Set-Top Boxes

Codes and Standards Enhancement (CASE) Initiative
For PY 2013: Title 20 Standards Development

Analysis *of* Standards Proposal for
Set-Top Boxes

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Prepared for:

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1 Executive Summary

The Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE), Southern California Gas (SCG), San Diego Gas & Electric (SDG&E) Codes and Standards Enhancement (CASE) Initiative Project seeks to address energy efficiency opportunities through development of new and updated Title 20 standards. Individual reports document information and data helpful to the California Energy Commission (CEC) and other stakeholders in the development of these new and updated standards. The objective of this project is to develop CASE Reports that provide comprehensive technical, economic, market, and infrastructure information on each of the potential appliance standards. This CASE report covers standard options for set-top boxes.

Set-top boxes allow consumers to access video content on their home screens. Initially intended as a simple electronic device for rendering paid-television (i.e. pay-TV) content for viewers, today's high end set-top box now has the technical capability of serving as a media center to the entire home. In the United States (U.S.), service providers deploy pay-TV set-top boxes to subscribers' homes as part of a pay-TV service package. There are approximately 30 million set-top boxes in use in California today, consuming a combined 3,800 gigawatt-hours per year (GWh/year). The majority of today's set-top boxes draw nearly the same power whether or not the device is being actively used to watch or record television.

PG&E, SCE, SCG and SDG&E (the California investor-owned utilities, herein referred to collectively as the "California IOUs") recommend that California adopt an energy efficiency standard for set-top boxes. We recommend that the proposed standard takes effect one year after adoption, addressing cable, satellite, cable digital television adapter (DTA), Internet Protocol (IP) and thin-client/remote set-top boxes.

There are four primary energy efficiency measures for set-top boxes that are technologically feasible today and have the potential to deliver significant energy savings: (1) reduce On mode power levels, (2) reduce Sleep mode power levels, (3) increase time spent in Sleep mode and (4) implement new system architectures. These efficiency improvements will enable a set-top box to comply with the proposed standard levels. The California IOUs estimate modest incremental costs in the timeframe of the proposed standard. There is no negative impact on California economy or jobs.

The CEC's adoption of the proposed standard would represent savings of over 200 GWh/yr for first year sales and 800 GWh/yr savings in year of stock turnover.[1] Total estimated energy savings from 2016-2023 are 4,200 GWh. Total energy savings represent approximately 1,840,000 metric tons of equivalent carbon dioxide (metric ton of CO_2e) savings for 2016-2023. The adoption of the proposed set-top box standard is a cost-effective means of helping California meet its long-term energy goals, climate initiatives and air quality guidelines.

[1] We model savings starting in the likely first full calendar year of implementation (2016) since the potential effective date would be sometime in 2015 (one year after adoption occurring sometime in 2014).

2 Acronyms

AEC – Annual electricity consumption
APD – Auto power down
CA – Conditional access
CEA – Consumer Electronics Association
CSA – Canadian Standards Association
CSL – Candidate standard level
DOE – United States Department of Energy
DTA – Digital transport adapter
DVR – Digital video recorder
EPA – Environmental Protection Agency
EPCA – Energy Policy and Conservation Act
GWh – Gigawatt hour
HD – High definition
HDD – Hard disk drive
HDMI – High definition multimedia interface
HNI – Home network interface
IEC – International Electrotechnical Commission
IP – Internet protocol
kWh – Kilowatt hour
MoCA – Multimedia Over Coax Alliance
MVPD –Mulitchannel video program distributor
NCTA – National Cable and Telecommunications Association
NODA – Notice of data availability
NOMAD – Naturally occurring market adoption
NOPR – Notice of proposed rulemaking
NPV – Net present value
OTA – Over the air
OTT – Over-the-top
PSU – Power supply unit
QPL – Qualified product list
RF – Radio frequency
STB – Set-top box
UEC – Unit electricity consumption

3 Product Description

3.1 Overview

Set-top boxes (Figure 3.1) allow consumers to access video content on their home screens. Initially intended as a simple electronic device for rendering paid-television (i.e. pay-TV) content for viewers, today's high end set-top box now has the technical capability of serving as a media center to the entire home. For the purposes of this CASE report and its proposed standard, the California IOUs use the following definition of a set-top box:

> A set-top box is a device combining hardware components with software programming designed for the primary purpose of receiving television and related services from terrestrial, cable, satellite, broadband, or local networks, and providing video output.[2]

Figure 3.1 Example Set-Top Box

Source: Motorola (2012)

In general, set-top boxes have two primary operating modes: (1) On (i.e. active) mode, and (2) Sleep mode. In On mode, a set-top box is connected to a mains power source, at least one principle function (e.g. watching or recording a show) is activated, and all principal functions are provisioned for use (EPA 2013a).[3] Sleep mode represents a range of reduced power states where the set-top box is connected to a mains power source but is not providing any principle function (EPA 2013a). The term Deep Sleep is relatively new to the pay-TV market. Deep Sleep state is a power state characterized by reduced power consumption and more than 30 seconds required to return to full On mode functionality (EPA 2013a).

The unit energy consumption (UEC) of a set-top box is calculated by multiplying the percentage of time spent in each operating mode by the associated power consumption level for that mode, and then summing these results for all operating modes. The resulting UEC value is expressed in kilowatt-hours (kWh) per year.

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[2] We consider displayless video gateways a type of set-top box. As such, we use a modified definition for a set-top box from ENERGY STAR's Draft 1 Version 4.1 specification (EPA 2013a). Some stakeholders do not consider displayless video gateways to be set-top boxes. We define a displayless video gateway as a type of set-top box combining hardware components with software programming designed for the primary purpose of receiving television and related services from terrestrial, cable, satellite, broadband, or local networks and providing video without any direct video connection.

[3] Principle functions are functions necessary for selecting, receiving, decoding, decompressing, or delivering live or recorded audio/video content to a display device, locale/remote recording device, or client (EPA 2013a). Monitoring for user or network requests is not considered a principle function for set-top boxes (EPA 2013a).

Set-top boxes in California consume a combined 3,800 GWh/year. The majority of today's set-top boxes draw nearly the same power in these two modes, whether or not the device is being actively used to watch or record television (DOE 2012b; NRDC 2011; Urban, Tiefenbeck, & Roth 2011). However, some new set-top boxes are capable of lower Sleep mode power levels. For example, CableLabs recently demonstrated new software for existing set-top boxes that allows the devices to reduce Sleep mode power levels by approximately 20 percent (NCTA 2012).

3.2 Product Classes

There are several different types, or product classes, of set-top boxes. The type of set-top box used in the home is dependent on both the type of service provider and which features the subscriber chooses. This CASE report covers the following product classes:

Cable: A set-top box whose primary function is to receive television signals from a broadband, hybrid fiber/coaxial, or community cable distribution system with conditional access (CA) or a set-top box capable of receiving cable service after installation of a CableCARD or other type of conditional access system (EPA 2013a).

Satellite: A set-top box that receives and decodes video content as delivered from a service provider satellite network and that is not Cable (EPA 2013a).

Internet Protocol (IP): A set-top box whose primary function is to receive television/video signals encapsulated in IP packets and that is not Cable, Satellite, or Cable DTA (EPA 2013a).

i. **Over-the-top (OTT) Internet Protocol (IP):** An IP set-top box that does not receive signals from a multichannel video programming distributor (MVPD) (EPA 2013a).

ii. **Service Provider Internet Protocol (IP):** An IP set-top box that receives signals from a MVPD (EPA 2013a).

Cable Digital Transport Adapter (DTA): A minimally-configured set-top box whose primary function is to receive television signals from a broadband, hybrid fiber/coaxial, or community cable distribution system (EPA 2013a).

Thin-client / Remote: A set-top box that can receive content over a home network interface (HNI) from another set-top box, but is unable to interface directly to the service provider network (EPA 2013a).

Note: We use the ENERGY STAR® product specification for set-top boxes, Draft 1 Version 4.1 (EPA 2013a), as the general framework for our proposed standard product class definitions (Section 3.2), additional functionality definitions (Section 3.3), and scope (Section 3.4).[4] We acknowledge there is a Draft 2 Version 4.1 (EPA 2013b) ENERGY STAR specification released for set-top boxes as of this writing, but for the purposes of this CASE report and proposed standard we focus on Draft 1 unless explicitly noted otherwise. However, we recommend the California Energy Commission consider any future drafts and final version of ENERGY STAR's Version 4.1 set-top box specification as it considers a possible standard.

3.3 Additional Functionality

Set-top boxes provide subscribers with a number of services and features, including high-definition (HD) programming, DVR and multi-room capability, among others. The selection of these features by the subscriber determines what type of set-top box the service provider deploys to the home, and ultimately its energy use. This CASE report covers the following functions and features:

[4] We consider displayless video gateways to be set-top boxes and revise product class definitions from ENERGY STAR's Draft 1 Version 4.1 specification (EPA 2013a) to reflect this.

Advanced Video Processing. The capability to encode, decode, and/or transcode audio/video signals in accordance with standards H.264/MPEG 4 or SMPTE 421M (EPA 2013a).

CableCARD. The capability to decrypt premium audio/video content and services and provide other network control functions via a plug-in conditional access module that complies with the ANSI/SCTE 28 HOST-POD Interface Standard (EPA 2013a).[5]

Digital Video Recorder (DVR). A set-top box feature that records television signals on a hard disk drive (HDD) or other non-volatile storage device integrated into the set-top box (EPA 2013a).[6] A DVR often includes features such as: Play, Record, Pause, Fast Forward (FF), and Fast Rewind (FR) (EPA 2013a). Set-top boxes that support a service provider network-based "DVR" service are not considered DVR set-top boxes for purposes of this CASE report. The presence of DVR functionality does not mean the device is defined as a set-top box.

DOCSIS®. The capability to distribute data and audio/video content over cable television infrastructure in accordance with the CableLabs® Data Over Cable Service Interface Specification (EPA 2013a).[7]

High Definition (HD) Resolution. The capability to transmit or display video signals with a minimum output resolution of 1280×720 pixels in progressive scan mode at minimum frame rate of 59.94 fps (abbreviated 720p60) or a minimum output resolution of 1920×1080 pixels in interlaced scan mode at 29.97 fps (abbreviated 1080i30) (EPA 2013a).

Home Network Interface (HNI). An interface with external devices over a local area network (e.g. Institute of Electrical and Electronics Engineers (IEEE) 802.11 (Wireless-Fidelity or Wi-Fi), Multimedia over Coax Alliance (MoCA), HomePNA alliance (HPNA), IEEE 802.3, HomePlug AV) that is capable of transmitting video content (EPA 2013a).

i. **MIMO Wireless HNI**: IEEE 802.11n/ac and related MIMO enabled WiFi functionality that supports more than one spatial stream in both send and receive (Antenna support is not relevant, thus the device must be 2 x n : 2[8] or better to fall under this definition) (EPA 2013a).

Multi-room. The capability to provide independent live and/or real time transfer of audio/video content to multiple devices (2 or more clients) within a single family dwelling. This definition does not include the capability to manage gateway services for multi-subscriber scenarios (EPA 2013a).

Multi-stream. A set-top box feature that may provide independent video content to one or more clients, one or more directly connected display devices, or a DVR (EPA 2013a). This definition does not include the capability to manage gateway services for multi-subscriber scenarios.

3.4 Scope of Products

The scope of products for this standards proposal is cable, satellite, IP, cable DTA, and thin-client/remote set-top boxes as defined in Section 3.2.[9] If a device falls under one of the product class definitions in Section 3.2, it is considered in the scope of this standard proposal unless explicitly excluded below.

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[5] See http://www.scte.org/standards/ for more information.

