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Demand Response-Ready Domestic Water Heater Specification

Preliminary Requirements for CEA-2045 Field Demonstration

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ABSTRACT

This document is a specification for a residential water heater with built-in demand response (DR) capabilities and a standard communication interface. The context for the development of this specification is a field demonstration project that EPRI is facilitating regarding the ANSI/CEA-2045 modular communication standard. In this project, utilities are fielding consumer end-use products and integrating them into a wide range of DR systems in order to assess the standard and determine the degree to which interoperability is achieved.

The project plan required that all of the field tests of a given product type be carried out using the same design, so that there is no regional customization and the concept of a mass-producible product is directly evaluated. This required that utilities work together to develop a common set of requirements that are sufficient for supporting each DR program. This collaborative process was conducted early in the project, resulting in the preliminary specification represented in this document. The project plan anticipates updating this specification later in order to incorporate any new requirements or adjustments that are identified during the field testing.

Keywords
CEA-2045
Water heater
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DR ready

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INTRODUCTION

In 2013 the Consumer Electronics Association released the ANSI/CEA-2045 standard. This standard defines a modular communication interface intended to be designed into end-use loads to enable demand response (DR). The CEA-2045 standard has been described in detail in EPRI report 3002004020, Introduction to the CEA-2045 Standard, EPRI, Palo Alto, CA 2014[1].

Utilities and manufacturers are assessing this new standard to determine the degree to which it meets the needs of consumers, aggregators, and utilities. EPRI is facilitating a collaborative project that is specifically studying the extent to which CEA-2045 provides compatibility and interoperability with the wide range of systems into which consumer loads might be connected. If a modular interface works as intended, achieving interoperability and being self-installable by consumers, it could significantly advance the state of demand response worldwide. A detailed description of the CEA-2045 Field Demonstration project, including its goals and plan, has been provided in EPRI report 3002004009, ANSI/CEA-2045 Field Demonstration Project Description[2].

The project plan required that all of the field tests of a given product type be carried out using the same design, so that there is no regional customization and the concept of a mass-producible product is directly evaluated. This required that utilities work together to develop a common set of requirements that are sufficient for supporting each DR program. This collaborative process was conducted early in the project, resulting in the preliminary water heater specification represented in this document. The project plan anticipates updating this specification later in order to incorporate any new requirements or adjustments that are identified during the field testing.

[1] http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002004020

[2] http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002004009

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MECHANICAL AND ELECTRICAL REQUIREMENTS

In the context of this document, the phase “normal operation” refers to the customer-selected mode of operation that would naturally be in effect if no energy management function were activated. In other words, the phrase “return to normal operation” does NOT mean that any customer configurations of their product are lost or discarded.

Water Heater Capacity and Type

- **REQ.ME1** The water heater shall be a standard 50-gallon resistive type of standard height/diameter (not a low-boy). Insulation/efficiency and other details are to be manufacturer-recommended.

Cycling Capability

- **REQ.ME2** The water heater shall be capable of an average of 12 on/off cycles or more per day over its service life.
- **REQ.ME3** The water heater shall track total on/off cycling and protect itself against excessive cycling based on total cycles per 100 day period (e.g., not more than 1200 on/off cycles in a 100 day period).

CEA-2045 Port Characteristics

- **REQ.ME4** The water heater shall be equipped with the AC form factor CEA-2045 port described in Appendix B of the CEA-2045 standard. Placement of the port will ideally be high on the water heater to allow for good RF propagation of wireless communication modules.
- **REQ.ME5** The water heater will allow space for any communication module up to the maximum size specified by the CEA-2045 standard.

Standards and Presets

- **REQ.ME6** The water heater shall meet the rating criteria of a standard electric water heater, UL 174, and/or the Canadian equivalent.
- **REQ.ME7** The water heater factory temperature set point shall be set to 120°F.

User Interface Characteristics

The water heater shall provide a user interface supporting the following items. This interface must be locally available to the consumer at the home, but can be provided by whatever means the water heater manufacturer prefers, including on the water heater, via remote interface console, or smart phone application.

- **REQ.UI1** An indicator of successful communication connectedness (based on the CEA “Outside Comm Connection Status” message)
- **REQ.UI2** An indicator of curtailment when in effect

- **REQ.UI3** The water heater must include a mechanism to override an event. (Note also the monitoring requirement of override occurrences in REQ.M2)
- **REQ.UI4 (Optional)** Two user adjustable temperature set points: 1) normal operations and 2) maximum temperature for temporary absorption of energy (see Point 4 on the vertical axis of Figure 3-1). Example use case: The maximum temperature set point could be activated when a “Load Up” event is in effect.

