**Sensor Data**

*(Energy flows, temperatures, pressures, flow rates, electric power output, etc.)*

Supervisory Controls

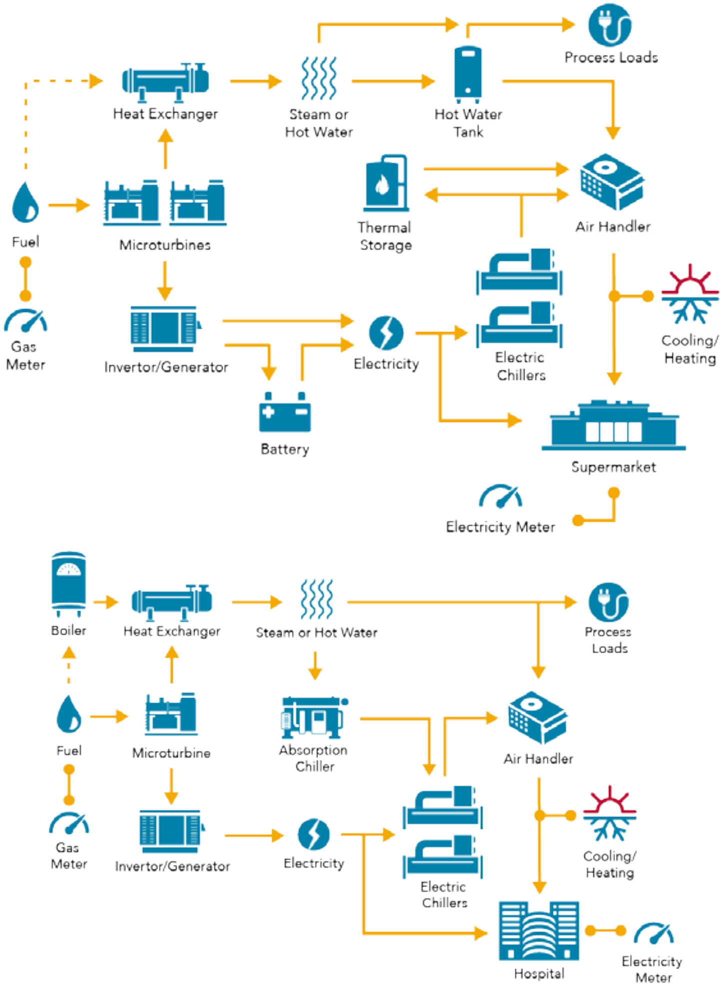
Short-term Imbalance from Solar

Control Actions

# Approach: Key Issues

Enable next-generation CCHP controls thru design, development, testing, and validation of algorithms deployed via VOLTTRON

- Resulting capability will:
  - **Address technical and economic** barriers
  - **Accelerate adoption** of building-integrated CCHP systems by providing improvements that **minimize operational cost and maximize return-on-investments (ROI)**
    - Increase in ROI for selected scenarios will be estimated
  - **Improve energy efficiency in buildings, grid reliability, and renewables integration**



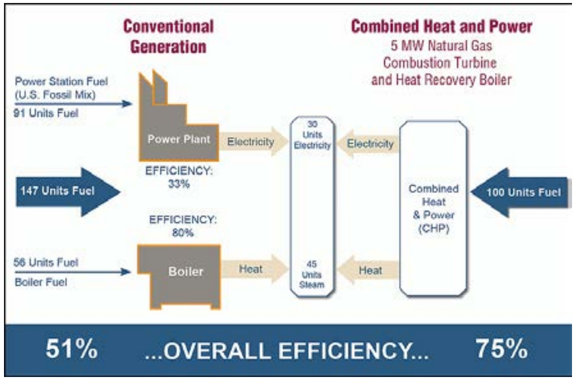
# Approach: Distinctive Characteristics

Generalized **open source optimization framework** that can be **configured to any combination of systems**

- Modular software design, so default algorithms/models can be replaced with user-defined
- Software will include default parameters for component models; however, software includes **adaptive elements** to **learn and update** parameters from field data
- Supports open source solvers: GLPK (GNU Linear Programming Kit) and CBC (Coin or Branch-and-Cut)
- Allows users to replace default solvers with other open source or proprietary solvers
- Benchmarking PNNL optimal dispatch with ASU and WSU approaches
- **Leveraging past and current work to support project objectives**
- Changes to the code can be tested using EnergyPlus building simulation model before validation in the field
- Leverages VOLTTRON features (BACnet, Historian, etc.)

# Impact: Target Market and Audience

- Target market = larger commercial and institutional buildings that integrate CCHP
- Total primary energy consumption of these buildings is approximately 8 Quads
- **Technical potential energy savings* = 2 to 3 Quads**
- Audience = commercial building owners/operators and energy service providers and potentially light industrial sector
- **Minimize operating cost and maximize return-on-investment and improved grid reliability**
- **Contribute to Building Technology Office, Grid Modernization Laboratory Consortium and Grid Modernization Initiative goals – optimizing transaction-based controls between buildings and grid**
  - Devices and Integrated System Testing (GMLC MYPP Tasks 2.1.1 – 2.1.4, 2.2.7, 2.2.8, 2.3.6, 2.3.7)