[6] Note the term DVR is often used two ways: one referencing the functionality (e.g. a set-top box with DVR functionality) and the other as the type of set-top box (e.g. HD-DVR) (DOE 2012b).

[7] See http://www.cablelabs.com/specifications/ for more information.

[8] The description "2 x n : 2" means 2 send streams x n antennas : 2 receive streams, where n will always be the same or larger as the largest number of streams (in this case 2).

[9] Tivo and other stand-alone DVRs that support CableCARD are considered cable set-top boxes.

This standards proposal **does not cover** the following product categories:

> **Terrestrial.** A terrestrial set-top box is a set-top box whose primary function is to receive television signals over the air (OTA) or via community cable distribution system without conditional access (CA) (EPA 2013a) and that is not a Cable, Satellite, Cable DTA, or IP set-top box as defined in Section 3.2. The pay-TV industry does not utilize terrestrial set-top boxes, which are only used in conjunction with analog televisions. Almost all terrestrial set-top boxes automatically power down to 2 watts in compliance with a government converter box coupon program (NTIA 2007; DOC 2007). For the purposes of this CASE report and proposed standard, terrestrial set-top boxes are out of scope.
>
> Devices not primarily used as a set-top box that offer similar functionality, such as video game consoles, Blu-ray players and internet-enabled televisions. These devices have significantly different operating models when compared to set-top boxes. For the purposes of this CASE report and proposed standard, these devices are out of scope.

4 Manufacturing and Market Channel Overview

The major pay-TV service providers play a key role in the overall pay-TV market through their substantial influence on set-top box, headend and overall system requirements.[10] Table 4.1 lists major U.S. pay-TV service providers by number of subscribers. Service providers own deployed set-top boxes, and they control installation, configuration, software updates, repair, refurbishment, retirement and resale of set-top box equipment. Today there are approximately 30 million set-top boxes installed in California homes (SNL Kagan 2012).

Table 4.1 Top U.S. Service Providers and their Subscriber Base, 2012

Segment	Service Provider	Subscribers (millions)
Cable	Comcast	22.0
	Time Warner	12.2
	Verizon	4.7
	Cox	4.5
	Charter	4.2
	Cable Vision	3.2
Satellite	DirecTV	20.1

[10] Headend refers to the pay-TV provider's master facility for receiving, processing and distributing television signals.

	Dish Network	14.1
Internet Protocol	AT&T U-verse	4.5
Other		7.5

Source: NCTA (2013a)

In the U.S., service providers deploy pay-TV set-top boxes to subscribers' homes as part of a pay-TV service package. The pay-TV set-top box market is different from the markets for most other consumer electronics devices. Manufacturers produce set-top box hardware, but unlike most other electronic devices, set-top box manufacturers do not develop, load or configure set-top box applications software—the service provider does. Table 4.2 lists major manufacturers and their associated market share.

Table 4.2 Major Pay-TV Set-top Box Manufacturers, 2010

Company	U.S. Market Share (%)	Cable	Satellite	Internet Protocol
Motorola	35	X		X
Cisco	18	X		X
Pace	18	X	X	X
EchoStar	12		X	
Other	18	X	X	X

Source: IMS (2010) and DOE (2012b)
Note: percentages do not add to 100 due to independent rounding

Service providers deploy virtually all set-top boxes to subscribers' homes as part of a pay-TV service package. Figure 4.1 depicts the pay-TV set-top box distribution model, with service providers playing the key role. Since service providers directly deploy pay-TV set-top boxes to subscriber homes, there is no retail market for pay-TV set-top boxes. OTT and stand-alone DVR set-top boxes (e.g. TiVo), however, are distributed through traditional retail channels.

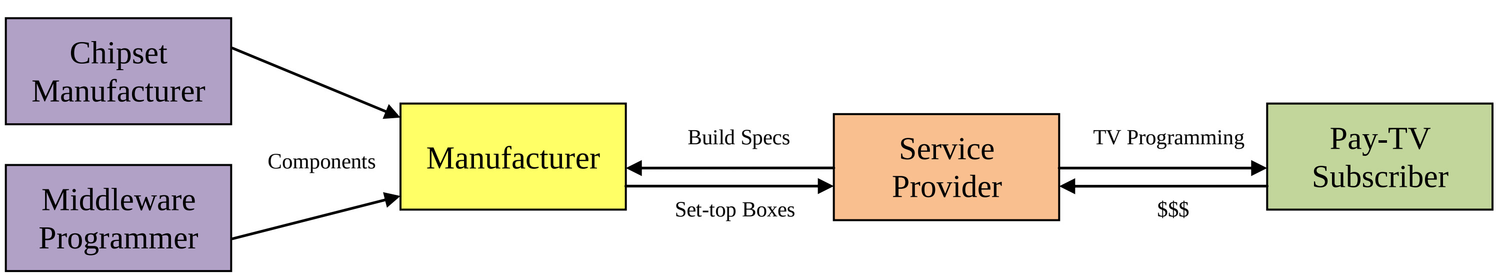

Figure 4.1 Pay-TV Set-Top Box Distribution Model
Source: DOE (2012b)

5 Energy Usage

5.1 Test Methods

5.1.1 Current Test Methods

There are a number of established test procedures for measuring set-top box energy consumption. Relevant test procedures include those from the U.S. Environmental Protection Agency's (EPA) ENERGY STAR program, U.S. Department of Energy (DOE) (proposed draft), the International Electrotechnical Commission (IEC), the Canadian Standards Association (CSA) and the Consumer Electronics Association (CEA). There is a high degree of harmonization across these different test procedures.

The most recently finalized ENERGY STAR test procedure revision, dated August 2011, requires power measurements for several different types of activities.[11] This version supports the ENERGY STAR Version 3.0 program requirements finalized in September 2011. The test procedure requires measurements for watching live TV, recording live TV to DVR, playing back recorded TV from DVR, recording live TV to removable media, and playing back recorded TV from removable media. Power measurements are taken in three different reference channels: network TV, live sports, and live news. Measurements of the following functions or modes are also required: multi-room, Sleep mode, Deep Sleep state and auto power down (APD).[12]

The U.S. DOE is in the process of creating an energy test procedure for set-top boxes that continues to iterate and improve upon the framework of the ENERGY STAR 3.0 test procedure. In January 2013, DOE released a test Procedure notice of Proposed Rulemaking (NOPR) (DOE 2013b) after evaluating test procedures from ENERGY STAR, CSA, CEA and IEC. DOE has tentatively identified that the test methods described in the draft Consumer Electronics Association (CEA) standard, CEA-2043 (explained further below), are appropriate to use as a basis for developing the DOE test procedure for set-top boxes (DOE 2013b). ENERGY STAR Draft 1 Version 4.1 specification (EPA 2013a), which was updated after the release of the DOE test procedure NOPR, references the DOE test procedure NOPR for set-top boxes (DOE 2013b) and provides an additional test procedure to addresse displayless video gateways, which are not in the scope of the DOE test procedure.

IEC's industry standard, IEC-62087, specifies methods of measurement for the power draw of television sets, video recording equipment, set top boxes, audio equipment and multifunction equipment for consumer use (IEC 2011). The IEC test procedure uses a simplified ENERGY STAR test procedure methodology, with less required activity measurements (no reference channels) and slightly different operating mode definitions (DOE 2012b).

Another relevant test procedure is CSA's C380-11(CSA 2011). C380-11 is a test procedure for the measurement of energy consumption of set-top boxes which updates the 2008 Edition to advance its harmonization with IEC 62087 and the ENERGY STAR specification (CSA 2011). C380-11 provides guidelines on how to apply IEC measurement results to ENERGY STAR version 3.0 results. The method explains how IEC terminology maps to ENERGY STAR terms such that IEC test measurements can be used in conjunction with the energy allowance equations documented in the ENERGY STAR program

[11] The test procedure is appended to the specification criteria document, EPA (2011b).

[12] APD is the capability of a device to switch itself from On mode to Sleep mode after a predetermined period of time (APD timing) has elapsed. APD timing begins when the following criteria have been met: 1) the device has ceased performance of all primary functions; or 2) the last user input has been received (e.g., remote control signal, volume adjustment).

requirements to determine product qualification status (DOE 2012b). In addition, the CSA method includes some small adaptations for North America such as testing at 120 V versus 230 V. The ENERGY STAR test procedure utilizes the same test setup and instrumentation requirements documented in the CSA procedure.

CEA has released industry standards for set-top box testing including CEA-2013 and CEA-2022 (CEA 2007a, 2007b). These CEA standards are very similar to the CSA's approach, adapted for the U.S. set-top box market. CEA-2013 defines maximum background mode (i.e. Sleep state) energy consumption of basic digital set-top boxes (CEA 2007a). CEA-2022 defines a method for measuring power consumption of a digital set-top box delivery when operating in an active (i.e. On mode) state (CEA 2007b). CEA is currently developing an updated draft standard, CEA-2043, that defines a method for measuring set-top box power consumption using the measurement parameters of IEC-62087 (CEA 2012). CEA-2043 will supersede CEA-2013 and CEA-2022.

5.1.2 Proposed Test Methods

The California IOUs propose the CEC adopt the ENERGY STAR Draft 1, Version 4.1 (EPA 2013a) test procedure, with some minor modifications. The ENERGY STAR test procedure it is the best available measurement tool because it obtains energy savings from all modes of operation and a wide range of product classes. We recommend including two improvements to the existing ENERGY STAR test procedure in the California approach: verification of (1) measurement of scheduled Deep Sleep per the sleep modes section of CEA 2043 (power level and default duration), and (2) verification of 15 minute APD after completion of maintenance/recording activities for cases where the set-top box was in Sleep mode before the activity.[13]

We recommend testing Deep Sleep power level and duration using the same test set-up and configuration required by DOE for APD test in Section 5.6.8. of the NOPR (DOE 2013b) with the following differences:

1. Start the test 15 minutes before the scheduled Deep Sleep event and verify that duration of the scheduled Deep Sleep matches the default duration stated by the service provider.
2. If the set-top box wakes prematurely from Deep Sleep for a maintenance activity (e.g. during live network test), then retest.

We recommend the CEC align with ENERGY STAR, which has committed to using the DOE test method as the basis for its approach. We expect the DOE's draft test procedure to continue to enable and support the IOU proposal in this report. When the final DOE test procedure is released, we recommend that CEC continue to include additional tests outlined by ENERGY STAR Draft 1, Version 4.1 and the two improvements recommended above. Given ENERGY STAR is able to require additional tests above and beyond the DOE procedure, we assume that CEC can do the same after the final DOE test procedure is released.

5.2 Baseline Energy Use Per Product

The California IOUs developed a set-top box energy use model based on a variety of data sources and methodologies. The model incorporates duty cycle and UEC data, explained in this section, along with market data (explained in Section 6.1) to calculate energy consumption and savings estimates. This section focuses on per unit energy use.

5.2.1 Duty Cycle

As discussed in Section 3, set-top boxes have two primary operating modes: (1) On mode, and (2) Sleep mode, Although some field studies have attempted to measure duty cycle, there are still many unknowns as to the full energy use implications of changing technologies and viewer behavior.

[13] These additional test procedure elements are recommended to support the secondary standards criteria proposed in Section 5.4.2.

We propose using duty cycles (i.e. usage assumptions) from Appendix AA in DOE's Test Procedure NOPR (DOE 2013b) for all DOE set-top box product classes (Table 5.1) and ENERGY STAR Draft 1, Version 4.1 (EPA 2013a) for set-top boxes that are considered displayless video gateways (Table 5.2). We chose these duty cycles because they are based on EPA analysis of Nielsen market data and are generally accepted by industry as the best usage assumptions available today. Four different duty cycles are used, depending on whether APD is enabled by default and whether the set-top box supports multi-stream capability. Displayless video gateways have two possible duty cycles, depending on whether ADP is enabled by default.