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CEA-2045 COMMUNICATION REQUIREMENTS

The communication requirements are described in three groups: Link-Layer, Control, and Monitoring as detailed in the following sub-sections.

Link-Layer Requirements

Table 3-1
Link-Layer Requirements

Requirement	CEA-2045 Message	Water Heater Implementation
REQ.LL1	Link ACK	Supported. Required per the standard.
REQ.LL2	Link NAK	Supported. Required per the standard. Water heater shall detect and report all the standard Link NAK codes.
	Request Different Power Mode	Not supported. Not applicable with the AC interface.
	Request Different Bit Rate	Not required. Default Bit Rate is acceptable.
REQ.LL3	Query & Response: Maximum Payload Length	Supported. In order to support the messages identified herein (Get_Information is the longest); the unit must support negotiation up to 64 bytes message length.
	Query & Response: Get SGD Slot Number	Not supported. Not applicable with only one slot on the device.
	Query and Response: Get Available Slot Numbers	Not supported. Not applicable with only one slot on the device.
	Send Next Command to Slot	Not supported. Not applicable with only one slot on the device.

Control Requirements

This section identifies the CEA-2045 control messages that must be supported and the associated water heater responses. Any one of these message/response combinations may be utilized by any number of utility program strategies. Examples of such strategies are identified in a later section of this report.

The responses defined herein are designed to achieve a somewhat predictable behavior so that the contribution of water heaters can be properly valued. Some of the responses identified in this specification make reference to the “stored thermal energy” in the tank. The general idea of these references is illustrated in Figure 3-1.

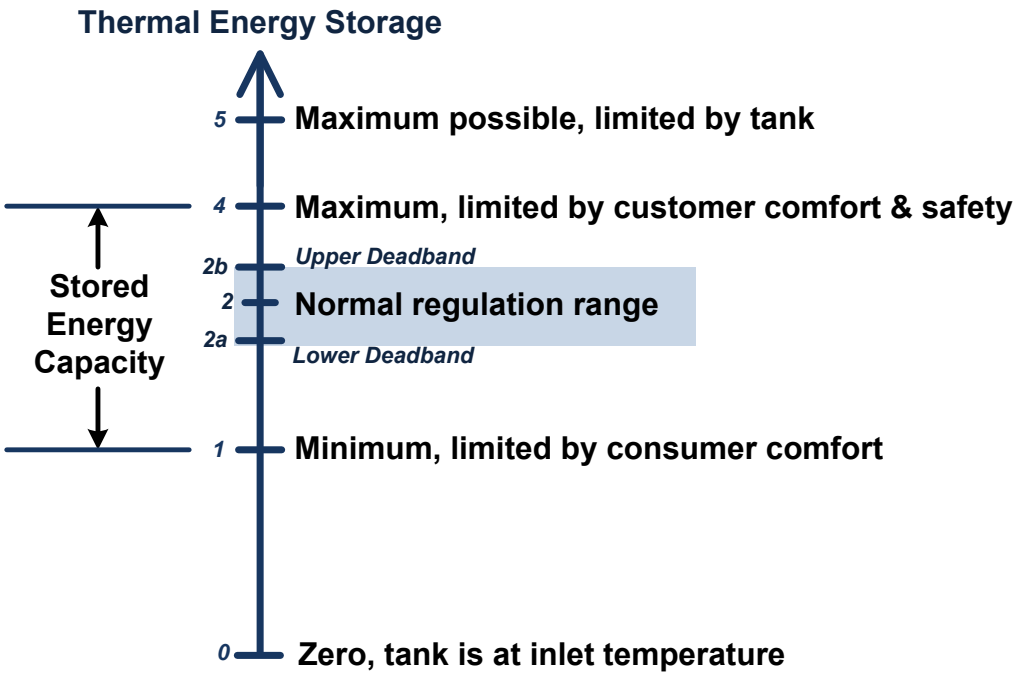

Figure 3-1
Reference Diagram for Stored Energy Levels

The levels shown are conceptual and the specifics of how each is determined are left to the water heater manufacturer. For example, a water heater with a built-in mixing valve might have a maximum energy storage capability that is substantially higher than the top of the normal regulation range, whereas the two temperatures might be the same for certain conventional water heater designs. It is understood that there are many ways in which a given stored energy level could be achieved with differing water temperatures and differing stratification of water temperature within the tank. Conceptual levels such as "minimum stored energy, limited by consumer comfort" may not be constant, as smart water heaters could hypothetically take historical use patterns into account to determine acceptable levels. Likewise, "maximum, limited by consumer comfort and safety" could be very close or very different from the top of the normal regulation range, depending on manufacturer design and perspective. These concepts are explained further as they are referenced in the following.