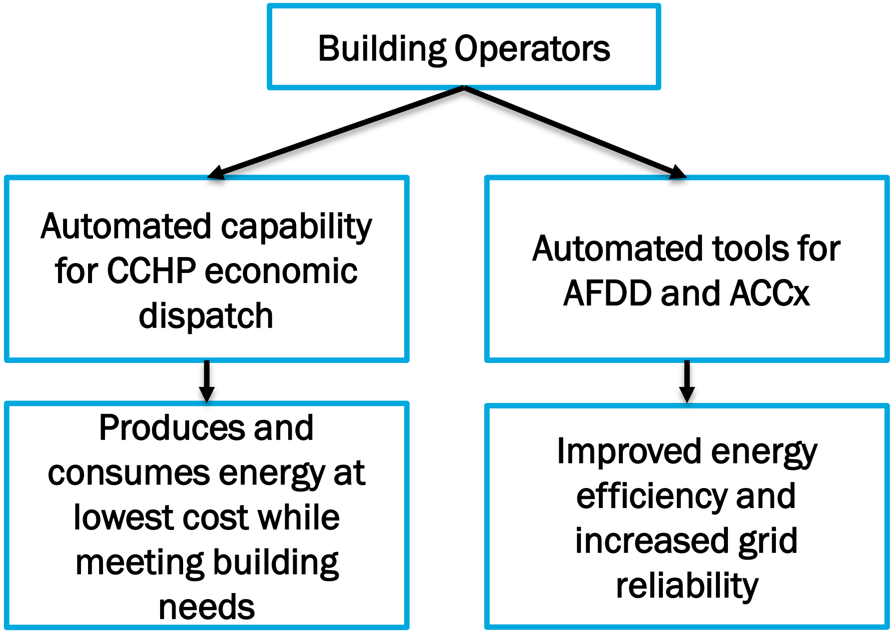


https://www.epa.gov/chp/chp-benefits

*US Department of Energy, Combined Heat and Power (CHP) Technical Potential in the United States, March 2016

# Impact of Project

- Deliver VOLTTRON-compatible, real-time control algorithms packaged as a fully functional toolkit
  - Supervisory control and generalized economic dispatch
  - Short-term weather and load forecasting
  - Management of short-term imbalance between local generation and demand
  - Performance monitoring and AFDD
  - Automated continuous commissioning (ACCx)


Building Operators

Automated capability for CCHP economic dispatch

Automated tools for AFDD and ACCx

Produces and consumes energy at lowest cost while meeting building needs

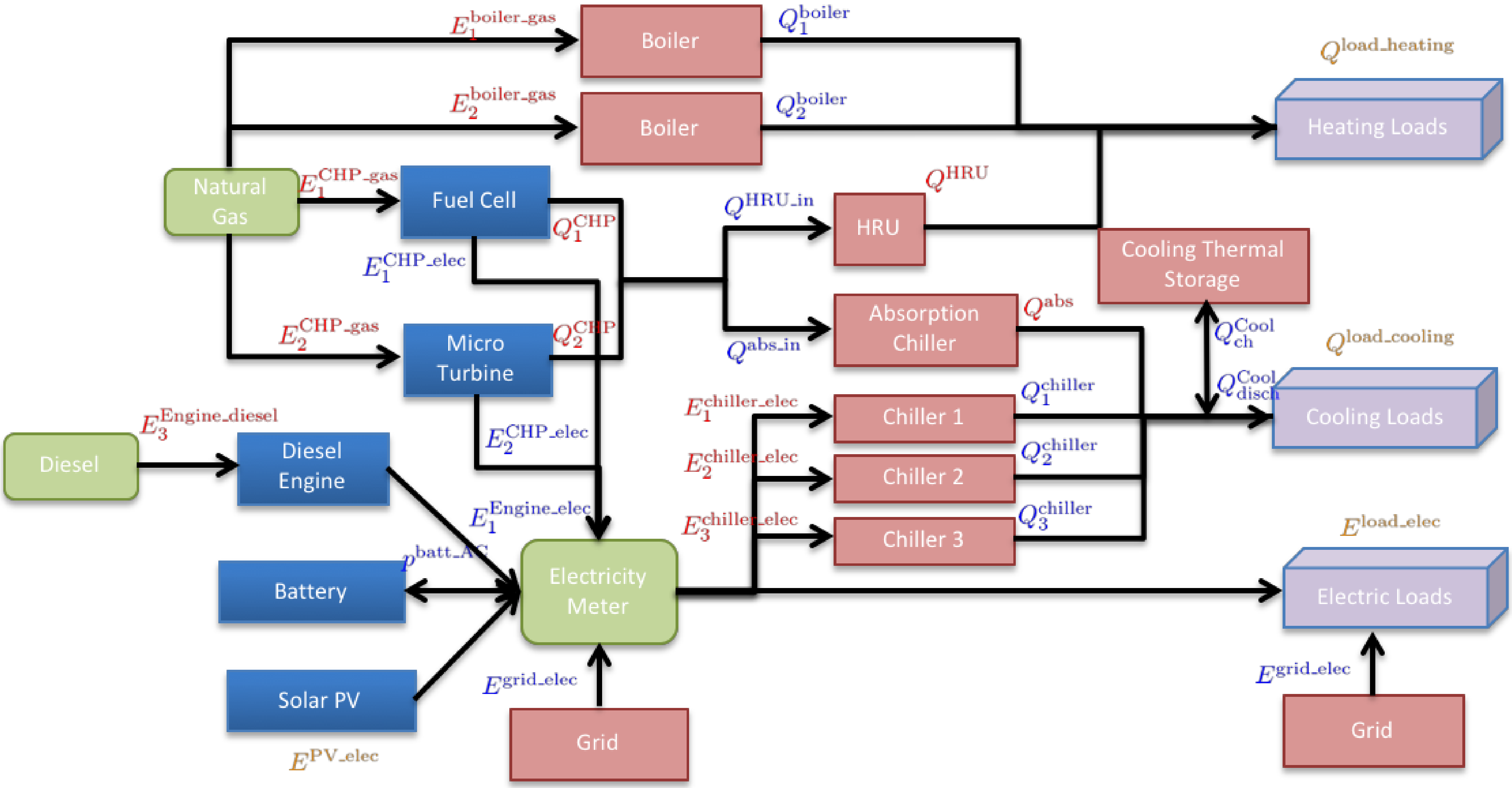
Improved energy efficiency and increased grid reliability

- **Short-term (immediate):** Open source economic dispatch and performance monitoring software for CCHP systems
- **Medium-term (<3 years):** One or more energy service providers commercializes the software and offers that as a service to their customers
- **Long-term (>3 years):** Software operational in at least 25 sites