Table 5.1 Proposed Hour Weightings for Set-Top Boxes

APD Enabled by Default?	Multi-stream?	On	Multi-Stream	Sleep	APD	Off
No	No	14	0	10	0	0
Yes	No	7	0	10	7	0
No	Yes	9	5	10	0	0
Yes	Yes	2	5	10	7	0

Source: Table 4 – DOE Proposed Hour Weightings in DOE Test Procedure NOPR (DOE 2013b).
Note: APD = Auto Power Down

Table 5.2 Proposed Hour Weightings for Displayless Video Gateways

APD Enabled by Default?	Multi-Stream	Sleep	APD
No	14	10	0
Yes	7	10	7

Source: Table 11: Number of Hours Assigned to Each Displayless Video Gateway Mode of Operation in ENERGY STAR Draft 1, Version 4.1 (EPA 2013a).
Note: APD = Auto Power Down

5.2.2 Unit Energy Consumption

In this section we estimate the UEC of set-top boxes not compliant with the proposed standard based on UEC values reported to ENERGY STAR.[14] To calculate the average UEC of set-top boxes that are non-compliant with our proposed standard, we use data from two ENERGY STAR qualified product lists (QPL):

- The ENERGY STAR v3.0 QPL dated April 08, 2013 (EPA 2013c).
- The last published ENERGY STAR v2.0 QPL dated August 15, 2011 (EPA 2011d).

[14] In section 5.4.3, we present the UEC of set-top boxes compliant with the proposed standard.

We calculate the weighted average UEC of set-top boxes not compliant with the proposed standard by calculating the following from the above datasets:

- The average UEC of non-compliant set-top boxes in the v3.0 QPL. We call this $UEC_{3.0}$.
- The average UEC of non-compliant and non-v3.0-qualified set-top boxes in the v2.0 QPL. We call this $UEC_{2.0}$.

We then calculate the average UECs of set-top boxes that are non-compliant with our proposed standard by using the following equation:

$$(UEC_{3.0} \times 0.65) + (UEC_{2.0} \times 0.35) = \text{Average non-compliant UEC}$$

We apply this equation for each product class. This equation is based on the assumption that 65% of today's new non-compliant set-top box purchases qualify for ENERGY STAR v3.0.[15] Table 5.3 shows the average UEC for non-compliant set-top boxes in 2013.

Table 5.3 Average Energy Use for Non-compliant Products

Product Class	Unit Electricity Consumption (kWh/yr)
Cable	154
Satellite	110
Internet Protocol[a]	101
Cable Digital Television Adapter	42
Thin Client / Remote	61

[a] Service provider Internet Protocol (IP) set-top boxes only. Over-the-top IP set-top boxes excluded from this analysis.

5.3 Efficiency Measures

There are four primary efficiency measures for set-top boxes that are technologically feasible today, and have the potential to deliver significant energy savings: (1) reduce On mode power levels, (2) reduce Sleep mode power levels, (3) increase time spent in Sleep mode and (4) implement new system architectures.

5.3.1 Reduce On Mode Power Levels

Average set-top box On mode power levels by set-top box category have decreased significantly since the introduction of high definition set-top boxes in the mid-2000's (Figure 5.1).

[15] Based on input from industry and EPA about today's penetration of v3.0 qualified set-top boxes.

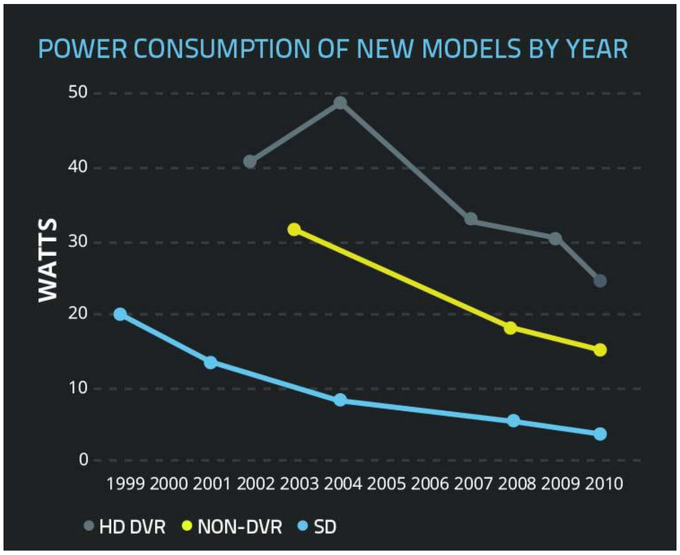

Figure 5.1 Set-top box power level trends

Note: Non-DVR means High Definition Non-DVR
Source: NCTA (2013b, 21)

However, new performance features such as full and ultra high definition television or multi-room server support for more client devices could cause an increase in On mode power levels. New capabilities often require discrete chip solutions to implement. Over time, manufacturers integrate these chips into a system on chip (SoC), which reduces cost and power. Then the SoC goes through die shrinks, which further reduces cost and power. This process is similar in some ways to the design cycle for game consoles and other products based on integrated circuits. Figure 5.2 illustrates the power trend for game consoles using the Sony Playstation as an example. Game console manufacturers develop new chip architectures every seven years or so. New chip architectures are generally not optimized for energy efficiency, but over time the improvements including reductions in die size (i.e., die shrinks) are made that reduce console energy consumption. Similar trends enable the set-top box power trends for new feature introductions shown in Figure 5.1.

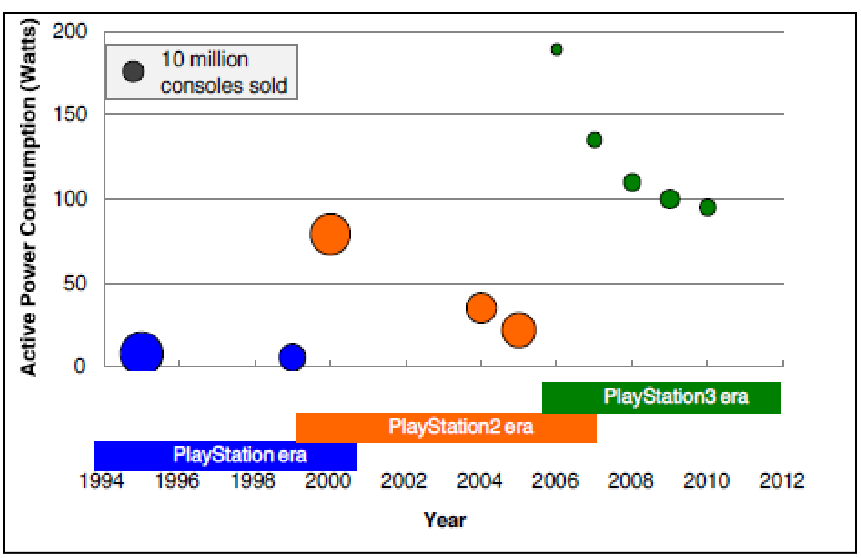

Figure 5.2 Game console power trends

Source: Hittinger, Mullins, and Azevedo (2012)

In addition to fundamental processor efficiency gains, there are many opportunities to improve the ability of set-top boxes to scale power to the utility provided to the subscriber. Opportunities generally applicable to the entire set-top box market include:

- Transcoding: Tomorrow's set-top boxes may have more than 6 transcoders in support of a wide array of unmanaged clients (e.g. iPads) and managed clients (e.g. thin client devices deployed by the service provider). However, fundamental power scaling technologies such as power islands, and voltage and frequency scaling should enable systems to use less power when not providing full functionality (e.g. only transcoding one stream instead of 8 streams).

- Home network interface: Tomorrow's set-top boxes may operate multiple network interfaces simultaneously, such as MoCA and Wi-Fi. However, power scaling technologies exist for both MoCA and Wi-Fi that enable set-top boxes to use less On mode power when operating at low data rate.

- Multi-stream: Tomorrow's set-top boxes may be able to turn off tuners and other needed functions or scale their power down when not tuning the maximum allowed number of television channels.

Additional opportunities are available for the cable set-top box market:

- Tomorrow's set-top boxes may require multiple CableCARDs to support more than six simultaneous video streams. It may be possible to power down the second card until it is needed. Powering up a secondary card would have to happen well in advance of the need given the expected long wake time for CableCARD.

- Data over cable service interface specification (DOCSIS®): Future revisions of the DOCSIS specification will support reduced power modes during periods of time when high bandwidth communications are not required (i.e., 1x1 mode).[16]

The following are examples of component efficiency improvements that would improve On mode power:

- Power supplies: The DOE performed teardown analysis of 19 set-top boxes in which they measured the energy efficiency of ac/dc power conversion. The results, shown in

- Figure 5.3 below, show that there is variability in power supply efficiency levels that and an opportunity for energy savings.

- More efficient hard disk drives: Similarly, market actor discussions suggest that some hard drives are more efficient than others that have the same performance characteristics. Other market actors point out that not all hard drives meet the performance requirements of complex multi-room servers; therefore it is important to make comparisons of hard drives with similar performance characteristics.

- Full band tuners: Full band tuners tune a broad frequency spectrum instead of narrow bands associated with individual broadcast channels. As a result, a single full band tuner can tune several channels at the same time. This saves energy relative to the single-channel tuner approach.

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[16] DOCSIS® is an international telecommunications standard that permits the addition of high-speed data transfer to an existing cable TV system (CableLabs® 2013a). Many cable television operators employ DOCSIS® to provide internet acesss over existing coaxial or fiber infrastructure (CableLabs® 2013a).

Index #	Product Group	PSU Efficiency
1	1 - Cable Base	76.0%
2	1 - Cable Base	76.0%
3	2 - Cable Video Client	85.0%
4	4 - Cable DVR	85.0%
5	5 - Cable DVR & Video Server	85.0%
6	6 - Satellite Base	76.0%
7	6 - Satellite Base	76.0%
8	7 - Satellite Video Client	76.0%
9	9 - Satellite Video Server	85.0%
10	10 - Satellite DVR & Video Server	85.0%
11	12 - IP Video Client	76.0%
12	14 - IP DVR	76.0%
13	15 - IP DVR & Video Server	76.0%
14	15 - IP DVR & Video Server	76.0%
15	16 - OTT	76.0%
16	16 - OTT	76.0%
17	16 - OTT	76.0%
18	17 - Thin Client	76.0%
19	17 - Thin Client	85.4%

Figure 5.3 PSU efficiencies from DOE NODA Engineering Analysis

Source: DOE NODA (DOE 2013a), Engineering Analysis, "Teardowns" Tab

5.3.2 Reduce Sleep Mode Power Levels

The majority of today's set-top boxes draw a similar amount of power in both On and Sleep modes, regardless of whether or not the device is being actively used to watch or record television (DOE 2012b; NRDC 2011; Urban, Tiefenbeck, & Roth 2011). Sleep mode power is relatively high because service providers wish to avoid long wake times that would hinder the viewing experience of their product. Sleep states with relatively high power are commonly called "Light Sleep." Sleep states with significantly reduced power compared to On mode and longer typical wake times are referred to as "Deep Sleep."

Today's most efficient DVR set-top boxes power down by as much as seven watts (EPA 2013c). Hardware efficiency improvements offer significant savings opportunities for set-top boxes. Examples include: silicon on chip improvements, tuner improvements, improved modem technology and power management via the set-top box middleware (Mudgal, Schischke, & Iyama 2008). Many of these efficiency improvements would undoubtedly improve On mode power levels as well.

5.3.3 Increase Time Spent In Sleep Mode

Increasing the time spent in Sleep mode is another energy-saving opportunity. If Sleep mode power is considerably lower than On mode power, spending less time at full power (by entering a sleep state with less delay time between the end of user activity and auto-power-down) significantly decreases overall energy use in set-top boxes.

