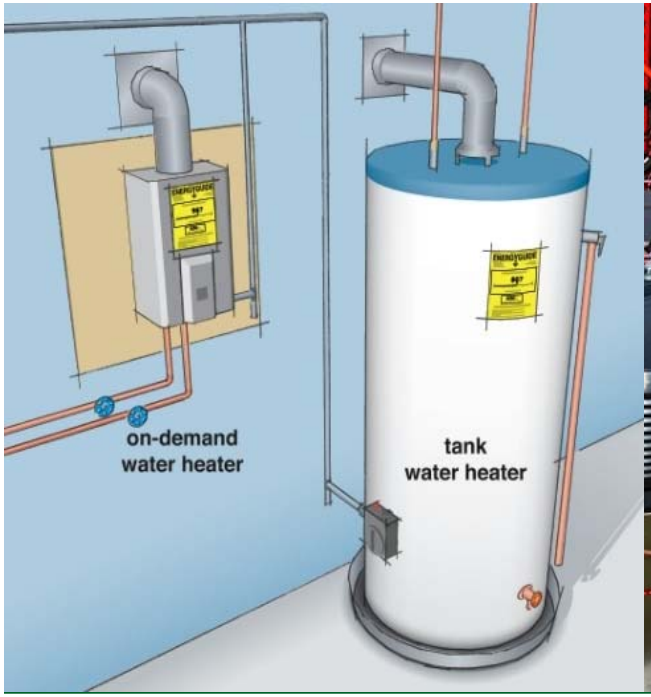

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

ENERGY STAR Connected Water Heaters Test Procedure Kick-Off

Department of Energy
Building Technologies Program

May 21, 2019

Kick-Off Meeting Schedule

- 10:00AM – 12:30PM
  - Opening Remarks
  - Agenda
    - Introduction/History
    - Scope
    - Criteria to be Tested
    - Current Water Heater Test Procedure
- 12:30PM – 1:15PM: Lunch
- 1:15PM – 3:00PM
  - Agenda
    - Possible Test Procedures
  - Open Discussion

Agenda

1. Introduction/History
2. Scope
3. Criteria to be Tested
4. Current Water Heater Test Procedure
5. Possible Test Procedures
6. Wrap-Up

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Goal of the Test Procedure Kick-Off Meeting

- To establish a framework to address the needs of all stakeholders

- Expected stakeholder benefits and uses of the Connected Water Heater Specification and Test Procedure:
  - Verification of specification
  - Guaranteed hot water and energy supply, lower energy bills
  - Quantifiable metric of how much energy storage is available, ability to manage load.
  - Reduce overall energy use, increase in renewable energy use
  - Quantifiable metric to validate policy goals

- **What other goals might exist?**

History of Specification/Test Procedure Development

- March 20, 2018 – Specification Kick-Off Meeting (Portland, OR)
- February 14, 2019 – Large Load Products Discussion Guide
  - Comment Deadline March 18, 2019
- March 7, 2019 – Large Load Product Discussion Guide Webinar
- March 27, 2019 – Specification Workshop (ACEEE Nashville, TN)
- April 16, 2019 – Draft Specification 1 of Version 3.3 published
  - Comment Deadline May 17, 2019

Anticipated Timeline

- Specification (EPA) and Test Procedure (DOE) developed concurrently
  - Specification finalizes when test method is mostly done
- Anticipated Q3-2019: Specification Draft 2
- Stakeholder meeting ENERGY STAR Products Partner Meeting, September 10-12, Charlotte, NC
- Anticipated Q4-2019: Specification and Test Method Draft 1
- Anticipated Q1-2020: Specification and Test Method Draft Final; not necessarily at exactly the same time
- Anticipated Q2-2020: Test Method Final

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Connected Water Heater Test Procedure Scope

- Must be an ENERGY STAR water heater
  - Included
    - Electric Heat Pump Water Heaters (HPWH)
    - Gas Storage & Instantaneous Water Heaters
  - Excluded:
    - Electric Resistance Water Heaters (ERWH), including DOE Grid-Enabled Water Heaters
    - Products intended only for commercial applications
    - Combination space-heating and water-heating appliances
    - Add on heat pump water heaters
    - 3rd party water heater controllers
  - Meet the criteria as stated in ENERGY STAR Product Specification for Residential Water Heaters Version 3.3, Sections 1-3
    - Criteria typically include UEF rating, warranty, and safety certifications