- **REQ.C1** The water heater logic shall be such that all control requests expire and the water heater returns to the previous customer-chosen mode of operation after twelve hours, unless the control request is reiterated or another request is received within that time. Under normal conditions, this expiration will not occur, but is included as a requirement as a consumer comfort protection mechanism in case of a malfunctioning DR system.
- **REQ.C2** The water heater logic shall be such that upon power cycle, operation returns to normal. Any operational state changes that were the result of communication received through the CEA-2045 interface must be restarted/renegotiated by the UCM following a power cycle. This requirement does not apply to user settings and other device configurations.

Table 3-2
Control Requirements

Requirement	CEA-2045 Message	Usage	Water Heater Response
REQ.C3	<Basic> Application ACK	As Specified	The water heater will support the application ACK as described in the CEA-2045 specification.
REQ.C4	<Basic> Application NAK	As Specified	The water heater will support the application NAK as described in the CEA-2045 specification.
REQ.C5	<Basic> Outside Comm Connection Status	As Specified	The water heater must monitor for this "heartbeat" signal. The communication status indicator (see requirement REQ.UI1) shall be based on this signal. If the water heater is processing a curtailment request and the heartbeat is not received within 15 minutes, the water heater will return to normal operation.
REQ.C6	<Basic> End Shed/Run Normal	As Specified	The end-shed/run normal event is used to inform the water heater that no events are in effect and to run normally. If received during a curtailment event, the event shall immediately end. Use 120 degrees F as the factory default.
REQ.C8	<Basic> Shed	The optional "Event Duration" field may be provided by a UCM. If supported see REQ C14	Shed Events are used as part of fixed-incentive based programs and require a predictable response: The water heater shall avoid operation, allowing the stored thermal energy in the tank to reach a "Minimum, limited by consumer comfort" level (see Figure 3-1). This could be accomplished, for example, by not operating the lower element and adjusting the upper temperature set-point to a reduced level. The effect of this command (if sustained for a long duration) would be to minimize the stored energy in the tank, maximizing the opportunity to be dispatched in an upward direction.
REQ.C9	<Basic> Critical Peak Event	The optional "Event Duration" field may be provided by a UCM. If supported see REQ C14	Critical Peak Events are typically used as part of fixed-incentive based programs and require a predictable response. These events are typically infrequent (only a few times a year) so responses are more aggressive. The water heater will act to reduce the stored thermal energy in the tank to the "minimum, limited by consumer comfort" level (see Figure 3-1). Because this message is used for infrequent events, and usually associated with high prices or incentives, the manufacturer may elect to be more aggressive in response.

Table 3-2 (continued)
Control Requirements

Requirement	CEA-2045 Message	Usage	Water Heater Response
REQ.C10	<Basic> Grid Emergency	The optional "Event Duration" field may be provided by a UCM. If supported see REQ C14	During an emergency event, the water heater shall immediately shutdown, not heating water until the event has ended. Note: Customer overrides shall be allowed, even for grid emergencies.
REQ.C11	<Basic> Present Relative Price	As Specified	The Relative Price command is used in association with a range of price-based programs and lends strongly to consumer-configurability of response (i.e., no particular response is mandatory from a utility perspective). The simplest of products could have responses that are selected by the manufacturer and fixed (non-adjustable). For this demonstration project, the water heater must offer consumers configurability of a "Low Price Threshold" and a "High Price Threshold." • If Present Relative Price is < "Low Price Threshold": – The water heater will act to maximize the stored thermal energy in the tank. For example, maintaining near the upper temperature limit throughout the tank. • If Present Relative Price is between "Low Price Threshold" and "High Price Threshold": – The water heater will behave normally, the same as when a "Run Normal" message has been received. • If Present Relative Price is above "High Price Threshold": – The water heater will act to reduce the stored thermal energy in the tank to the "minimum, limited by consumer comfort" level.