# Progress: Project Status

- Projects has just passed the mid-stage and preparing for field-validation
- Development of component models completed, including conversion to Python
  - Draft final report and three journal papers accepted, and at least three more in preparation
- Development and formulation of the optimization framework complete, including conversion to Python
  - Exercised the framework with a few use cases
- Benchmarking of the optimization framework complete
- Developed an EnergyPlus hospital prototype with CCHP system; integration of this model with VOLTTRON is also complete
- Integration of all algorithms with VOLTTRON is complete; testing with EnergyPlus underway
- Development of an adaptive update of component models is in progress
- Development of AFDD and conditioned-monitoring algorithms complete
- Validation of the economic dispatch software with real equipment pending

# Progress: Benchmarking (Scenario C)



*Decision variables (used to calculate control inputs)*

*Other decision variables*

*Provided forecasts*

# ASU Optimization Approach

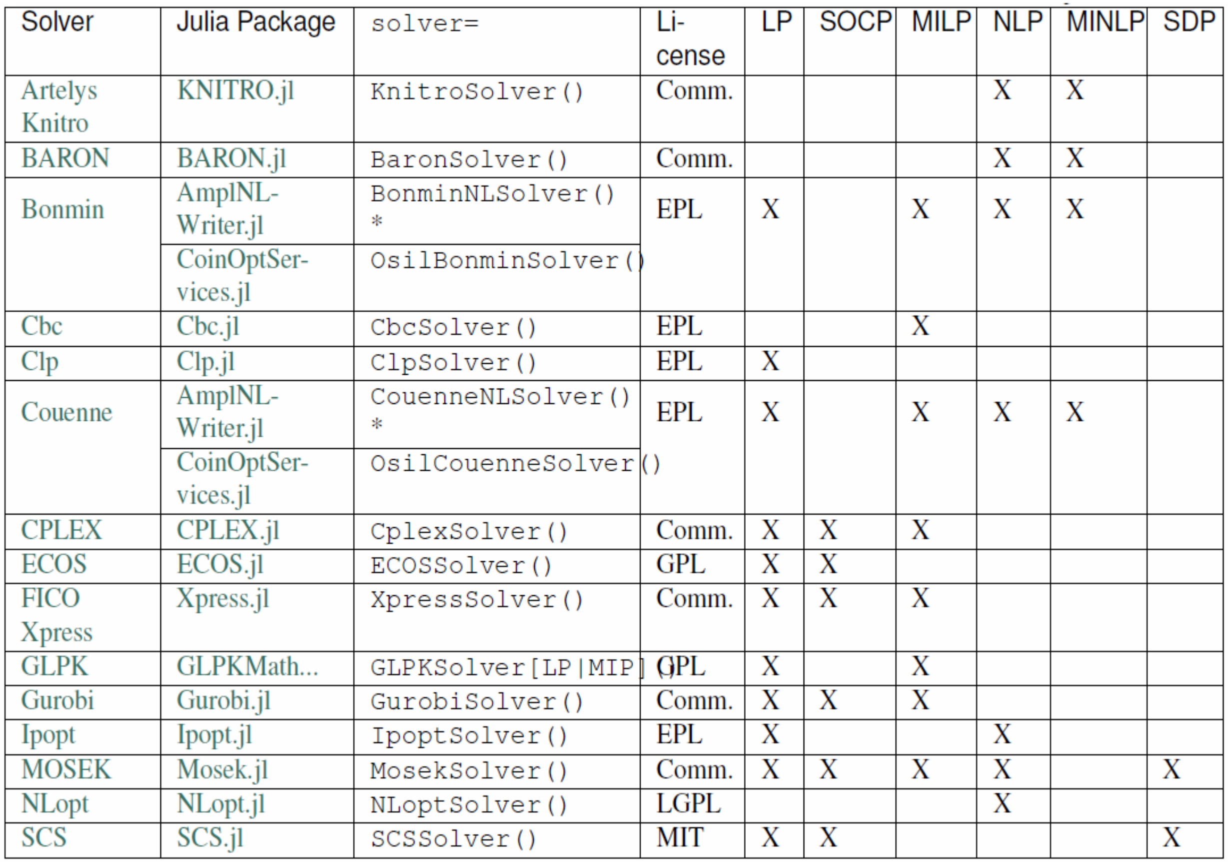
- A commercial optimization software package (Lingo) is used
- Segmented linear component models were used to convert the non-linear problem into a mixed integer linear programming problem
- Optimal break-points and slopes for the segmented linear models were identified using a separate optimization model developed in MATLAB
- Using global solver option in Lingo, the optimization model was able to find global optimum solutions in all of the investigated scenarios
- In addition to energy balance and component efficiency curves, operational constraints such as time-locks, start-up costs, ramp-up and ramp-down rates, and minimum allowable part-load constraints were incorporated into the optimization models
- Effects of accounting for condenser water inlet temperatures were analyzed by including cooling tower performance models in the optimization framework

# WSU Optimization Approach

- Developed specifically as a receding horizon control
  - Hierarchal method linking planning (24-hour) to real-time control
- Uses convex optimization techniques
  - Standard quadratic programming formulation
    - Guaranteed global solution
  - Piecewise quadratic cost functions
    - Allows for continuous operation between end-points of segments
- Generalized formulation for *n* generators, *c* chillers, *b* buildings, *f* cooling tower fans ….
- Constrained by generator and storage capacity and rate limits as well as startup costs
- Variable time steps, e.g., 5-minute to 2-hour intervals
- Connected to a visual user interface
- Reduces complexity of mixed-integer problem
- Coded in MATLAB, but transferable to Python