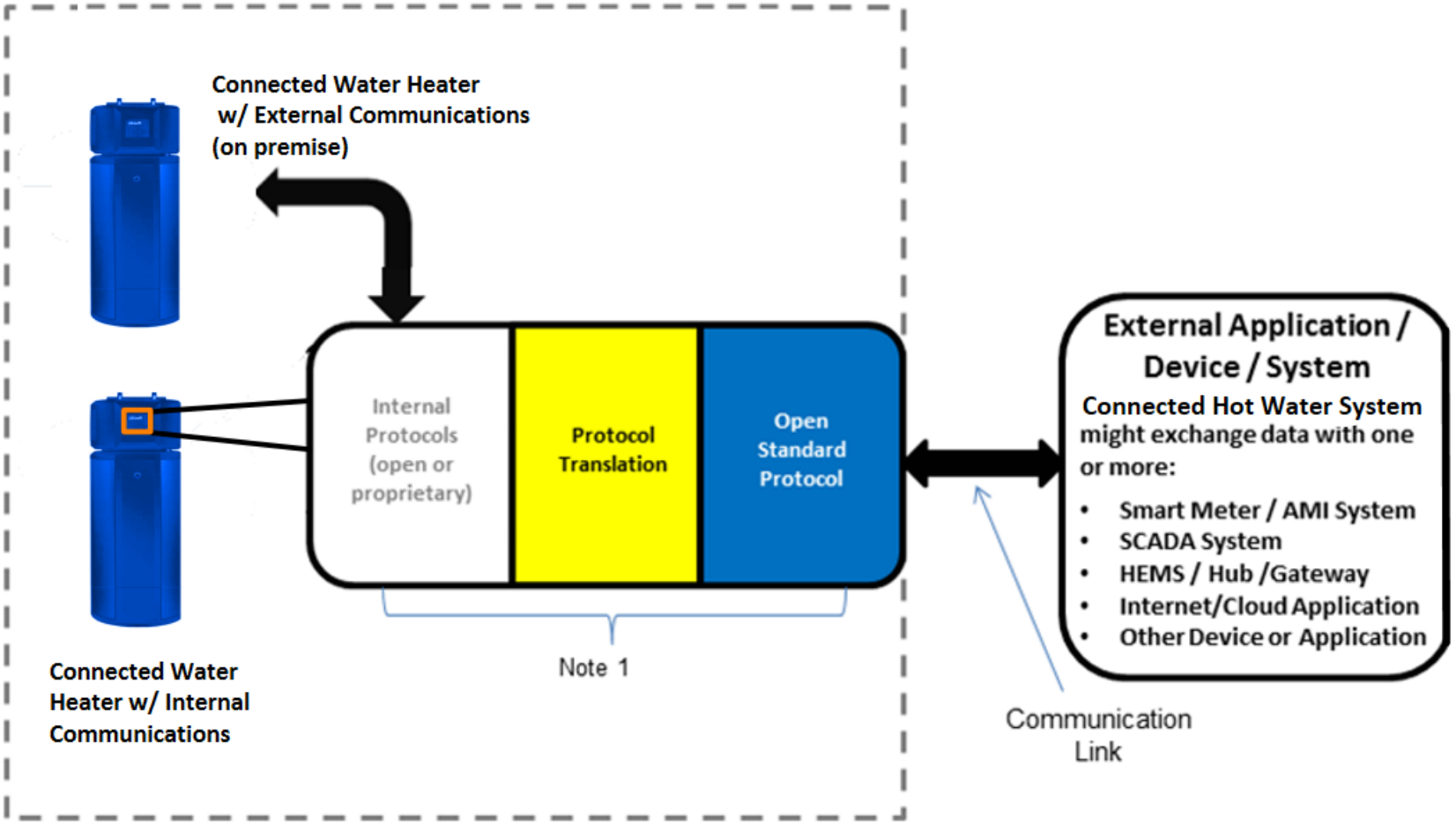
Connected Criteria in the Draft Specification

- **Connected criteria = User Amenity + Demand Response (DR)** (as appropriate for product type)
  - Electric Heat Pump Water Heaters: Full DR requirements
  - Gas Storage Water Heaters: Limited DR requirements
    - As per current gas curtailment programs (*e.g.*, during a polar vortex)
  - Gas Instantaneous Water Heaters: Exempt from DR
    - Connected if meets non-DR requirements (*i.e.*, user amenity requirements)

- The test procedure under development only applies to the DR part of the connected criteria and NOT the user amenity portion

Connected Water Heater

A connected water heater includes the ENERGY STAR certified water heater, integrated or separate communications hardware, and additional hardware and software required to enable connected functionality.