Table 3-2 (continued)
Control Requirements

Requirement	CEA-2045 Message	Usage	Water Heater Response
REQ.C12	<Intermediate> Autonomous Cycling and Terminate Cycling	As specified	This message passes the water heater a request for operation at a particular duty cycle (note that the "off"-time percentage is passed, not the "on"-time). The water heater acts to carry out this duty-cycle of operation, to the extent possible, given total cycle-count limits and remaining within the bounds of upper and lower temperature limits and maximum and minimum stored energy. The period of cycling (i.e., one cycle) shall be one-hour for the water heater. The water heater may be designed such that it has no real-time clock and can only support a cycling "start-time" of 0 (start now). In this case, if a command is received with a start-time that is not equal to zero, the water heater may respond with an Intermediate DR Message response code byte = 0x02 (bad value) and ignore the command. When the start-time = 0, then the "on"-time of the event shall start immediately (after the start randomization, if used). Example: the water heater has passed an Autonomous Cycling command of 90% with start-time = 0 and start-randomization not used. The water heater will turn on immediately for 6 minutes, remain off for the next 54 minutes, then repeat in each successive hour until another control request is received. Note: This request may be preceded by other requests that result in reducing or minimizing the stored energy in the tank such that there is available storage capacity to allow responding to this duty-cycle request.
REQ.C13	<New Basic Message > Load Up (use Opcode1 0x17, Opcode2 = Duration)	The optional "Event Duration" field may be provided by a UCM. If supported see REQ C14	Sent from the UCM to SGD to request that the SGD go to the "Maximum, limited by customer comfort and safety" level as indicated in Figure 3-1. This message can be used in conjunction with other curtailment messages such as Shed.

- **REQ.C14** If the UCM provides an "Event Duration" in association with any energy management function, then the water heater shall assume that the event has ended when EITHER the duration expires or an "End Shed" is received, whichever comes first.

Monitoring Requirements

This section identifies the CEA-2045 monitoring messages that must be supported and the associated water heater usage.

- **REQ.M1** The data update time of the following messages must be less than 1-second.

Table 3-3
Monitoring Requirements

Requirement	CEA-2045 Message	Usage	Water Heater Response
REQ.M2	<Basic> Customer Override	As Specified	As noted in requirement REQ.UI3, the water heater must provide consumers with an event override option. If selected, the end device must report the override to the UCM using this message. If an override occurs, the water heater must return to normal operation and ignore any new curtailment messages for the next 4 hours. The water heater must also provide a simple mechanism to proactively override any curtailment event requests for a duration of up to 24 hours.
REQ.M3	<Basic> Query & Response: What is your Operational State	As Specified	The water heater shall support the operational state query.
REQ.M4	<Intermediate> Query & Response:		The water heater shall support these messages. Reporting: 0 – Idle Normal, when the water heater is not heating, but is in a normal mode of operation 1 – Running Normal, when the water heater is presently heating (heat pump unit, or any heating elements are energized), as part of normal operation. 2 – Running Curtailed Grid, when the water heater is presently heating (heat pump unit, or any heating elements are energized), as part of a curtailment operation. 3 – Running Heightened Grid, when the water heater is presently heating as part of a heightened operation (e.g. Load-Up or low price) 4 – Idle Grid, when the water heater is not presently heating, but would be if not for some grid curtailment signal. 5- SGD Error Condition, if anything is internally broken.

Table 3-3 (continued)
Monitoring Requirements

Requirement	CEA-2045 Message	Usage	Water Heater Response
REQ.M5	<Intermediate> Query & Response: Info Request		Water heater shall support, at a minimum, all mandatory device information plus the model number and serial number optional fields associated with the Info Request. It is understood that these fields may be reflective of the controller module rather than being specific to the water heater. Device Type shall be reported as a 0x0002 "Water Heater Electric."
REQ.M6	<Intermediate> GetCommodity Read Request and GetCommodity Read Reply	To provide Energy Usage and Energy Storage information to UCM	Water heater shall support the following requests from a UCM • Electric power (present consumption rate W) and cumulative lifetime energy consumed W-h. Commodity Code = 0 "Electricity Consumed" – *Total Energy Storage Capacity Commodity Code = 6 – *Present Energy Storage Capacity Commodity Code = 7 – - Total Energy Storage Capacity and Present Energy Storage Capacity are new messages defined in the "Recommended Changes to the ANSI/CEA-2045 Standard." [3] All of these values can be estimates based on operating state; metering electronics are not required. In dialogue with water heater manufacturers, it has been noted that heating elements may vary from model to model and may be replaced after the units are deployed. For power and energy, it is acceptable for these estimations to assume that the heater elements are 4500W.

[3] New Energy Storage Commodity codes are included in the latest CEA-2045 draft. For details see: http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002003988

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EXAMPLE UTILITY CONTROL STRATEGIES

This section is included for informational purposes only. It describes several example utility program types and identifies the messages that may be used in association with these programs. From the water-heater design perspective, this information is irrelevant. Only the message-to-response mappings provided in the previous sections matter.