# PNNL Optimization Approach

- Optimization problem type: Mixed-integer Linear Programming
- Programming language and solver alternatives
  - Generate optimization problem directly in CPLEX LP file format, which is then solved by different solvers
  - Generate optimization problem using JuMP in Julia, solve the problem using supported solvers
  - Generate optimization problem using PuLP in Python, solve the problem using supported solvers



| Solver | Julia Package | solver= | License | LP | SOCP | MILP | NLP | MINLP | SDP |
|---|---|---|---|---|---|---|---|---|---|
| Artelys Knitro | KNITRO.jl | `KnitroSolver()` | Comm. | | | | X | X | |
| BARON | BARON.jl | `BaronSolver()` | Comm. | | | | X | X | |
| Bonmin | AmplNL-Writer.jl<br>CoinOptServices.jl | `BonminNLSolver()` *<br>`OsilBonminSolver()` | EPL | X | | X | X | X | |
| Cbc | Cbc.jl | `CbcSolver()` | EPL | | | X | | | |
| Clp | Clp.jl | `ClpSolver()` | EPL | X | | | | | |
| Couenne | AmplNL-Writer.jl<br>CoinOptServices.jl | `CouenneNLSolver()` *<br>`OsilCouenneSolver()` | EPL | X | | X | X | X | |
| CPLEX | CPLEX.jl | `CplexSolver()` | Comm. | X | X | X | | | |
| ECOS | ECOS.jl | `ECOSSolver()` | GPL | X | X | | | | |
| FICO Xpress | Xpress.jl | `XpressSolver()` | Comm. | X | X | X | | | |
| GLPK | GLPKMath... | `GLPKSolver[LP\|MIP]()` | GPL | X | | X | | | |
| Gurobi | Gurobi.jl | `GurobiSolver()` | Comm. | X | X | X | | | |
| Ipopt | Ipopt.jl | `IpoptSolver()` | EPL | X | | | X | | |
| MOSEK | Mosek.jl | `MosekSolver()` | Comm. | X | X | X | X | | X |
| NLopt | NLopt.jl | `NLoptSolver()` | LGPL | | | | X | | |
| SCS | SCS.jl | `SCSSolver()` | MIT | X | X | | | | X |

# Progress: Benchmarking of Use Cases (receding horizon)

| Scenario C | | |
|---|---|---|
| | Winter Day | Summer Day |
| PNNL | $681 (34)* | $1299 (1) |
| ASU | $676 (17) | NA |
| WSU | $680 (30) | $1367 (2) |

*($Penalty)

# Stakeholder Engagement

- The project team has had a number of discussions with potential users of the technology
  - Low-cost, flexibility in adapting to difference CCHP configurations and easy to use
- Project partner, Frontier Energy, provides economic dispatch and other CCHP operational support to a number of CCHP systems in New York
- After successful field-validation of this technology, Frontier Energy wants to use it to expand their offerings
- The project team plans to engage additional stakeholders while the technology is being field-validated
  - Potential users and commercializers

# Project Integration and Collaboration

**Project Integration:** Actively engaged energy service providers

- Will deploy the software at one or more sites to test and validate the algorithms
- Working with energy service providers who are potential users and commercializers of the software will help accelerate adoption of the tools developed in the project

**Collaborators:**

| Partner | Role |
|---|---|
| PNNL (Lead) | Development of optimization framework, AFDD, ACCx, VOLTTRON deployment, testing |
| ASU | Developed solar weather forecast, solar generation forecast, selected component models, AFDD and benchmarking |
| WSU | Developed selected component models, AFDD, and benchmarking of optimization approach |
| Frontier Energy | Development of validation plan, field validation site selection and support |

**Communications:** The project team has already published 3 journal papers and identified a number of potential papers and publications that will be presented at conferences or published in research journals

# Remaining Project Work: Planned Activities

- Complete comprehensive testing of the optimization framework with EnergyPlus
- Conduct selected testing of AFDD and condition-monitoring algorithms with online data
- Complete testing of adaptive model update feature
- Complete documentation of PNNL, WSU and ASU economic dispatch approach, AFDD methods and user guide for using the software
- Draft 3 to 4 additional journal papers
- Draft an experimental plan for field validation
- Begin field validation with real equipment in summer

# Thank You

Pacific Northwest National Laboratory, Arizona State University, Washington State University and Frontier Energy