Currently, most set-top boxes are set up at the time of installation to turn off in conjunction with the TV. However, changes made by the subscriber, and communication issues between the set-top box and TV, result in many set-top boxes that do not turn off when the TV turns off.[17] By resolving issues with current methods of turning off the set-top boxes with TVs, it is reasonable to expect savings.

In addition, set-top boxes can save energy by returning to Sleep mode with little delay after the completion of a maintenance or recording activity. For example, a set-top box that wakes at 1:00 am to record a show and then returns quickly to Sleep mode after completing the recording rather than remaining on for multiple hours can reduce overall energy consumption considerably.

5.3.4 Implement New System Architectures

Multi-room Architectures

The current industry trend to adopt multi-room system architectures presents energy savings opportunities. Muti-room architectures avoid the need for service providers to populate homes with multiple, high-energy-use DVRs needed to support consumer demand for this functionality. Thin-client multi-room architectures (Figure 5.4) rely on a DVR server and one or more thin clients that access content from the server and are not capable of communicating directly with the service provider headend. In this architecture, the multi-room server must include the tuners needed to serve the entire household and maintains conditional access connection with the service provider for content security.

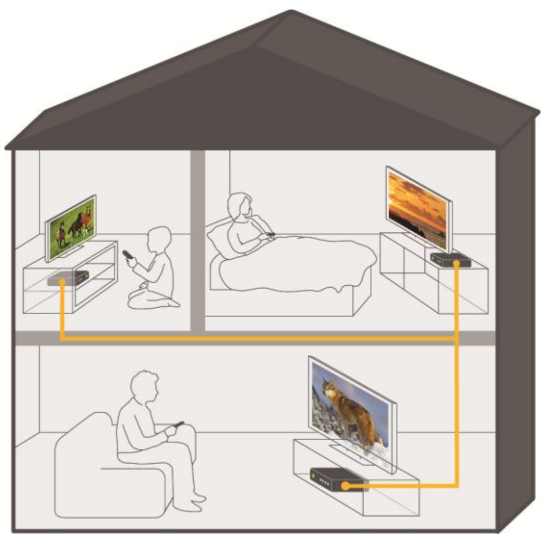

Figure 5.4 Example multi-room configuration with thin clients.

Source: NRDC (2011)

Figure note: A multi-room configuration where a multi-room DVR downstairs serves content to two thin client set-top boxes upstairs. The thin clients are typically connected coaxial cable using the MoCA protocol.

Hybrid-client multi-room architectures, in contrast to thin-client multi-room architectures, feature a DVR server and one or more hybrid clients that can access content from the server or the service provider. A hybrid client is capable of receiving live television signals directly with the service provider, but it does not need its own hard drive because it accesses recorded content from the server.

Today's thin-client systems use less energy than hybrid-client systems because thin-clients draw less power than hybrid-client systems. Even though the DVR servers that support thin clients have more tuners and

[17] Although many service providers program their set-top box remote controls to simultaneously power on and off both the set-top box and the TV with one button, sometimes the set-top box and TV get out of synch such that the TV turns off when the set-top box turns on. A possible means for addressing this issue is to update the High Definition Multimedia Interface (HDMI) specification to require a standard way for set-top boxes to know the power state of the TV.

therefore use more energy than DVRs that serve hybrid clients, the thin client multi-room model generally uses less energy. Both thin or hybrid client systems use less energy than multi-DVR configurations.

Some multi-room technologies enable multi-room DVRs to stream video directly to smart TVs and other enabled consumer electronics devices (e.g. Blu-ray disk players) without the need of a client set-top box. These technologies, such as RVU, have the potential to eliminate the need for even thin clients—thereby reducing household energy consumption.[18] However, these technologies have not received much traction and widespread deployment. One barrier in adopting technologies like RVU as an energy efficiency measure is most pay-TV systems use coaxial cable to distribute content to televisions throughout the house. As a result, most service providers offer multi-room solutions that use these already-installed cables as opposed to running new cables. Unless smart TVs include coaxial cable ports that support MoCA, RVU implementations requiring MoCA adapter boxes that convert MoCA signals to Ethernet would need to be employed. Currently, these adapter boxes use nearly as much energy as thin clients, and therefore would offset the energy reduction associated with RVU approaches. We do not expect industry to integrate conditional access based, pay-TV set-top box capability (using technologies such as RVU) into TVs or other consumer electronics devices.

5.4 Standards Case Energy Use Per Product

The California IOUs propose an efficiency standard based on ENERGY STAR Version 4.1 requirements (EPA 2013a). The proposed standard addresses all set-top box product classes in Section 3.2, takes effect one year after adoption, and would cost-effectively reduce residential energy consumption in California homes.

5.4.1 Primary Standards Criteria

The California IOUs' proposed standard uses the same UEC approach as ENERGY STAR Draft 1, Version 4.1 program requirements (EPA 2013a) with the following exceptions:[19]

- We do not provide an incentive for client only mode.
- We provide an incentive for up to 4 hours of scheduled deep sleep only if a set-top box is configured to support scheduled deep sleep by default and has a user friendly way to enter deep sleep using the remote control. This incentive would be equal to the product of the number of hours of scheduled deep sleep provided in the default as deployed **AND** the difference between Light Sleep and Deep Sleep power levels.

Table 5.4 shows the proposed requirements. Note that the Version 4.1 specification is currently under review, and we anticipate that final Version 4.1 requirements document to be released in summer 2013.

Table 5.4 Proposed Energy Allowances for Base Functionality and Additional Functionality

Functionality	Energy Allowance (kWh/yr)
Base Functionality	
Cable	45
Satellite	50
Service Provider Internet Protocol (IP)	25

[18] For more information about the RVU Alliance and its technology, see http://www.rvualliance.org/.

[19] ENERGY STAR refers to this as "annual energy consumption" (AEC).

Over-the-top (OTT) Internet Protocol (IP)	10
Cable Digital Television Adapter	35[*]
Thin-client / Remote	10
Additional Functionality	
Advanced Video Processing	8
CableCARD	15
Digital Video Recorder (DVR)	36
DOCSIS®	15
High Definition (HD)	16
Home Network Interface	8
MIMO WiFi HNI	$N_{2.4\ GHz} + 2 \text{ X } N_{5\ GHz}$ Where: N is the number of spatial streams at the given frequency
Multi-room	40
Multi-stream – Cable/Satellite	8
Multi-stream – Internet Protocol (IP)	6

[*]ENERGY STAR did not include an allowance for Cable DTAs in Draft 1, Version 4.1 (EPA 2013a), but they have restored this value to 35 kWh/yr in Draft 2 (EPA 2013b), so we list the Draft 2 value here.

We chose ENERGY STAR Draft 1, Version 4.1 levels for the following reasons:

- ENERGY STAR levels achieve a relatively high level of cost-effective savings.
- The ENERGY STAR functional adder approach will enable CEC to encourage energy efficiency and power scaling for mature set-top box technologies while providing some allowance for the uncertainty associated with new features.
- Some market actors have expressed satisfaction with respect to the structure of the ENERGY STAR program requirements.

In the UEC approach, we multiply measured power in On and Sleep modes by an estimated number of hours spent per year in On mode and in Sleep mode, respectively. The result is a single energy value representing the energy usage of the device (UEC, in kWh) over the course of an entire year. Comparing the UEC of a set-top box to its total energy allowance determines its compliance with the proposed standard.

The UEC methodology incorporates an allowance for base functionality plus allowances for additional functions. Set-top boxes have different base allowances according to their market segment, or product class. Where applicable, we recommend additional allowances for set-top boxes that deliver extra functionality to the subscriber, such as DVR or multi-stream capability. The base allowance and additional functionality allowances serve as the primary efficiency metric for the proposed standard.

5.4.2 Secondary Standards Criteria

In addition to the primary UEC metric, the proposed standard also includes secondary compliance criteria for maintenance activities, APD, Deep Sleep state, and Energy Efficient Ethernet.[20]

Maintenance Activities.

[20] We include test procedure recommendtations to support these proposed secondary criteria in Section 5.1.2.

- Products that have exited Sleep mode or Deep Sleep state and completed maintenance or other user-requested activities shall automatically return to Sleep mode or Deep Sleep state in less than 15 minutes.

Auto Power Down (APD). Products that offer an APD feature shall meet the following requirement:

- Products shall be deployed by the service provider with APD enabled by default, with APD to occur after a period of inactivity less than or equal to 4 hours.

Note: In the current ENERGY STAR Version 3.0 requirements, recording is considered a primary function, which upon completion triggers the 4-hour countdown requirement to APD. This 4-hour allowance is too generous for recording activities when the set-top box wakes from sleep to record a show. For example, a set-top box that wakes at 1:00 am to record a show can return quickly to sleep after completing the recording without reducing functionality to the subscriber. We propose naming these events *wake-to-record* events, and treating them in the same manner as maintenance activity (as detailed above), in which the device is required to automatically return to sleep 15 minutes or less after the event concludes.

Deep Sleep. The following requirements are used for Deep Sleep:

i. For a power state to qualify as a Deep Sleep, measured power consumption (P_{DEEP_SLEEP}) shall be less than or equal to 15 percent of the power draw in On mode (as measured per the ENERGY STAR test procedure for "Watching Live TV" [PTV]), or 3.0 watts, whichever is greater. In addition, the set-top box must have default settings that include a scheduled deep sleep of up to 4 hours.

ii. For set-top boxes with a user interface, a means of manually activating Deep Sleep shall be accessible to the end user via a clearly marked button or switch on the remote control and/or the front face of the set-top box. This is in addition to the scheduled deep sleep requirement.

iii. If Deep Sleep capability is enabled in the as-deployed default product configuration, an override function may be provided to allow the end-user to disable Deep Sleep functionality.

Energy Efficiency Ethernet. The Energy Efficient Ethernet (EEE) protocol, developed by the Institute of Electrical and Electronics Engineers (IEEE), allows a networking device, such as the networking components in an IP set-top box or other internet-enabled set-top box, to use less power when not transferring data. The networking device wakes up to the fastest interface when data is transferred, and is able to transfer the data in a matter of microseconds (Bolla et al. 2010).[21] We recommend requiring all new set-top boxes with an Ethernet port to be EEE-certified, so they can successfully interface with other EEE-certified networked devices within a household.

5.4.3 Standards Case Unit Energy Consumption

Table 5.5 summarizes the estimated, average UEC for set-top boxes compliant with the proposed standard. To calculate the average UECs of set-top boxes that are compliant with our proposed standard, we calculated the average reported UEC values of compliant set-top boxes in the ENERGY STAR Version 3.0 QPL- dated April 08, 2013 (EPA 2013c).

[21] For example, 10Gb/s interface can reportedly wake up in less than 3 microseconds.

Table 5.5 Average Energy Use for Compliant Products

Product Class	Unit Electricity Consumption (kWh/yr)
Cable	121
Satellite	84
Internet Protocol[a]	68
Cable Digital Television Adapter	35
Thin Client / Remote	39

[a] Service provider Internet Protocol (IP) set-top boxes only. Over-the-top IP set-top boxes excluded from this analysis.

6 Market Saturation & Sales

6.1 Current Market Situation

The U.S. pay-TV market consists of cable, satellite and telco/IP service provider types. Nielsen estimates that there are 114 million U.S. television households in 2012 (Nielsen 2011). Of these, approximately 101 million (89%) are pay-TV households (SNL Kagan 2012). Each one of these pay-TV households has some kind of set-top box equipment to enable subscribers to view pay-TV content.