Discussion Topics: Scope

- Keep in mind that the specification and test procedure apply to all ENERGY STAR water heaters, not just HPWH
  - Should the test procedure be applicable to non-ENERGY STAR water heaters as well (*e.g.*, ERWH)?

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How are Connected Criteria organized in the Spec?

- **Communications:** Open standard(s) and API or interface docs
- **Functionality:**
  - Remote Management and Consumer Feedback (User Amenity): Services for homeowners and for home energy management integration
  - Demand Response: Specific choices of communication protocols, responses to specific messages and requests
    - Let manufacturer protect user experience; avoid prescriptive requirements (e.g. reduce tank temp by X ^{o}F)
    - Let manufacturers compete on optimal logic/control strategies to provide grid services
- **Testing:** Refer to test requirements section
- **Appendix:** details on how a given open standard implementation would look (e.g. OpenADR 2.0 / CTA 2045-A).

Functionality: Demand Response

a. Communications: CTA-2045-A and/or OpenADR 2.0

b. Consumer Override: Easily accessible means for consumers to override DR events
   - Except for Grid Emergency/Off Mode events
   - When DR event is overridden, CWHP shall return to its previous operating mode.

c. Loss of Connectivity
   - On loss of connectivity, CWHP will revert to either the stored schedule, continue with DR events (in progress or planned), or continue with normal operation

Functionality: Demand Response Continued

d. DR Information and Messaging
   - Required
     - Device Type
       - ERWH, HPWH, Gas Storage, Gas Instantaneous, etc.
     - Operational State
       - Current CWHP running state and DR event status
     - Current Available Energy Storage Capacity (kWh or Btu)
       - Energy capacity available for load up, in current conditions
     - Power / Demand (Instantaneous) (kW or Btu/h)
       - Measured or Estimated
   - Optional
     - Energy Use (kWh or Btu)
       - Measured or estimated cumulative energy use
     - Current Total Energy Storage Capacity (kWh or Btu)
       - Energy storage capacity available over and above the hot water stored to provide user service at the moment.

Functionality: Demand Response - Required Requests

e. DR Requests and Responses

- General Curtailment (Shed)
  - Reduce energy consumption, allowing the stored thermal energy in the tank to reduce moderately
  - HPWH: on recovery, should not use resistance elements
- Emergency Curtailment (Critical Curtailment)
  - Reduce energy consumption substantially and urgently, allowing the stored thermal energy in the tank to reduce more than general curtailment
- Grid Emergency (Off Mode)
  - Stop using power immediately if safe to do so
- Load Up
  - Increase energy consumption allowing the stored thermal energy to increase within product's safety limits
  - HPWH: Avoid resistance element usage to satisfy Load Up
- Return to Normal Operation
  - Event cancellation (in progress and/or advance event)
  - Return to normal pre-event operation

Functionality: Demand Response - Optional Requests

e. DR Requests and Responses (continued)

- Set Point Adjustment
  - Adjust product thermostat set point up or down
- Relative Price Signals
  - Information to CWHP
    - Current energy cost
    - Upcoming pricing changes (*e.g.*, relative price)
  - Allows product control logic to react to data
    - E.g. Shed / Load Up

Discussion Topics: Criteria to be Tested

- How are connected water heaters currently used in the field?
  - What distinguishes better performers?
  - What do DR programs look for in a connected water heater now?
- Loss of Connectivity: Are all DR events time limited?
  - If connectivity is lost during a DR event, could the unit be put into a permanent shed?
- Load Up: “Avoid” electric resistance is used.
  - How should we test for this ambiguity?