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# REFERENCE SLIDES

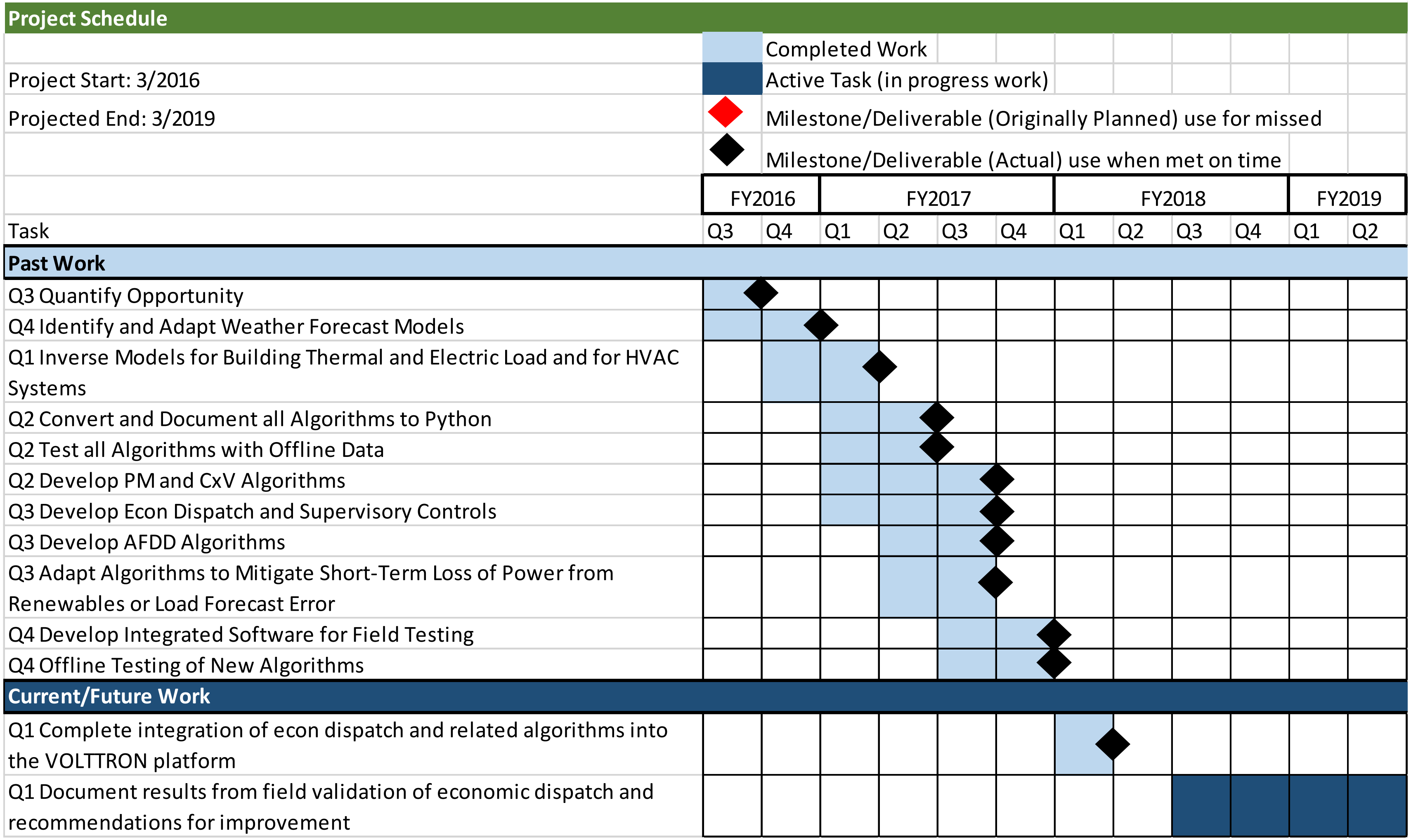
# Project Budget

**Project Budget**: $2,250K
**Variances**: No variances
**Cost to Date**: Cost through March 2018, totals $1,394K
**Additional Funding**: None

| Budget History | | | | | |
|---|---|---|---|---|---|
| 3/31/2016– FY 2017 (past) | | FY 2018 (current) | | FY 2019 – 3/31/2019 (planned) | |
| DOE | Cost-share | DOE | Cost-share | DOE | Cost-share |
| $1,036K | $0K | $1,008K | $0K | $256K | $0K |

# Project Plan and Schedule

- Project started in 3/2016 and is scheduled for completion with field testing and validation in 3/2019
- Schedule and Milestones (see table below)
- All milestones and deliverables are on track



**Project Schedule**

Project Start: 3/2016

Projected End: 3/2019

▨ Completed Work

■ Active Task (in progress work)

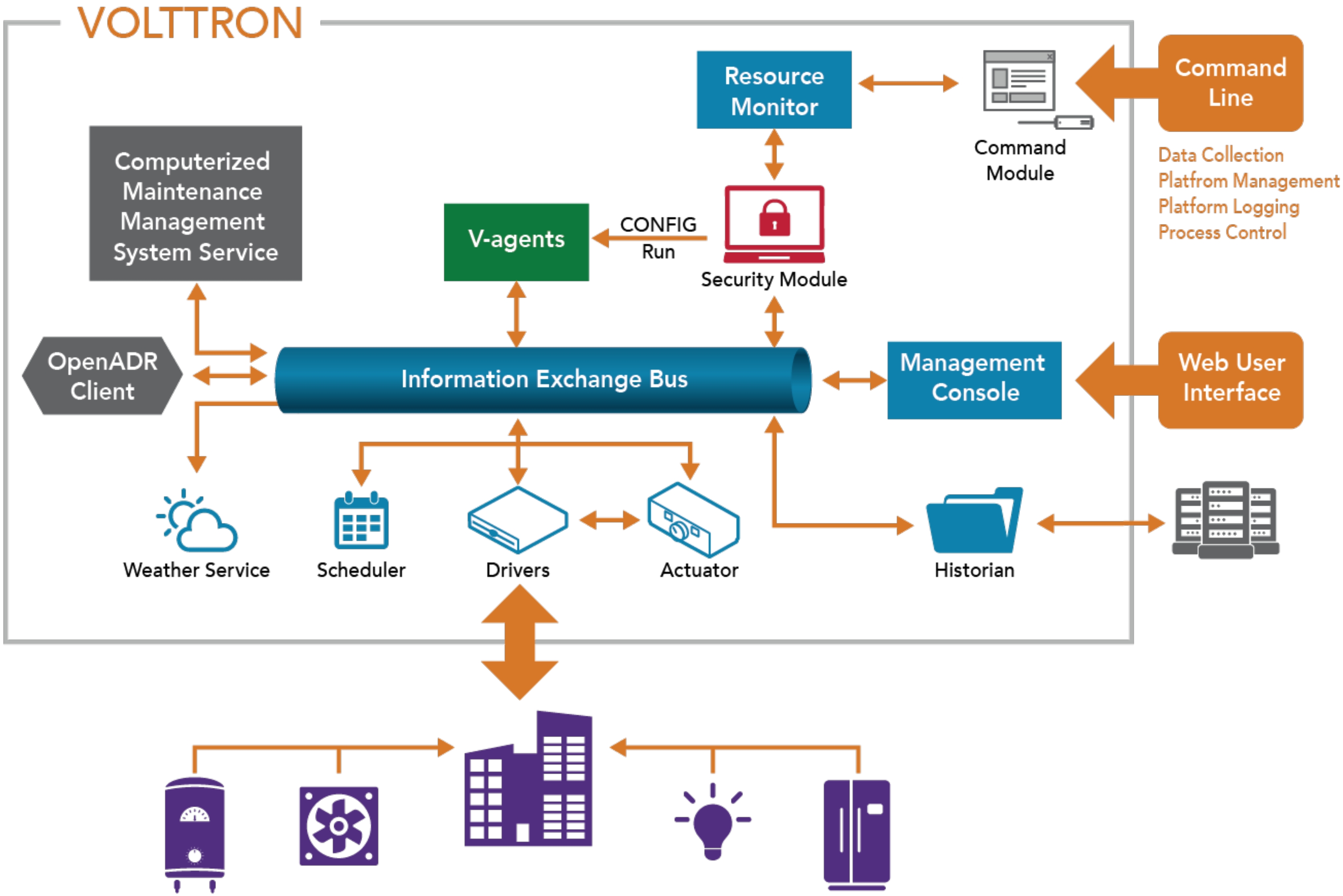
♦ Milestone/Deliverable (Originally Planned) use for missed