6.1.1 Baseline Case

The California IOUs developed a set-top box energy use analysis model that incorporates market and energy data from a variety of data sources. This section explains the market aspects of the model (see Section 7.1 for information covering the energy aspects of the model). The analysis utilizes national set-top box stock (i.e. installed-base) data from SNL Kagan (2012) for 2010-2011 and its projected stock for 2012-2015.[22] To estimate set-top box stock for 2016-2023, we use a best-fit (least squares) linear regression forecast. The forecast returns a forecast of a future value based on existing values provided. In other words, we assume that growth in stock will continue in a similar fashion from 2016-2023 as it did from 2010-2015. In addition, we use SNL Kagan's (2012) observed and projected trends for mix of market share of product classes and sub-classes from 2010-2015 for 2016-2023.

Because the majority of our market data is for the U.S., we scaled data using the ratio of California population to U.S. population, which is 12 percent (U.S. Census 2012).[23] Table 6.1 shows estimated California stock and sales figures for set-top boxes in 2013. Today there are approximately 6.5 million new set-top boxes deployed to California homes each year (SNL Kagan 2012). Approximately 30 million set-top

[22] Except for the Thin Client / Remote product category, where data were provided by IMS (2012).
[23] We chose to scale based on CA population rather than number of CA households, assuming that the number of set-top boxes existing in CA is dependent more on population than number of households.

boxes are installed in California homes today (SNL Kagan 2012). Supplemental market data in provided in Appendix A: in this report.

Sales of set-top boxes are unique from other product categories because service providers purchase pay-TV set-top-boxes to deploy to the end-consumer. In our analysis, new set-top boxes that service providers purchase (and presumably deploy) each year come from two sources:

i. **Replacement set-top boxes**. A service provider deploys a replacement set-top box when an existing subscriber set-top box reaches the end of its design life or needs replacement for other reasons. We calculate replacement set-top boxes for a given year by multiplying a replacement rate (%) by the set-top box stock of the previous year. We assume the following replacement rates based on multiple market sources: 12.5% for cable, 20% for satellite, 12.5% for IPTV, 12.5% for cable DTAs and 12.5% for thin-clients (SNL Kagan 2012; Froehlich 2012; DirecTV 2011; DISH Network 2011).[24] We recognize that service providers refurbish set-top boxes more often than deploying new set-top boxes. We do not factor refurbishment or repair rates into our analysis since they do not directly affect sales of new set-top boxes. We focus on new, replacement set-top boxes because these boxes, along with new boxes from growth in subscribers (as explained below), are the two drivers of set-top box sales.

ii. **New set-top boxes attributable to subscriber growth.** These set-top boxes are deployed when a new subscriber signs up for service and receives a new set-top box or set-top boxes. For a given year, new set-top boxes attributable to subscriber growth are equal to the difference between the current year's stock and the previous year's stock of set-top boxes as provided by SNL Kagan's (2012) forecast.

The sum of replacement set-top boxes and new set-top boxes attributable to subscriber growth represents the net pool of new set-top boxes purchased in a given year. These boxes make up the cohort of set-top boxes requiring compliance with the proposed standard after effective date. The energy use data and assumptions of these new boxes are explained in Section 7.1.

Table 6.1 California Stock and Sales, 2013

Product Class	Annual Sales	Stock
	Units (millions)	Units (millions)
Cable	2.0	10
Satellite	2.7	11
Internet Protocol[a]	0.88	3.8
Cable Digital Television Adapter	0.91	4.4

[24] These replacement rates are related to design life, which is covered in Section 8.2.

Thin Client / Remote	0.086	0.19
Total	**6.55**	**30.0**

Source: Ecova analysis of SNL Kagan (2012)
[a] Service provider Internet Protocol (IP) set-top boxes only. Over-the-top IP set-top boxes excluded from this analysis.

Table 6.2 shows growth rates for set-top box sales. Using the replacement rates listed above, we estimate sales growth is 9 percent in total from 2007 to 2012 based on analysis of SNL Kagan (2012). IP set-top boxes saw the largest sales growth during this timeframe, with sales growing by 20 percent. In general, cable set-top box sales growth is flat during this analysis period.

Table 6.2 California Compound Annual Growth Rate (CAGR) for Sales of Set-Top Boxes, 2007–2012

Product Class	CAGR (%) 2007–2012
Cable	0.087%
Satellite	5.7%
Internet Protocol[a]	20%
Cable Digital Television Adapter[b]	N/A
Thin Client / Remote[b]	N/A
Total[c]	**8.9%**

Source: Ecova analysis of SNL Kagan (2012)
[a] Service provider Internet Protocol (IP) set-top boxes only. Over-the-top IP set-top boxes excluded from this analysis.
[b] CAGR was not available for Cable Digital Television Adapter or Thin Client set-top boxes for these years.
[c] Weighted by 2013 sales estimates based on analysis of SNL Kagan (2012).

6.1.2 High Efficiency Options

Current high efficiency options for set-top boxes vary by service provider type. Because market share data for high efficiency options were not available, we estimated compliance rates (i.e. products already meeting the proposed standard level) for each product class in 2013 based on trends in market research data (SNL Kagan 2012), and analysis of ENERGY STAR v3.0 qualified products (EPA 2013c). Table 6.3 shows the approximate proposed standard compliance rate for sales of new set-top boxes in 2013. An estimated 19 percent of sales of new set-top boxes in 2013 meet the proposed standard levels.[25]

[25] In comparison, DOE estimates approximately 10 percent of 2013 shipments of set-top boxes meet its CSL 2 via its efficiency distribution analysis as part of its manufacturer impact analysis for set-top boxes (DOE 2013a).

Table 6.3 California Proposed Standard Compliance Rates for 2013 Sales

Product Class	Estimated Compliance Rate (%)
Cable	24%
Satellite	15%
Internet Protocol[a]	26%
Cable Digital Television Adapter	15%
Thin Client / Remote	30%
Total[b]	**19%**

[a] Service provider Internet Protocol (IP) set-top boxes only. Over-the-top IP set-top boxes excluded from this analysis.
[b] Weighted by 2013 sales estimates based on analysis of SNL Kagan (2012)

6.2 Future Market Adoption of High Efficiency Options

Set-top boxes will likely integrate several energy-saving improvements in the coming years as a result of the following industry and research initiatives:

- Cable industry's 2011 commitment to energy efficiency improvements
- An industry-wide voluntary commitment to ENERGY STAR set top box deployments
- California Plug Load Research Center initiative to explore additional energy savings technologies in set-top boxes.

Independent of these initiatives, we also expect current industry trends to impact adoption of high efficiency options.

Cable industry's 2011 commitment to energy efficiency improvements

On November 18, 2011, the U.S. cable industry, via the National Cable and Telecommunications Association (NCTA) and CableLabs®, announced a new energy efficiency initiative for set-top boxes (NCTA 2011b).[26] The initiative sets out the following objectives:

> "The energy initiative will promote the development, testing, and deployment of technologies that will enable cable subscribers to reduce and manage energy consumption in the home, including establishing new requirements for both cable video devices and network support systems. Among other things, these specifications will enable the manufacturing of devices that have 'Sleep' capabilities to reduce power consumption when subscribers are not actively watching television."

[26] NCTA is the principal trade association of the cable industry in the U.S. CableLabs® is the cable industry's primary research and development consortium.

> "After successful field testing of set-top boxes with next generation power management semiconductors, cable operators will begin promoting the deployment of these devices as part of their ongoing efforts to provide functional, reliable and energy efficient services."
>
> "In addition, cable operators providing service to approximately 85 percent of U.S. cable customers have committed to ensure that by the end of 2013 at least 90 percent of all new set-top boxes they purchase and deploy will be ENERGY STAR 3.0 devices."

Cable service providers announced their intention to develop Light Sleep and Deep Sleep, and have already deployed Light Sleep features. They plan Deep Sleep field trials beginning in late 2014 (Figure 6.1). Deep Sleep as defined by this industry initiative may not align with the ENERGY STAR definition. The cable industry is exploring what is achievable in terms of Deep Sleep power levels relative to Light Sleep where Deep Sleep wakes quickly to On mode. Generally, lower power Deep Sleep power levels are acheiveable with longer wake times. European set-top boxes are capable of less than 1 watt in Deep Sleep, but they require minutes to wake to On mode. Unless part of a scheduled sleep, consumers do not often use this mode in Europe.

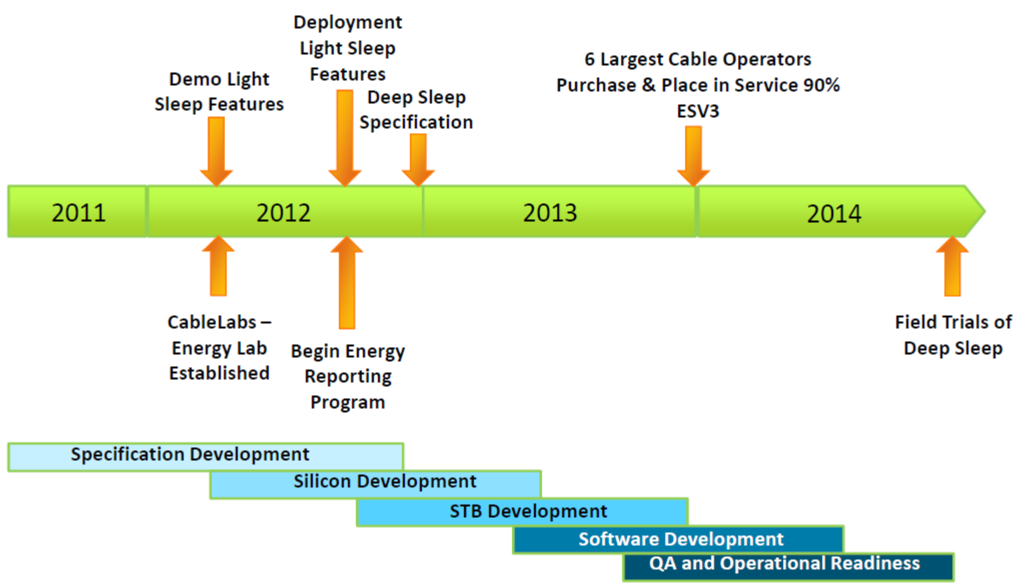

Figure 6.1 Proposed timeline by cable industry for energy efficiency improvements

Source: NCTA (2011a)

An additional element of the cable industry's initiative is the development of the Energy Lab, a new facility within CableLabs® that will concentrate exclusively on improving set-top box energy efficiency (NCTA 2011a) via a number of planned research tasks. The cable industry's commitments will require significant research as well as updates to multiple protocols and standards. As an example, CableLabs recently released a white paper (CableLabs® 2013b) that presents guidelines for service providers in the configuration and operation of set-top box mode, cable mode, and power scaling mode (DOCSIS 1x1 mode).

Industry voluntary agreement

While the NCTA/Cablelabs initiative is limited in scope to the cable industry, fifteen leading service providers from all segments of the pay-TV industry serving 90% of pay-TV customers participate in a

Voluntary Agreement.[27] All of these MVPDs are committed to ensuring that 90% of their new set-top boxes purchased and deployed after December 31, 2013 shall meet the efficiency standards established for ENERGY STAR Version 3.0.

CalPlug research initiative

Outside of industry-led research, CalPlug (California Plug Load Research Center) is conducting its own research, partially funded by the CEC. CalPlug focuses on solutions to completely power down set-top boxes when not needed by consumers and waking them before the users would normally use the set-top box. CalPlug algorithms monitor user behavior patterns and auto-schedule a deep sleep mode based on the learned patterns in much the same way that the Nest thermostat auto-programs set points for users who select this automated mode of operation. It is not yet clear whether or not industry will adopt this technology that completely powers down set-top boxes during periods of inactivity based on historical usage trends.