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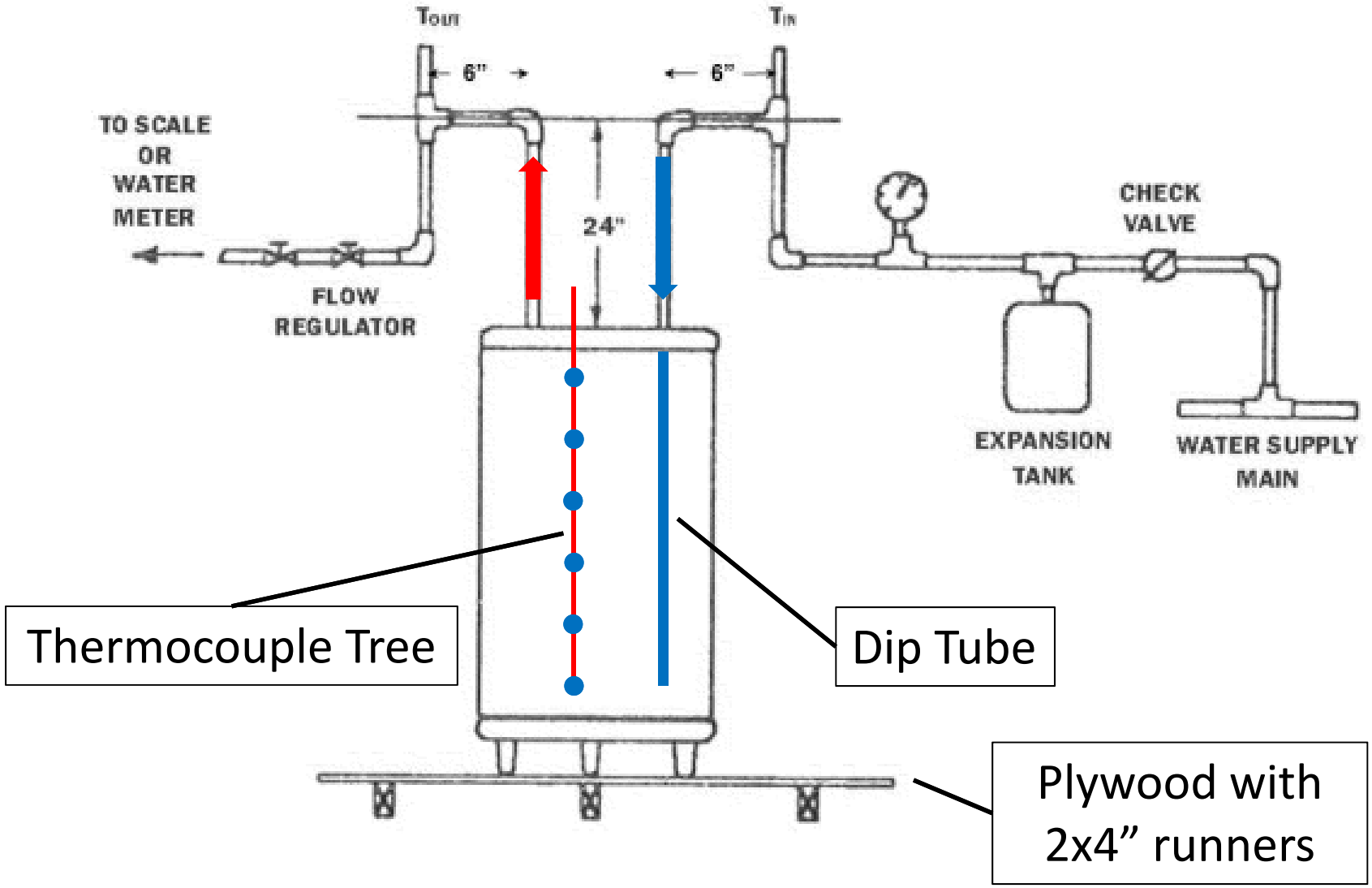
UEF Test Procedure: Test Conditions

Ambient Temperature	67.5°F ± 2.5°F
Supply Water Temperature	58°F ± 2°F
Outlet/Setpoint Water Temperature	125°F ± 5°F

- Accuracy and precision of the instruments are specified for all measurements necessary to measure and calculate the stored energy, energy delivered, and energy received by the water heater

- The outlet/setpoint water temperature is initially set between 120°F to 130°F but over the entire test there is no requirement for the outlet water to be between 120°F to 130°F

UEF Test Procedure: Test Setup (Storage Water Heater)



UEF Test Procedure: Overview

- Storage Volume Measurement
- Preconditioning
  - 12 hour soak-in for water heaters with rated storage volumes ≥2 gallons
- Delivery Capacity Tests [First-Hour Rating (FHR) or Max GPM]
  - FHR: Max gallons of hot water a storage CWHP can deliver in 1 hour
  - Max GPM: Max flow rate of hot water an instantaneous CWHP can deliver continuously at the test conditions
- 24hr Simulated-Use Test
  - Designed to approximate the actual use of water heaters in the field for a typical day

UEF Test Procedure: First-Hour Rating (FHR)