◆ Milestone/Deliverable (Actual) use when met on time

| | FY2016 | | FY2017 | | | | FY2018 | | | | FY2019 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Task | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 |
| **Past Work** | | | | | | | | | | | | |
| Q3 Quantify Opportunity | ▨ ◆ | | | | | | | | | | | |
| Q4 Identify and Adapt Weather Forecast Models | ▨ | ▨ ◆ | | | | | | | | | | |
| Q1 Inverse Models for Building Thermal and Electric Load and for HVAC Systems | | ▨ | ▨ ◆ | | | | | | | | | |
| Q2 Convert and Document all Algorithms to Python | | | ▨ | ▨ ◆ | | | | | | | | |
| Q2 Test all Algorithms with Offline Data | | | ▨ | ▨ ◆ | | | | | | | | |
| Q2 Develop PM and CxV Algorithms | | | ▨ | ▨ | ▨ ◆ | | | | | | | |
| Q3 Develop Econ Dispatch and Supervisory Controls | | | ▨ | ▨ | ▨ ◆ | | | | | | | |
| Q3 Develop AFDD Algorithms | | | | ▨ | ▨ ◆ | | | | | | | |
| Q3 Adapt Algorithms to Mitigate Short-Term Loss of Power from Renewables or Load Forecast Error | | | | ▨ | ▨ ◆ | | | | | | | |
| Q4 Develop Integrated Software for Field Testing | | | | | ▨ | ▨ ◆ | | | | | | |
| Q4 Offline Testing of New Algorithms | | | | | ▨ | ▨ ◆ | | | | | | |
| **Current/Future Work** | | | | | | | | | | | | |
| Q1 Complete integration of econ dispatch and related algorithms into the VOLTTRON platform | | | | | | | ▨ ◆ | | | | | |
| Q1 Document results from field validation of economic dispatch and recommendations for improvement | | | | | | | | | ■ | ■ | ■ | ■ |