Current industry trends

Set-top box manufacturers and service provides have the opportunity to deploy boxes with additional energy-saving improvements to:

- the main processor (i.e., system on chip) and tuner components. For these components, silicon cost is the primary driver of efficiency improvements
- hard disk drives, where data density and support for mobile products like notebook computers drive basic efficiency improvements
- power supplies where cost-focused efforts to improve datacenter power supply efficiency yield benefits across other market segments.

It's important to note that while we will see base level efficiency improvements in all of the mentioned components, we also expect to see continued variation between less efficient and more efficient components.

Lastly, as discussed in Section 5.3.4, there are energy-savings opportunities related to new system architectures. Some of today's major service providers are already deploying multi-room architectures. Multi-room technology is new to the market, but it has the opportunity to limit California set-top box energy use by eliminating the need for multiple fully-functional and energy intensive set-top boxes in one home (DOE 2012b).

While these initiatives will improve the energy efficiency of set-top boxes, a proposed standard would contribute to additional savings because it would provide an enforcement mechanism supporting the current Voluntary agreement and because we continue to see large variation in the energy consumption of set-top boxes that have a similar level of functionality. A standard would ensure universal adoption of a cost-effective efficiency level.

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[27] *Voluntary Agreement for Ongoing Improvement to the Energy Efficiency of Set-Top Boxes*, Decemember 6, 2012. Available: http://www.ce.org/CorporateSite/media/ce_news/FINAL-PUBLIC-VOLUNTARY-AGREEMENT-(12-6-2012).pdf

7 Savings Potential

7.1 Statewide California Energy Use

The California IOUs developed a set-top box energy use model that incorporates market and energy data from a variety of data sources. While Section 6 explained the market aspects of our analysis model, this section explains how we apply energy use data to market data to estimate California energy use.

Our analysis model utilizes a set-top box field measurement study (NRDC 2011) as a snapshot of estimated energy use of set-top box installed-base in 2010.[28] NRDC (2011) sampled the On and Sleep mode power draw of 64 set-top boxes throughout the U.S. We use these power data in our analysis to calculate an average UEC for each product category in 2010. It is important to note that data from NRDC (2011) are used only to inform the historical energy use of stock. Data from NRDC (2011) are not used to inform the UEC of new boxes, which determine the energy savings estimates from the proposed standard.

Beginning in 2011, the model calculates the new cohort of set-top boxes purchased and deployed in a given year. The new cohort of set-top boxes is equal to the sum of new replacement set-top boxes and new set-top boxes attributable to subscriber growth—as described in Section 6.1.1. The energy use of these new set-top boxes is a variable mix of boxes that are compliant and non-compliant with the proposed standard:

1. **Compliant set-top boxes**. These are new set-top boxes that are already compliant with the proposed standard today.[29] Table 5.5 shows the average UEC of compliant set-top boxes. We use data from ENERGY STAR's qualified product list (EPA 2013c) to inform the energy use of today's compliant models.[30] The UEC of compliant set-top boxes does not change over time. However, the share of annual sales of compliant set-top boxes *increases* over time. This varies for each product class based on market trends and industry initiatives.
2. **Non-compliant set-top boxes**. These are new set-top boxes that are not compliant with the proposed standard today. Table 5.3 shows the average UEC of non-compliant set-top boxes. We use data from two ENERGY STAR qualified product lists (EPA 2013c, 2011d) to inform the energy use of today's non-compliant models.[31] The UEC of non-compliant set-top boxes does not change over time. However, the share of annual sales of non-compliant set-top boxes *decreases* over time. This varies for each product class based on market trends and industry initiatives.

Our resulting analysis finds that today's installed-base of set-top boxes in California consumes a combined 3,800 GWh/year and today's annual sales of set-top boxes consume an estimated 800 GWh/year. Table 7.1 shows current energy use for estimated sales and stock in 2013. We multiply the UEC for each product category by the appropriate sales or stock data in each year (from Table 6.1) to generate the energy use estimates shown in Table 7.1.

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[28] Field measurement and data analysis conducted for the study took place in 2010 while the written study was published in 2011.

[29] Also known as naturally occurring market adoption (NOMAD).

[30] Additional information about how the energy use of these boxes was calculated is included in Section 5.4.3. ENERGY STAR QPL data is the central data source for determining these UECs.

[31] Additional information about how the energy use of these boxes was calculated is included in Section 5.2.2. ENERGY STAR QPL data is the central data source for determining these UECs.

Table 7.1 California Statewide Baseline Energy Use – Current Year

Product Class	Annual Sales (2013)		Entire Stock (2013)	
	Coincident Peak Demand (MW)[b]	Annual Energy Consumption (GWh/yr)	Coincident Peak Demand (MW)	Annual Energy Consumption (GWh/yr)
Cable	40	330	220	1800
Satellite	44	360	180	1400
Internet Protocol[a]	10	80	46	370
Cable Digital Television Adapter	5.8	47	28	230
Thin Client / Remote	0.54	4.4	1.3	10
Total	**101**	**813**	**473**	**3810**

[a] Service provider Internet Protocol (IP) set-top boxes only. Over-the-top IP set-top boxes excluded from this analysis.
[b] Statewide demand (and demand reduction) is quantified as coincident peak load (and coincident peak load reduction),the simultaneous peak load for all end users, as defined by Koomey and Brown (2002).

To model the future potential energy use and savings impact of the proposed standard, we developed two scenarios. Our first scenario models the energy use of California set-top boxes in the absence of any energy conservation standards. This scenario is known as the 'non-standards case'. The non-standards case scenario assumes no change in the compliance rate over time. For each year's sales until stock turnover, we use compliance rates from Table 6.3.[32] The estimated UEC of set-top boxes in the non-standards case scenario is comprised of a mix of non-compliant (Table 5.3) and compliant (Table 5.5) UEC estimates.

Our second scenario models the energy use of California set-top boxes with the proposed standard taking effect in 2016, approximately one year after adoption of the proposed standard. This scenario is known as the 'standards case'. From 2013-2015, the non-standards case scenario and standards case scenario are identical. However, starting in 2016 in the standards case scenario, we assume that each new cohort of set-top boxes (i.e. both new replacements and new set-top boxes attributable to subscriber growth) are 100% compliant with the proposed standard. Starting in 2016, we use the compliant set-top box UEC estimates from Table 5.5 for each new cohort of set-top boxes in the standards case scenario.

[32] In Appendix B, we calculate an alternative non-standards case energy use scenario assuming a changing compliance rate over time. We estimated a compliance rate in this alternative non-standards case based on our assessment of the future adoption of high efficiency options for each year's sales until stock turnover. Estimated energy savings resulting from this scenario are also shown in Appendix B. In either scenario, the proposed standards are cost effective.

For both scenarios, we use an analysis period of 2016-2023 based on design life and expected stock turnover.[33] We use the same market data for both scenarios. We estimate that entire stock turnover will take place in the last year of this analysis period, starting in 2023.

Below we present the estimated statewide energy use findings of this scenario analysis. Table 7.2 shows the estimated energy use of set-top boxes in California for the non-standards case, for both first full calendar-year sales (2016) and in year of entire stock turnover (2023). Our findings indicate that should California not adopt set-top box energy conservation standards, estimated California energy use of set-top box stock will grow to 4,610 GWh/yr and draw 572 MW at peak demand after stock turnover.

Table 7.3 shows the estimated energy use of set-top boxes in California for the standards case, for both first-year sales and year of entire stock turnover. Should California adopt the proposed standard, estimated California energy use of set-top box stock will grow to 3,800 GWh/yr and draw 472 MW at peak demand in year of stock turnover.

The difference in energy use between the non-standards case scenario and the standards case scenario represents estimated, expected energy savings from the proposed standard. We present and discuss estimated statewide savings in more detail in the next section (Section 7.2).

Table 7.2 California Statewide Non-Standards Case Energy Use - After Effective Date

Product Class	For First-Year Sales		Year of Stock Turnover	
	Coincident Peak Demand (MW)[b]	Annual Energy Consumption (GWh/yr)	Coincident Peak Demand (MW)	Annual Energy Consumption (GWh/yr)
Cable	41	330	250	2000
Satellite	45	360	200	1600
Internet Protocol[a]	12	97	99	800
Cable Digital Television Adapter	3.3	27	11	85
Thin Client / Remote	1.8	14	14	110
Total	**103**	**832**	**572**	**4610**

[a] Service provider Internet Protocol (IP) set-top boxes only. Over-the-top IP set-top boxes excluded from this analysis.
[b] Peak demand values calculated by multiplying GWh by a 0.92 kW/MWh load factor ratio from the 'Miscellaneous' category in Table 3 from Brown and Koomey (2003).

[33] Savings are likely to start occurring in 2015 if the CEC adopts standards in 2014 with an effective date one year after adoption. Given the uncertainty of the exact effective date in 2015, we model savings starting in the likely first full calendar year, 2016.

Table 7.3 California Statewide Standards Case Energy Use – After Effective Date

Product Class	For First-Year Sales		Year of Stock Turnover	
	Coincident Peak Demand (MW)[b]	Annual Energy Consumption (GWh/yr)	Coincident Peak Demand (MW)	Annual Energy Consumption (GWh/yr)
Cable	33	260	220	1800
Satellite	31	250	150	1200
Internet Protocol[a]	9.2	74	78	630
Cable Digital Television Adapter	2.5	20	10	81
Thin Client / Remote	1.4	11	13	100
Total	**76.9**	**620**	**472**	**3800**

[a] Service provider Internet Protocol (IP) set-top boxes only. Over-the-top IP set-top boxes excluded from this analysis.
[b] Peak demand values calculated by multiplying GWh by a 0.92 kW/MWh load factor ratio from the 'Miscellaneous' category in Table 3 from Brown and Koomey (2003).

7.2 Statewide California Energy Savings

The difference in energy use between the non-standards case scenario and the standards case scenario represents estimated, expected energy savings from the proposed standard.

Table 7.4 shows the estimated energy savings from the adoption of the proposed standard. We based estimated savings starting in the likely first full calendar year of sales, 2016.. We based estimated savings in year of entire stock turnover on projected stock in 2023. Our findings indicate that should California adopt the proposed standard, estimated California energy savings are 213 GWh/yr for first-year sales of new set-top boxes and 811 GWh/yr in year of entire stock turnover. We estimate 4,200 GWh total, cumulative energy savings over the analysis period (2016-2023).

Table 7.4 Estimated California Statewide Energy Savings with Standards Case – After Effective Date

Product Class	For First-Year Sales		Year of Stock Turnover	
	Coincident Peak Demand Reduction (MW)[b]	Annual Energy Savings (GWh/yr)	Coincident Peak Demand Reduction (MW)[b]	Annual Energy Savings (GWh/yr)
Cable	8.5	68	32	260
Satellite	13.9	110	46	370

Internet Protocol[a]	2.8	22	21	170
Cable Digital Television Adapter	0.82	6.6	0.47	3.8
Thin Client / Remote	0.39	3.1	0.80	6.5
Total	**26.0**	**213**	**101**	**811**

[a] Service provider Internet Protocol (IP) set-top boxes only. Over-the-top IP set-top boxes excluded from this analysis.
[b] Statewide demand (and demand reduction) is quantified as coincident peak load (and coincident peak load reduction),the simultaneous peak load for all end users, as defined by Koomey and Brown (2002).

7.3 Other Benefits and Penalties

Because more efficient set-top boxes operate at lower internal temperatures, the lifetime of some product classes of set-top boxes could increase. In addition, service providers may experience some operations and maintenance (O&M) benefits such as fewer service visits to homes with more efficient set-top boxes.

7.4 State or Local Government Costs and Savings

There are no known additional costs to state or local governments from the implementation of the standards proposal, given the CEC's existing authority for establishing appliance standards and staffing to administer the process. Energy savings are expected for local and state governments from the purchase of more efficient products as a result of the proposed standard, with the savings amount dependent on the volume of products purchased.