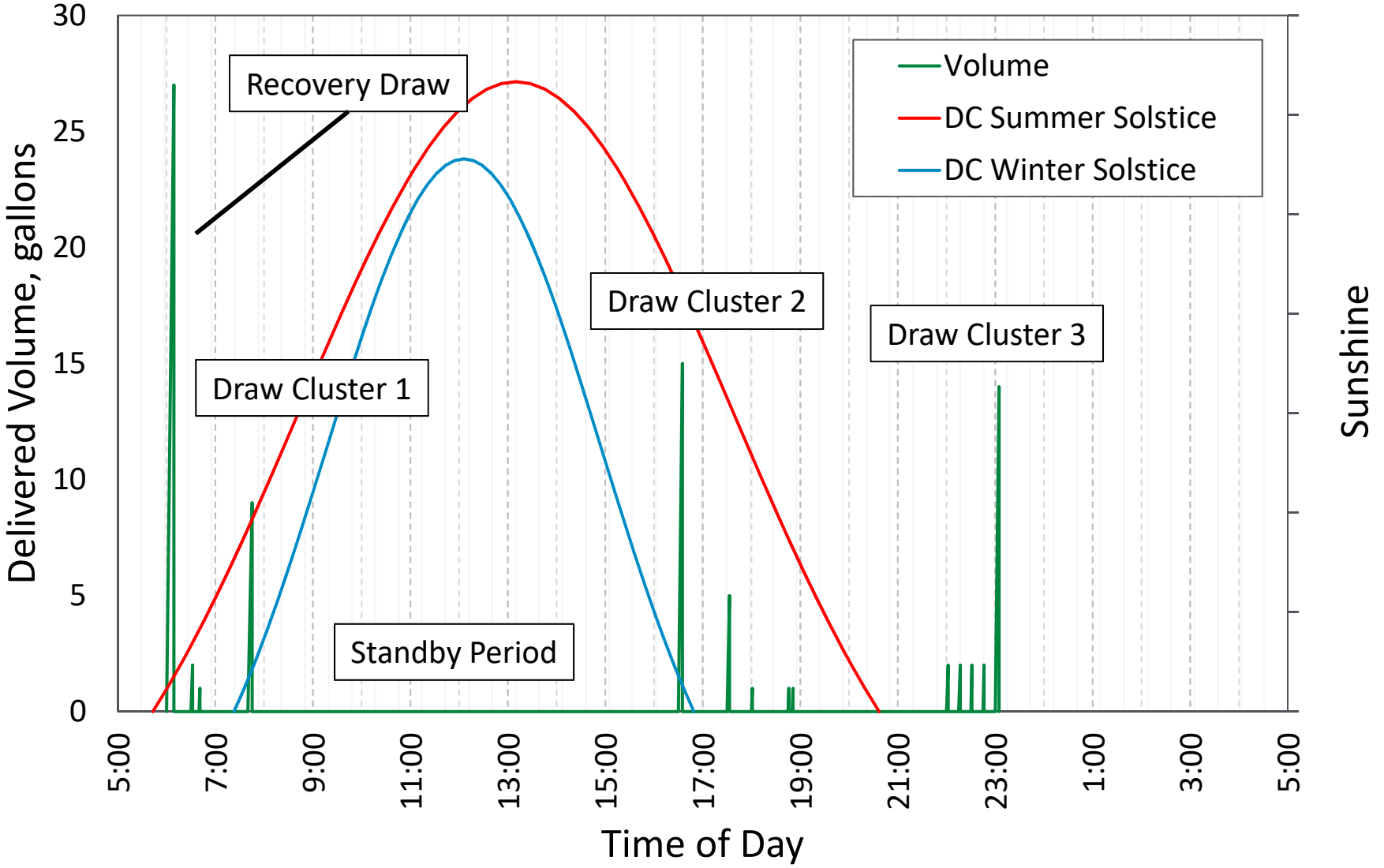
- Maximum gallons of hot water a storage water heater can deliver in 1 hour

- Procedure:
  - Start with a fully heated tank.
  - Initiate a draw and continue until the outlet temperature drops to 15°F below the initial outlet temperature
    - Unit will be in recovery at the end of the draw.
    - Ideally, initial outlet temperature is 125°F and the lowest temperature that hot water is delivered at 110°F.
  - After cut-out (recovery end), initiate another draw and end with the criteria stated above. Repeat for 1 hour.
  - FHR is the sum total of all the gallons of hot water delivered