# ADDITIONAL BACKUP SLIDES

# Inside VOLTTRON™



VOLTTRON

Resource Monitor

Command Module

Command Line

Data Collection
Platfrom Management
Platform Logging
Process Control

Computerized Maintenance Management System Service

V-agents

CONFIG
Run

Security Module

OpenADR Client

Information Exchange Bus

Management Console

Web User Interface

Weather Service

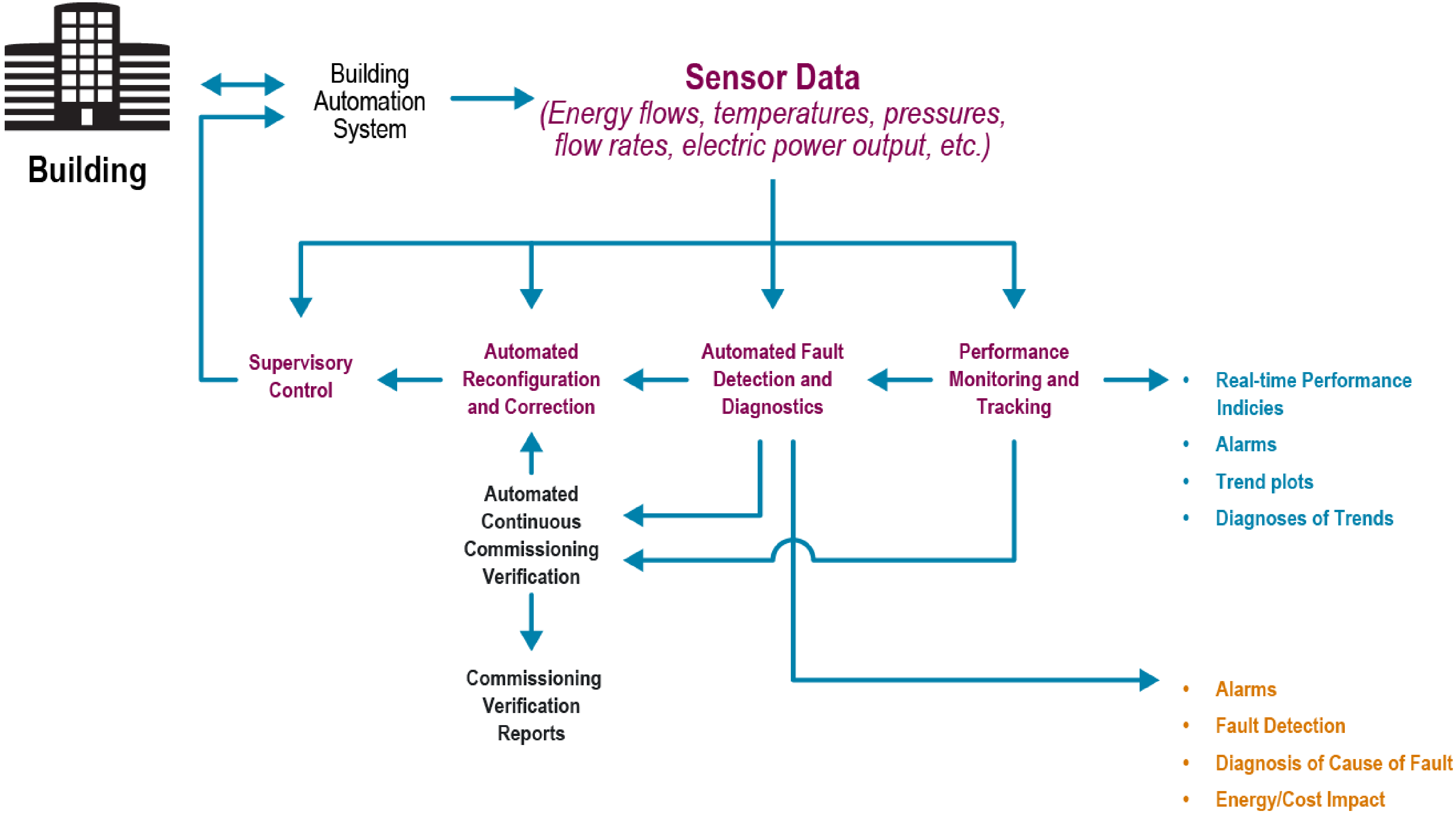
Scheduler

Drivers

Actuator

Historian

# Approach: Energy Efficiency Process



**Building**

Building Automation System

**Sensor Data**

*(Energy flows, temperatures, pressures, flow rates, electric power output, etc.)*

Supervisory Control

Automated Reconfiguration and Correction

Automated Fault Detection and Diagnostics

Performance Monitoring and Tracking

- Real-time Performance Indicies
- Alarms
- Trend plots
- Diagnoses of Trends

Automated Continuous Commissioning Verification

Commissioning Verification Reports

- Alarms
- Fault Detection
- Diagnosis of Cause of Fault
- Energy/Cost Impact

# Optimization for Convex and Non-Convex Component Models

## Convex

$$\min_{x_h^{\text{CHP}}, x_h^{\text{boiler}}, x_h^{\text{chiller}}, x_h^{\text{abs}}, x_h^{\text{HRU}}, E_h^{\text{grid\_elec}}} \sum_{h=1}^{24} \left[\lambda^{\text{gas}}(E_h^{\text{CHP\_gas}} + E_h^{\text{boiler\_gas}}) + \lambda^{\text{elec}} E_h^{\text{grid\_elec}}\right] \tag{1a}$$

subject to:

$$\text{Electric energy balance:} \quad E_h^{\text{PV\_elec}} + \sum_i E_{i,h}^{\text{CHP\_elec}} + E_h^{\text{grid\_elec}} - \sum_i E_{i,h}^{\text{chiller\_elec}} = E_h^{\text{load\_elec}} \tag{1b}$$

$$\text{Heating balance:} \quad \sum_i Q_{i,h}^{\text{boiler}} + Q_h^{\text{HRU}} = Q_h^{\text{load\_heating}} \tag{1c}$$

$$\text{Cooling balance:} \quad Q_h^{\text{abs}} + \sum_i Q_{i,h}^{\text{chiller}} = Q_h^{\text{load\_cooling}} \tag{1d}$$

$$\text{Component model:} \quad y_{i,h} = b_k S_{i,h} + \sum_k a_k x_{i,h,k} \tag{1e}$$

$$x_{i,h} = x_i^{\min} S_{i,h} + \sum_k x_{i,h,k} \tag{1f}$$

$$x_i^{\min} S_{i,h} \le x_{i,h} \le x_i^{\max} S_{i,h} \tag{1g}$$

(1h)

One binary variable for on/off status

$$\text{CHP wasted heat} \quad Q_{i,h}^{\text{CHP}} = E_{i,h}^{\text{CHP\_gas}} - c\, E_{i,h}^{\text{CHP\_elec}} \tag{1i}$$

$$\text{Waste heat balance:} \quad Q_h^{\text{HRU\_in}} + Q_h^{\text{abs\_in}} = \sum_i Q_{i,h}^{\text{CHP}} \tag{1j}$$

$$\text{HRU recover:} \quad Q_h^{\text{HRU}} \le a^{\text{HRU}} Q_h^{\text{HRU\_in}} \tag{1k}$$

## General

$$\min_{x_h^{\text{CHP}}, x_h^{\text{boiler}}, x_h^{\text{chiller}}, x_h^{\text{abs}}, x_h^{\text{HRU}}, E_h^{\text{grid\_elec}}} \sum_{h=1}^{24} \left[\lambda^{\text{gas}}(E_h^{\text{CHP\_gas}} + E_h^{\text{boiler\_gas}}) + \lambda^{\text{elec}} E_h^{\text{grid\_elec}}\right] \tag{1a}$$

subject to:

$$\text{Electric energy balance:} \quad E_h^{\text{PV\_elec}} + \sum_i E_{i,h}^{\text{CHP\_elec}} + E_h^{\text{grid\_elec}} - \sum_i E_{i,h}^{\text{chiller\_elec}} = E_h^{\text{load\_elec}} \tag{1b}$$

$$\text{Heating balance:} \quad \sum_i Q_{i,h}^{\text{boiler}} + Q_h^{\text{HRU}} = Q_h^{\text{load\_heating}} \tag{1c}$$

$$\text{Cooling balance:} \quad Q_h^{\text{abs}} + \sum_i Q_{i,h}^{\text{chiller}} = Q_h^{\text{load\_cooling}} \tag{1d}$$

$$\text{Component model:} \quad y_{i,h} = \sum_k (b_k S_{i,h,k} + a_k x_{i,h,k}) \tag{1e}$$

$$x_{i,h} = \sum_k x_{i,h,k} \tag{1f}$$

$$x_{i,k}^{\min} S_{i,h,k} \le x_{i,h,k} \le x_{i,k}^{\max} S_{i,h,k} \tag{1g}$$

$$S_{i,h} = \sum_k S_{i,h,k} \tag{1h}$$

Piecewise linear model and multiple binary variables for active pieces

$$\text{CHP wasted heat} \quad Q_{i,h}^{\text{CHP}} = E_{i,h}^{\text{CHP\_gas}} - c\, E_{i,h}^{\text{CHP\_elec}} \tag{1i}$$

$$\text{Waste heat balance:} \quad Q_h^{\text{HRU\_in}} + Q_h^{\text{abs\_in}} = \sum_i Q_{i,h}^{\text{CHP}} \tag{1j}$$

$$\text{HRU recover:} \quad Q_h^{\text{HRU}} \le a^{\text{HRU}} Q_h^{\text{HRU\_in}} \tag{1k}$$