8 Economic Analysis

8.1 Incremental Cost

The incremental cost of bringing categories of set-top boxes into compliance with the proposed standard depends on several key factors, including, but not limited to: set-top box product class, service provider type and associated communication protocols, DVR functionality, among others. The efficiency improvements discussed in Section 5.3 will enable a set-top box to comply with the proposed standard levels. To develop estimated incremental costs for the proposed standard, we reviewed the DOE's Notice of data availability (NODA) for set-top boxes (DOE 2013a).

DOE's NODA represents the best publically available data for estimated incremental costs resulting from potential energy conservation standards for set-top boxes. Within the NODA, we leveraged DOE's engineering analysis to inform incremental cost estimates for our proposed Title 20 standard.[34] DOE's engineering analysis establishes the relationship between the cost and efficiency levels of set-top boxes through product teardowns and design improvements. For each of DOE's 17 potential product classes, DOE identified existing technology options (including prototype designs) and assessed their feasibility to improve

[34] Other analyses included in DOE (2013a) are DOE's manufacturing impact analysis, life-cycle cost analysis, and national impact analysis.

the energy efficiency of set-top boxes without adversely affecting product utility or product availability (DOE 2013a). DOE identified the best design options to improve the efficiency of set-top boxes and considered these options in its analysis of three candidate standard levels (CSLs) (DOE 2013a). DOE estimated the manufacturer production costs for a baseline product—a product representing models having features and technologies typically found in minimally-efficient products currently available on the market (DOE 2013a). DOE then applied incremental design improvements to this baseline product, and calculated associated incremental manufacturer product costs relative to its three CSLs. DOE's manufacturer production costs were derived from product teardowns, using more efficient components and modeling efficiency savings from power scaling when components are not in use (DOE 2013a). For the purposes of this CASE Report, the term incremental cost is synonymous with incremental manufacturer product costs (including material, labor and overhead).[35]

We used DOE's incremental cost estimates from its engineering analysis as inputs to our own economic analysis because it is the best publically available data that uses a detailed engineering tear-down methodology. We assume that DOE's CSL 2 represents a comparable level of stringency as our proposed standard after comparing set-top boxes with similar functionality. Table 8.1 shows one example from DOE's engineering analysis: product teardown and design improvements for a Cable DVR & Video Server.[36] We use this product category as an illustrative example for highlighting the design improvements and associated costs expected for meeting the proposed standard.[37] Moving from left to right in Table 8.1, the columns show increasing energy savings from a particular design option and associated incremental costs. Each design option builds upon the previous columns to the left. Below we summarize DOE's applied design improvements and incremental cost for a Cable DVR & Video Server meeting DOE's CSL 2:

- Improving the hard-disk drive (HDD) for set-top boxes with DVR functionality is a one design option. As a first step towards improving the efficiency of DOE's baseline Cable DVR/Server, DOE implements a more efficient (i.e. "Improved") HDD—resulting in approximately $4.50 of additional costs (DOE 2013a).

- A set-top box's power-supply unit (PSU) is another component where manufacturers can cost-effectively realize fundamental efficiency improvements. DOE's design chooses a more efficient power supply option, either 18 W or 60 W, depending on the product class and size of the needed power supply. For this Cable DVR/Server example, DOE selected a 60 W PSU with 88% efficiency. The incremental cost of this improved PSU is estimated to be $1.58 (DOE 2013a).

- As a third design improvement, DOE implements a more efficient, full-band radio frequency (RF) tuner for its Cable DVR/Server set-top box. The estimated incremental cost of this design option is approximately $3.89 (DOE 2013a).

- DOE implements a more efficient HNI interface, MoCA 2.0, as a final design improvement in meeting its CSL 1 efficiency level. The estimated incremental cost of this design option is approximately $4.20 (DOE 2013a).

- At this stage, the modeled set-top box meets the efficiency requirements of DOE's CSL 1. As a next step towards improving the efficiency of the Cable DVR/Server, DOE implements a best *available* HDD. The estimated incremental cost of this design option is approximately $11.99 (DOE 2013a).

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[35] As described by DOE in DOE (2013a).

[36] For DOE's 16 other product classes, see DOE (2013a).

[37] We chose this example because a Cable DVR with video server is one of the most highly-featured boxes in DOE's analysis.

- DOE implements a more efficient silicon on chip (SoC) circuit for its Cable DVR/Server as a final design option in meeting its CSL 2. Again, we assume that CSL 2 provides a close approximation to the stringency of our proposed Title 20 standard. The estimated incremental cost of this design option is approximately $5.49 (DOE 2013a).

Table 8.1 DOE Design Options for Cable DVR with Video Server and Associated Incremental Costs

	Baseline				CSL 1		CSL 2			CSL 3
	Teardown	**HDD**	**PSU_60W**	**RF**	**HNI**	**HDD**	**Cable_SOC**	**PSU_60W**	**SOC Power Scaling**	**HDD Power Scaling**
Source	**5**	**Improved**	**Efficiency Level 3**	**Full-band Tuner**	**MoCA 2.0**	**Best Available**	**Improved**	**Efficiency Level 4**		**Best Available**
MPC	$208.57	$213.07	$214.65	$218.54	$222.74	$234.73	$240.22	$241.54	$241.54	$241.54
Incremental Cost	$0.00	$4.50	$6.08	$9.97	$14.17	$26.16	$31.65	$32.97	$32.97	$32.97
AEC (kWh/yr)	277.9 kWh	250.7 kWh	242.1 kWh	214.8 kWh	207.2 kWh	188.7 kWh	169.5 kWh	163.9 kWh	130.5 kWh	120.9 kWh
PWATCH	31.89 W	28.89 W	27.91 W	24.79 W	23.09 W	20.98 W	18.79 W	18.17 W	18.17 W	18.17 W
PSLEEP	31.50 W	28.50 W	27.53 W	24.41 W	22.71 W	20.61 W	18.41 W	17.81 W	12.41 W	10.87 W
PAPD	N/A	28.50 W	27.53 W	24.41 W	22.71 W	20.61 W	18.41 W	17.81 W	12.41 W	10.87 W
PMULTISTREAM	31.89 W	28.89 W	27.91 W	24.79 W	27.06 W	24.96 W	22.77 W	22.02 W	22.02 W	22.02 W

Note: Moving from left to right, the columns show increasing energy savings from a particular design option and associated incremental costs. Each design option builds upon the previous columns to the left. We assume that DOE's candidate standard level 2, the orange-highlighted column, represents a comparable level of stringency as our proposed, Title 20 standard.
Source: DOE (2013a)

In summary, the total incremental cost of the design implementations described above for DOE's Cable DVR/Server is estimated to be $31.65 (DOE 2013a). This is an approximate 15 percent increase in costs relative to the baseline Cable DVR/Server. The resulting energy savings from these design improvements, however, are approximately 89 kWh/yr. DOE's engineering analysis for this product category, along with the 16 other categories DOE explores, offers preliminary cost estimates indicating practical, cost-effective design opportunities exist today that enable set-top boxes to achieve similar efficiency requirements as our proposed standard.

Table 8.2 shows the estimated incremental cost of bringing each of the proposed product classes of set-top boxes into compliance with our proposed Title 20 standard. Because DOE categorizes its analysis across 17 product groups that are different from our proposed product classes, we mapped DOE's categories to our product classes to estimate incremental costs for each product class. For each of our proposed product classes, we calculated incremental cost estimates for non-DVRs and DVRs. For product classes without DVR functionality (e.g., OTT IP set-top boxes, Cable DTAs, thin clients) we calculate incremental costs for non-DVRs only. We leveraged incremental cost estimates presented in DOE (2013a) using the following assumptions and methodology:

- For Cable set-top boxes, we divided our cost analysis among non-DVRs and DVRs. For non-DVRs, we used a simple average of incremental costs presented in DOE (2013a) for 'Cable Base', 'Cable Video Client', and 'Cable Video Server'. For DVRs, we used a simple average of incremental costs presented in DOE (2013a) for 'Cable DVR' and 'Cable DVR & Video Server'.

- For Satellite set-top boxes, we divided our cost analysis among non-DVRs and DVRs. For non-DVRs, we used a simple average of incremental costs presented in DOE (2013a) for 'Satellite Base', 'Satellite Video Client', and 'Satellite Video Server'. For DVRs, we used a simple average of incremental costs presented in DOE (2013a) for 'Satellite DVR' and 'Satellite DVR & Video Server'.

- For IP set-top boxes, we divided our cost analysis among i) non-DVRs and DVRs for service provider IP set-top boxes, and ii) OTT set-top boxes. For non-DVRs, we used a simple average of incremental costs presented in DOE (2013a) for 'IP Base', 'IP Video Client', and 'IP Video Server'. For DVRs, we used a simple average of incremental costs presented in DOE (2013a) for 'IP DVR' and 'IP DVR & Video Server'. DOE's analysis for OTT set-top boxes estimates a negative incremental cost of $(5.31) for OTT set-top boxes. For the purposes of this CASE Report and our analyses, we assume zero incremental costs for OTT set-top boxes.

- DOE (2013a) does not include Cable DTAs in its engineering analysis. We assume zero incremental costs for Cable DTAs.

- For Thin Clients, we used the incremental cost estimate presented in DOE (2013a) for 'Thin-Client'.

Table 8.2 Estimated incremental cost of bringing categories of set-top boxes into compliance with the proposed standard

Product Class	non-DVR or DVR (if applicable)	Estimated Incremental Cost ($)
Cable	non-DVR	9.58
	DVR	29.55
Satellite	non-DVR	9.17
	DVR	27.12
Internet Protocol	non-DVR	4.29
	DVR	21.57
	OTT	-
Cable Digital Television Adapter		-
Thin Client / Remote		7.34

8.2 Design Life

Table 8.3 shows the design life for each set-top box product class. We determined design life primarily using data from SNL Kagan (2012) and also interviewed several market actors to inform our analysis. Design life varies according to the service provider type. Design life is the length of time before a service provider, for various reasons, pulls a set-top box out of deployment and deploys a new box. The best available data does not enable us to distinguish among product sub-classes, and so design life by class is shown below.

Table 8.3 Design Life by Product Class

Product Class	Design Life (years)
Cable	8
Satellite	5
Internet Protocol	8
Cable Digital Television Adapter	8
Thin Client / Remote	8

8.3 Lifecycle Cost / Net Benefit

We evaluated the cost and benefits of set-top box product classes over their respective lifecycles using the CEC methodology for calculating net present value (NPV). NPV estimates are based on average statewide present value electricity prices, supplied by the CEC. We calculate the present amount of the energy savings (in kWh) of the proposed standard by taking the difference between the non-standards case annual energy use of each product and the standards case annual energy use of each product after the standard is enacted. We then multiplied this difference by the discounted average price of electricity (in $/kWh) over the products' design life. Next we calculated the total benefit of the standard per unit by subtracting the total present value costs from the present value of energy savings (Table 8.4). We assumed no additional costs in calculating total per unit benefits. We also excluded expected benefits mentioned in Section 7.3, such as increased product lifetime and O&M benefits such as fewer anticipated service technician visits to subscribers' homes.

Using the per unit lifecycle costs and benefits from Table 8.4, Table 8.5 shows the NPV for first year sales after the standard is enacted and total NPV by entire stock turnover. The NPV of the proposed set-top box standard, based on the projected first year sales in 2016, is $124 million. The cumulative total NPV of the proposed standard by entire stock turnover in 2023 is nearly $1 billion. Our analysis indicates the proposed standard is cost effective. When taking into account the significant number of set-top boxes in use in California, the large lifecycle benefit to cost ratios result in considerable NPVs.