UEF Test Procedure: 24-Hour Simulated Use Test

- Designed to approximate the actual use of water heaters in the field
- Results of the delivery capacity tests (FHR and Max GPM) are used to determine the appropriate draw pattern (usage pattern)
  - 4 draw patterns (Very Small, Low, Medium, and High)
  - A draw pattern specifies the volume, flow rate, and start time of the draw
- Typically, there are 3 draw clusters to simulate early morning use, use after work, and late night use.
- Important variables
  - Recovery Efficiency (RE)
  - Standby Loss Coefficient (UA)
  - UEF

UEF Test Procedure: High Draw Pattern



UEF Test Procedure: 24-Hour Simulated Use Test Cont.

- Recovery Efficiency (RE)
  - The ratio of energy delivered to the water to the energy content of the fuel consumed by the water heater.
  - Calculated during the initial draw of the test
    - Initial draw is large and removes a significant amount of energy from the tank allowing for a long recovery where efficiency could be calculated with repeatability

- Standby Loss Coefficient (UA)
  - Calculated from period between the 1st and 2nd draw clusters
  - Energy input to heat water minus standby losses, scaled with time, mean tank temperature and ambient temperature

- UEF
  - Energy delivered through hot water / energy input into the unit from burners/elements/heat pump

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Possible TP's: Energy Consumption

- Water Heater Control Options
  - HPWH: Heat pump On/Off and/or Elements On/Off
    - Resistive elements should not be used during Curtailments and avoided during Load Ups
  - Gas Storage: Burner On/Off (Modulating is possible but not currently used in products on the market)
  - Gas Instantaneous: Burner On/Off, Modulating is predominant

- Methods to Measure/Compare Energy Consumption
  - No specifically defined limits between energy consumption states
  - Energy in, out, and stored can be measured throughout the test with the full test setup from UEF test procedure
  - Comparing specific values at a recovery start could reduce test length
    - E.g., delivered volume, outlet temperature, or mean tank temperature

Possible TP's: What should be checked?

- Signals and responses
  - To verify open standards are being used appropriately
- Verify reaction of the connected water heater
  - Energy consumption during different DR events
- Measure energy capacity of the connected water heater
  - At different times before, during, and after DR events
  - Compare to message values provided by the connected water heater
    - What tolerances should be specified?
- Measure efficiency during different DR events
- Price responsiveness
  - Currently lack data and market conditions
  - What factors should be considered to estimate market conditions?
    - Relative high and low prices?

Possible TP's: What metrics are most helpful and necessary?

Which metrics are most useful in verifying performance while minimizing burden?

- kWh used during different curtailments before cut-in
  - Difference in energy storage between normal operation and curtailment states
- kWh available for Load Up
  - Instantaneous (*e.g.*, Max Energy State - Current Energy State)
  - As a reported metric (*e.g.*, Max Energy State - Baseline Energy State at Normal Operation)
- Gallons of hot water available to consumer at different states
  - Normal operation (rated FHR)
  - Normal operation → Curtailment (less than rated FHR since there is less recovery)
  - After being loaded up (greater than rated FHR)
  - Depleted (CWHP has not fully recovered, Less than rated FHR)
- $ used after receiving a simulated pricing signal

Possible TP's: Ideas for Procedures

- After receiving different DR requests (to verify connected water heater response and/or measure energy content of the tank)
  - What should the baseline look like (draw patterns, FHR, etc.)?
  - What order should the DR requests arrive in?
    - Normal Operation → General Curtailment → Emergency Curtailment → Normal Operation
  - Could have an issue with stacking (mean tank temperature steadily rises after repeated draws and recoveries)
- Simulated-Use Tests (not necessarily those in the UEF TP)
  - Will a connected water heater always be loaded up before a shed?
  - How often would a shed occur after no load up?
  - How long will a shed typically last?
    - Set length or until another DR request is received?
- **Others Ideas?**

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Anticipated Timeline

- Specification and Test Procedure (DOE) developed concurrently
- **Mid July: Test Procedure Check-In 1**
- Anticipated Q3-2019: Specification Draft 2
- Stakeholder meeting ENERGY STAR Products Partner Meeting, September 10-12, Charlotte, NC **(Test Procedure Check-In 2)**
- **Mid November: Test Procedure Check-In 3**
- Anticipated Q4-2019: Specification and Test Method Draft 1
- Anticipated Q1-2020: Specification and Test Method Draft Final; not necessarily at exactly the same time
- Anticipated Q2-2020: Test Method Final