Direct Load Control

Utility Direct Load Control programs have traditionally used external relays to control the power to end-use devices. These are simple control methods, and are commonly used for water heating and pool pump control. A predictable response is needed for these programs. Messages potentially used in conjunction with this control strategy include:

Table 4-1
Example Messages Related to Direct Load Control

CEA-2045 Message	How Used
<Basic> Shed	To inform devices that a control event is in effect.
<Basic> End Shed/Run Normal	To inform devices to return to normal at the close of an event.

Time of Use (TOU)

Utility Time-of-Use programs involve an energy price that varies with time. For residential programs, the schedules for these price variations are fixed and known to consumers in advance. Advanced meters capture and report the consumption during each time interval of the day, allowing for bill calculation.

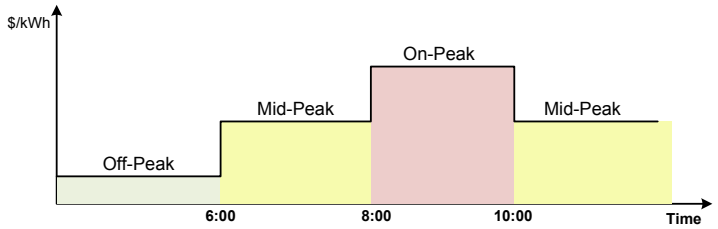

Figure 4-1
Time-of-Use Example

To aid consumers in managing their consumption patterns, price information can be provided to end-use devices. Messages potentially used in conjunction with this control strategy include:

Table 4-2
Example Messages Related to Time-of-Use

CEA-2045 Message	How Used
<Basic> Present Relative Price	The Present Relative Price signal to the water heater is varied according to what is currently in effect.

Critical Peak Pricing (CPP)

Critical Peak Pricing programs are a dispatchable form of Time of Use. Critical Peak events are called, usually with day-ahead notification, to the consumer. Typically, CPP program agreements limit the number of event days per year to a small number (e.g., 10) and involve prices that are substantially higher than normal.

Critical peak events may be used in conjunction with regular daily TOU. Messages potentially used in conjunction with this control strategy include:

Table 4-3
Example Messages Related to Critical Peak Pricing

CEA-2045 Message	How Used
<Basic> Critical Peak Event	To inform devices that an infrequent Critical Peak event is in effect.
<Basic> End Shed/Run Normal	To inform devices to return to normal at the close of an event.

Grid Emergencies

Grid emergencies are not a part of any normal program. Grid Emergency messages would only be sent to end devices during emergency situations when complete power outages are the alternative. Messages potentially used in conjunction with this control strategy include:

Table 4-4
Example Messages Related to Grid Emergencies

CEA-2045 Message	How Used
<Basic> Grid Emergency	To request that devices shutdown due to a grid emergency
<Basic> End Shed/Run Normal	To inform devices to return to normal once the emergency condition is over

Cycling-Based Managed Load Operation

Managed Load Operation represents a number of control strategies in which the water heater may be requested to operate at particular times (to absorb energy) in addition to avoiding operation at other times. Use cases associated with this kind of management include following variable generation resources such as wind energy. Messages potentially used in conjunction with this control strategy include:

Table 4-5
Example Messages Related to Cycling-Based Managed Load Operation

CEA-2045 Message	How Used
<Basic> Shed	To put the water heater in a state such that its capacity to store energy is increased or maximized
<Intermediate> Start Autonomous Cycling	To request that the water heater absorb energy at an average rate (over a one hour cycle) determined by the specified duty cycle
<Intermediate> Terminate Autonomous Cycling	To inform the water heater to return to normal operation once the managed load operation is past.

Up/Down Energy Storage Management

The number of scenarios in which end-use loads could be used to store energy is growing with increases in variable generation such as wind and solar. Water heaters could be used to absorb excess energy to compensate for this variable resource. One way in which this could be performed is by scheduling a curtailment event to reduce the water heater's stored energy prior to the time when storage is needed. Messages potentially used in conjunction with this control strategy include:

Table 4-6
Example Messages Related to Up/Down Energy Storage Management

CEA-2045 Message	How Used
<Basic> Shed	To put the water heater in a state such that its capacity to store energy is increased or maximized
<Basic> Load Up	To request that the water heater absorb energy to the extent possible
<Basic> End Shed/Run Normal	To inform the water heater to return to normal operation once the managed load operation is past

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