$y_{i,h}$ and $x_{i,h}$:

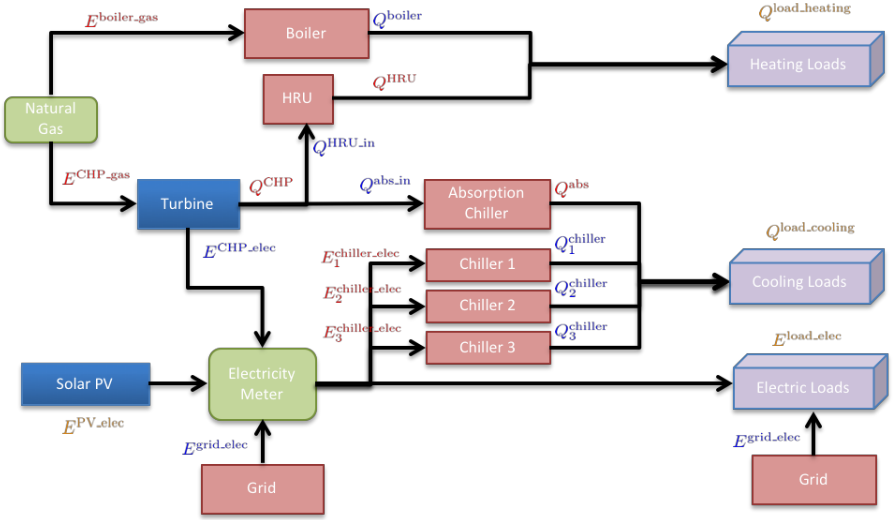
- CHP: $E_{i,h}^{\text{CHP\_gas}}$ (gas consumption in mmBTU) and $E_{i,h}^{\text{CHP\_elec}}$ (electricity generation in kWh)
- Boiler: $E_{i,h}^{\text{boiler\_gas}}$ (gas consumption in mmBTU) and $Q_{i,h}^{\text{boiler}}$ (heat generated in mmBTU)
- Chiller: $E_{i,h}^{\text{chiller\_elec}}$ (electricity consumption in kWh) and $Q_{i,h}^{\text{chiller}}$ (cooling heat generated in mmBTU)
- Abs chiller: $Q_{i,h}^{\text{abs\_in}}$ (heat consumption in mmBTU) and $Q_{i,h}^{\text{abs}}$ (cooling heat generated in mmBTU)

# Other Constraints

- Minimum up and down time
- Ramping up and down rate
- Energy state limits on battery and thermal storage
- Start-up cost

# Progress: Benchmarking

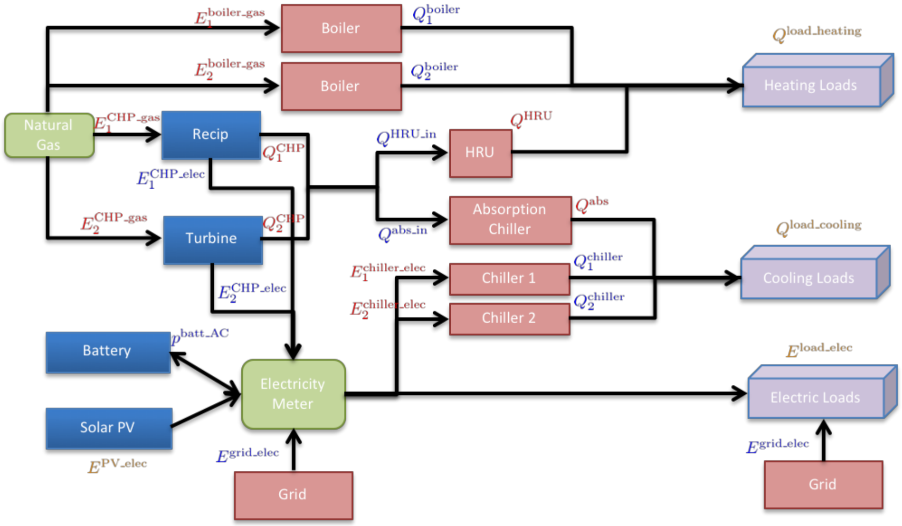
## Scenario A



*Decision variables (used to calculate control inputs)*

*Other decision variables*

*Provided forecasts*



*Decision variables (used to calculate control inputs)*

*Other decision variables*

*Provided forecasts*

## Scenario B

# Progress: Benchmarking of Use Cases

## Optimization over a 24-hour period

| | | | | |
|---|---|---|---|---|
| Scenario A | | | | |
| PNNL | $939 (with penalty) | | | |
| ASU | $942 (with penalty) | | | |
| WSU | $939 (with penalty) | | | |
| Scenario B | | | | |
| | Summer High Cost | Summer Low Cost | Winter High Cost | Winter Low Cost |
| PNNL | $1787 (0.092)* | $1689 (0.186) | $2618 (0.234) | $1936 (0.112) |
| ASU | $1788 (0.242) | $1691 (0.302) | $2589 (0.362) | $1930 (0.503) |
| WSU | $1788 (0.204) | $1702 (1.366) | $2630 (5.936) | $1934 (2.68) |
| Scenario C | | | | |
| PNNL | $682 (with penalty) | | | |
| ASU | $680 (with penalty) | | | |
| WSU | $677 (with penalty) | | | |

*($Penalty)