Ways to Work Together: Future TP Check-In Calls

- An initial draft of the CWHP Test Procedure is planned for Quarter 4 of 2019

- Stakeholder check-ins about every 2 months would allow for 3 by the end of 2019
  - Check-In 1: Mid-July
  - Check-In 2: September Product Partner Meeting (Charlotte, NC)
  - Check-In 3: Mid-November

- Check-in's would be open to anyone who is interested and would be held via webinar (and possibly in person at the Partner Meeting)

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Back-up Slides

NEEA's: Northern Climate Uniform Energy Factor

- Northern Climate Uniform Energy Factor (UEF_{NC}) is representative of water heater performance for equipment installed in semi-conditioned (*e.g.*, basements, unheated utility rooms) and unconditioned (*e.g.*, garages, crawl spaces) locations in northern climates.
- Two 24-hour Simulated Use Tests and a bin weighted calculation
  - Based on the Heating Seasonal Performance Factor (HSPF) for space conditioning heat pumps
- Test Conditions:
  - UEF_{67}: to the DOE's 24-hour Simulated Use Test
  - UEF_{50}: 50°F dry bulb, 43.5°F wet bulb (58% RH), 50°F inlet water

NEEA's: Northern Climate Uniform Energy Factor

$$UEF_{NC} = \sum_{j=1}^{10} UEF_j * f_j$$

where:

j is the bin number from Table 2

f_j is the fraction of hours for that bin

If no ER is used in either UEF_{67} or UEF_{50}

$$UEF_j = (T_j - 50)*m_{UEF} + UEF_{50}$$

$$m_{UEF} = (UEF_{67} - UEF_{50}) / (67.5 - 50)$$

If ER is used in either UEF_{67} or UEF_{50}

For bin temperatures <50°F

$$UEF_j = (T_j - 50)*m_{compT50} + UEF_{50}$$

$$m_{compT50} = (UEF_{50} - UEF_{R,Ccutoff}) / (50 - C_{cutoff})$$

For bin temperatures ≥50°F and ≤67.5°F

$$UEF_j = (T_j\text{-}50)*m_{UEF} + UEF_{50}$$

For bin temperatures >67.5°F

$$UEF_j = UEF_{67}$$

$$UEF_{R,j} = Q_{wtr}/(Q_{wtr} + Q_{stbdy,j})$$

$$Q_{wtr} = m^* c_p * \Delta T / \eta_{elem}$$

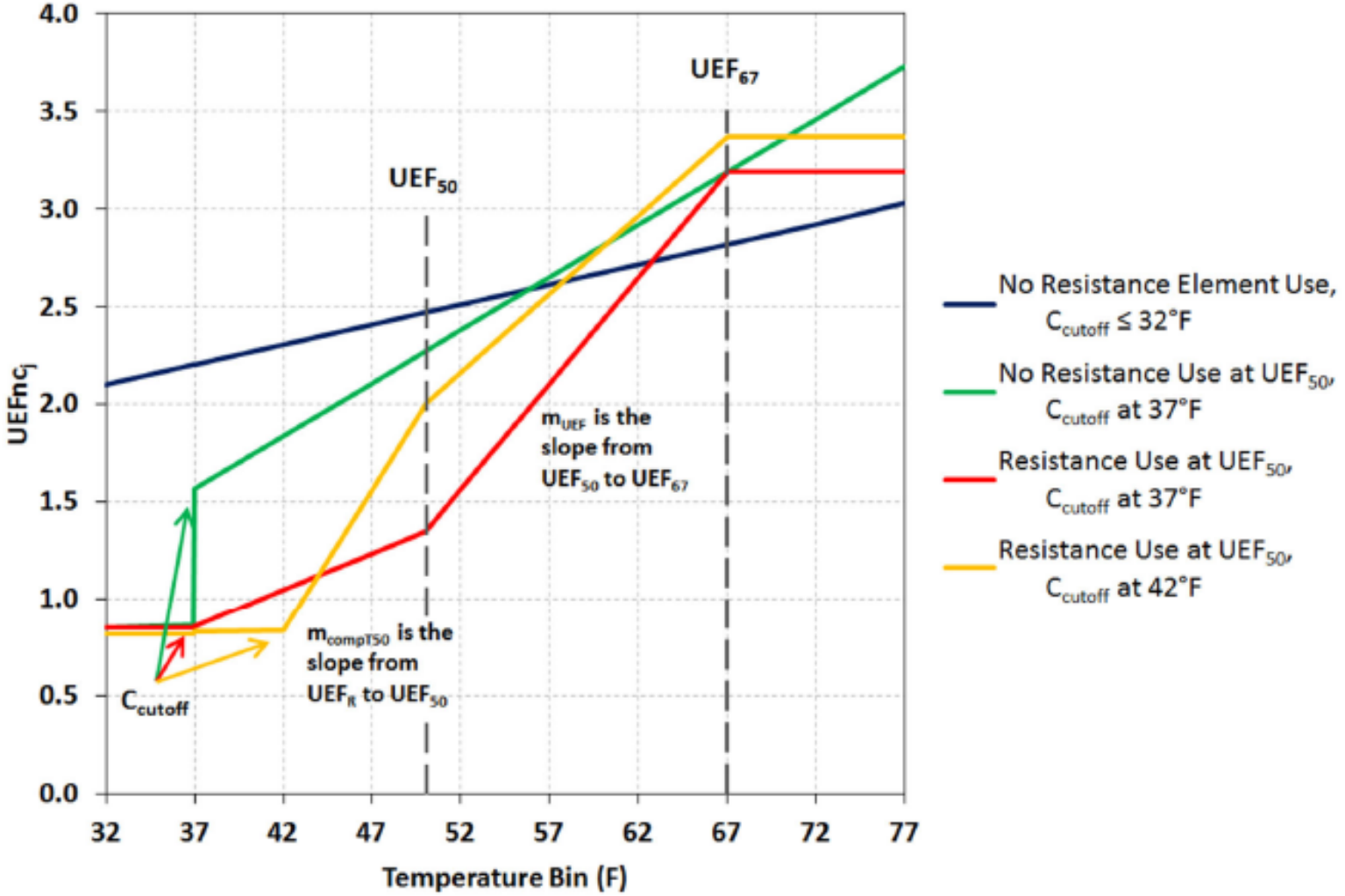
$$Q_{stdby,j} = UA * (T_{tank} - T_j) * 24 \text{ hrs}$$

Table 2. Temperature Bins

j	T_j (°F)	f_j
1	77	0.021
2	72	0.121
3	67	0.124
4	62	0.131
5	57	0.132
6	52	0.141
7	47	0.121
8	42	0.096
9	37	0.071
10	32	0.04

NEEA's: Northern Climate Uniform Energy Factor

Figure 1. UEF_{NC} vs Temperature



Functionality: Demand Response - Operational States

Running State	DR Condition	Description
Idle (Water heater IS NOT heating)	Normal	In normal mode of operation
	Grid	In grid service operational mode
	Heightened	Processing a Load Up request
	Opted Out	DR is overridden (no/insignificant energy use)
Running (Water heater IS heating)	Normal	In normal mode of operation
	Curtailed Grid	In grid service operational mode
	Heightened Grid	In grid service operational mode and processing a Load Up request.
	Opted Out	DR is overridden (significant energy use)
Cycling (grid service event)	On	Is heating
	Off	Is not heating
SGD Error	-	Device is malfunctioning

Other Connected Criteria Specifications

- California's Title 24
  - Joint Appendices 13 (JA13)
- Consortium for Energy Efficiency (CEE)
  - Residential Water Heating Initiative (March 16, 2018)
  - https://library.cee1.org/content/cee-residential-water-heating-initiative/
- Northwest Energy Efficiency Alliance (NEEA)
  - Advanced Water Heating Specification V6.0
  - https://neea.org/img/documents/Advanced-Water-Heating-Specification_181010_152257.pdf
- Air-Conditioning, Heating, & Refrigeration Institute (AHRI)
  - AHRI Standards 1380 (I-P/2019), Demand Response through Variable Capacity HVAC Systems in Residential and Small Commercial Applications
  - http://www.ahrinet.org/App_Content/ahri/files/STANDARDS/AHRI/AHRI_Standard_1380_I-P_2019.pdf
- **Others we should be aware of?**

Discussion Topics: Current Test Procedure

- What other instruments and test equipment would be useful and/or necessary?
- Should other test conditions be used?
  - Region specific values probably won't work since this test applies to the entire nation, but would a CWHP in a DR program experience different conditions in the field?
- When is wind power most available?
  - What other renewable energy sources might we want to account for?
- Would a recovery efficiency and/or UEF during different DR events be useful?