Table 8.4 Costs and Benefits Per Unit for Qualifying Products

Product Class	non-DVR or DVR (if applicable)	Design Life (years)	Lifecycle Costs per Unit (Present Value $)			Lifecycle Benefits per Unit (Present Value $)		
			Incremental Cost	Add'l Costs[b]	Total PV Costs	Energy Savings[c]	Add'l Benefits[d]	Total PV Benefits
Cable	non-DVR	8	9.58	0.00	9.58	46.12	0.00	46.12
	DVR	8	29.55	0.00	29.55	46.02	0.00	46.02
Satellite	non-DVR	5	9.17	0.00	9.17	19.29	0.00	19.29
	DVR	5	27.12	0.00	27.12	31.54	0.00	31.54
Internet Protocol[a]	non-DVR	8	4.29	0.00	4.29	39.91	0.00	39.91
	DVR	8	21.57	0.00	21.57	66.59	0.00	66.59
Cable Digital Television Adapter		8	0.00	0.00	0.00	9.25	0.00	9.25
Thin Client / Remote		8	7.34	0.00	7.34	31.28	0.00	31.28

PV = Present Value

[a] Service provider Internet Protocol (IP) set-top boxes only. Over-the-top IP set-top boxes excluded from this analysis.

[b] We assume no additional costs.
[c] Calculated using the CEC's average statewide present value (2012 $) statewide energy rates that assume a 3% discount rate. http://www.energy.ca.gov/2012_energypolicy/documents/index.html
[d] We assume no additional benefits.

Table 8.5 Lifecycle Costs and Benefits for Qualifying Products

Product Class	Non-DVR or DVR (if applicable)	Lifecycle Benefit / Cost Ratio	Net Present Value ($)[b]		
			Per Unit	For First Year Sales	Total Until Stock Turnover[c]
Cable	non-DVR	4.8	36.54	40,000,000	330,000,000
	DVR	1.6	16.47	8,700,000	65,000,000
Satellite	non-DVR	2.1	10.12	32,000,000	270,000,000
	DVR	1.2	4.42	3,100,000	29,000,000
Internet Protocol[a]	non-DVR	9.3	35.62	21,000,000	190,000,000
	DVR	3.1	45.02	9,900,000	99,000,000
Cable Digital Television Adapter		n/a	9.25	4,500,000	12,000,000
Thin Client / Remote		4.3	23.94	4,800,000	45,000,000
Total				**124,000,000**	**1,040,000,000**

[a] Service provider Internet Protocol (IP) set-top boxes only. Over-the-top IP set-top boxes excluded from this analysis.
[b] Positive value indicates a reduced total cost of ownership over the life of the appliance.
[c] This calculation assumes a constant NPV for each year's sales until stock turnover.

9 Acceptance Issues

9.1 Infrastructure issues

Meeting the proposed efficiency standard is technologically feasible today. We estimate that approximately 19 percent of new set-top boxes in 2013 would meet the proposed standard requirements. We do not expect the proposed standard to affect the user experience with long wake times from Deep Sleep or other latency-related concerns. However, adoption of new technologies and functionality could possibly require higher on mode power in the future. One example of one such technology is Ultra High Definition Television (UHDTV). UHDTV is a digital video format currently proposed by NHK Science & Technology Research Laboratories, which they call "Super Hi-Vision" (NHK 2012a, 2012b). In general, UHDTV could be the next step beyond today's HD technology. UHDTV has a resolution up to 16 times the number of pixels of existing HD (NHK 2012a, 2012b). Early UHDTV set-top boxes will likely require discrete chipsets, which will use more energy than the integrated system-on-chip solutions developed after the adoption of the current HD standard in the mid-2000s. It could take up to four to six years for industry and silicon vendors to agree upon and develop similar integrated system-on-chip solutions compatible with a new UHDTV standard. Should UHDTV be adopted widely, it may result in temporary increases in On mode power for some set-top box product classes.

9.2 Existing Standards

Currently ENERGY STAR is the only set-top box energy efficiency specification with significant impact in the U.S. market. The U.S. Department of Energy (DOE) recently initiated rulemaking and data collection activities for a federal set-top box standard.

9.2.1 ENERGY STAR Program

The third version of ENERGY STAR's voluntary set-top box program requirements went into effect on September 1, 2011 (EPA 2011b, 2011a). ENERGY STAR Version 3.0 program requirements are based on a total energy consumption (TEC) allowance for (i) base functionality and (ii) additional functionalities of the unit (Table 7). Version 3.0 also defines general criteria for external power supplies, maintenance activities, APD and Sleep.

The ENERGY STAR Version 4.0 specification was intended go into effect on July 1, 2013 (EPA 2011c), but has been delayed due to revisions in progress. Draft 1, Version 4.1 (EPA 2013a) implements lower AEC allowances for base types and additional functionalities in order to increase stringency from Version 3.0. In both its Version 3.0 and 4.0 specifications, ENERGY STAR requires Partner Commitments from set-top box service providers in addition to manufacturer requirements. ENERGY STAR Partner manufacturers agree to obtain certification and to properly label only products that meet ENERGY STAR program requirements. Service providers, on the other hand, must ensure that at least 50 percent of all new set-top boxes purchased are ENERGY STAR qualified and that the set-top boxes continue to meet the ENERGY STAR requirements for the duration of their deployment. ENERGY STAR also requests that partner service providers install thin client set-top boxes in multi-room configurations to minimize the number of DVRs deployed to subscribers (EPA 2011b, 2011a).

9.2.2 U.S. Department of Energy Rulemaking

In 2011, DOE initiated a rulemaking and data collection process to develop a potential test procedure and energy conservation standard for set-top boxes and network equipment (DOE 2012a).[38] In June 2011, DOE tentatively determined that set-top boxes and network equipment qualify as covered products under Part A, Title III of the Energy Policy and Conservation Act (EPCA) (DOE 2011). In January 2012, DOE released its *Rulemaking Overview and Preliminary Market and Technology Assessment* (DOE 2012b), a stand-alone report that provides an overview of the rulemaking process for the benefit of interested parties, and provides a preliminary market and technology assessment. In January 2013, DOE published a Notice of Proposed

[38] DOE amended its rulemaking schedule for set-top boxes to suspend the issuance of a proposed rule for a regulatory test procedure or energy conservation standard until after October 1, 2012 (DOE 2012a). The suspension allowed industry representatives and energy efficiency advocates time to negotiate a non-regulatory agreement to improve the energy efficiency of set-top boxes (DOE 2012a). During the suspension, DOE continued work to develop a set-top box test procedure. An agreement was not reached, and DOE continues its rulemaking.

Rulemaking (NOPR) for a test procedure for set-top boxes (DOE 2013b). More recently, DOE published a Notice of Data Availability (NODA) for set-top boxes (DOE 2013a).

A DOE standard would take effect five years after the publication of the final rule. Given the possible DOE standard for set-top boxes and small network equipment would not go into effect until the 2018 or 2019 timeframe based on the statutory delay of 5 years from adoption, there is not an immediate preemption risk for pursuing a California standard. However, if California delays the adoption date, the risk of preemption increases, which would have a significant impact on the achievable savings in California.

9.3 Stakeholder Positions

We summarize select stakeholder positions in response to potential California standards for set-top boxes below. We use responses to CEC's Invitation to Participate (ITP) in the 2013 Appliance Efficiency Rulemaking as the basis for these summaries.[39]

- ENERGY STAR and other voluntary measures are sufficient
- States should defer to the DOE
- The technology is changing too fast to regulate
- Consumer electronic devices are already efficient and use much less energy than other end uses
- The Federal Cable Act preempts CEC from imposing energy standards
- Set-top boxes are an integral part of the pay-TV system and there are potential impacts associated with this larger pay-TV system
- CEC's evaluation of potential energy efficiency benefits should include the benefits of multi-function devices
- Set-top box features and energy consumption evolve over the life of the product
- Set-top boxes include immature and dynamic technologies, therefore making it difficult to regulate without restricting innovation and integration

10 Environmental Impacts

The adoption of the proposed small network standard is a cost-effective means of helping California meet its long-term energy goals, climate initiatives and air quality guidelines. It is highly unlikely that the standard would cause any major non-energy environmental penalties.

10.1 Hazardous Materials

There are no known incremental hazardous materials impacts from the efficiency improvements as a results of the proposed standards.

10.2 Air Quality

This proposed measure is estimated to reduce total criteria pollutant emissions in California by 139,500 lbs/year in 2023, after stock turnover, as shown in Table 10.1 due to 811 GWh in reduced end user

[39] Full responses to Consumer Electronics, Docket 12-AAER-2A, available: http://www.energy.ca.gov/appliances/2013rulemaking/documents/responses/Consumer_Electronics_12-AAER-2A/

electricity consumption with an estimated value of $6,683,700. Criteria pollutant emission factors for California electricity generation were calculated per MWh based on California Air Resources Board data of emission rates by power plant type and expected generation mix (CARB 2010). The monetization of these criteria pollutant emission reductions is based on CARB power plant air pollution emission rate data times the dollar per ton value of these reductions based on Carl Moyer values where available, and San Joaquin Valley UAPCD "BACT" thresholds for sulfur oxides (SOx). These dollar per ton values vary significantly for fine particulates, as discussed in Appendix C: (CARB 2011a, CARB 2013a and San Joaquin Valley UAPCD).

Table 10.1 Estimated California Criteria Pollutant Reduction Benefits (lbs/year) After Stock Turnover

	lbs/year	Carl Moyer $/ton (2013)	Monetization
ROG	22,342	$17,460	$195,048
Nox	76,202	$17,460	$665,246
Sox	8,009	$19,300	$73,285
PM2.5	32,933	$349,200	$5,750,117
Total			**$6,683,700**

10.3 Greenhouse Gases

Table 10.1 shows the first year and stock turnover GHG savings by year and the range of the societal benefits as a result of the standard. By stock turnover in 2023, this standard would save 354,000 metric tons of CO2e, equal to between almost $20 million and $60 million of societal benefits. The total avoided CO2e is based on CARB's estimate of 437 MT CO2e/GWh of energy savings from energy efficiency improvements, and includes additional electrical transmission and distribution loses estimated at 7.8% (CARB 2008). The range of societal benefits per year is based on a range of annual $ per metric ton of CO2 (in 2013 dollars) sourced from the U.S. Government's Interagency Working Group on Social Cost of Carbon (SCC) (Interagency Working Group 2013). The low end uses the average SCC, while the high end incorporates SCC values which use climate sensitivity values in the 95th percentile, both with 3% discount rate. It is important to note that this range can be lower and higher, depending on the approach used, so policy judgements should consider this uncertainty. See Appendix D: for more details regarding this and other approaches.

Table 10.2 Estimated California Statewide Greenhouse Gas Savings and Cost Savings for Standards Case

First Year GHG Savings (MT of CO2e/yr)	Stock Turnover GHG Savings (MT of CO2e/yr)	Value of Stock Turnover GHG Savings - low ($)	Value of Stock Turnover GHG Savings - high ($)
89,200	354,000	19,900,000	59,800,000

11 Recommendations

11.1 Recommended Standards Proposal

The California IOUs recommend that California adopt an efficiency standard for set-top boxes. The proposed set-top box standard uses a UEC metric to address the energy use of set-top boxes and includes secondary requirements for maintenance activities, auto power down and Energy Efficient Ethernet. The proposed standard addresses all set-top box product classes in Section 3.2, takes effect one year after adoption, and would cost-effectively reduce residential energy consumption in California homes.

11.2 Proposed Changes to the Title 20 Code Language

The following is proposed language, by Section, for the Title 20 Appliance Efficiency Regulations.

Section 1601. Scope.

(x) Set-Top Box which meets the respective product type definition in Section 1602.

Section 1602. Definitions.

"Set-Top Box" means a device combining hardware components with software programming designed for the primary purpose of receiving television and related services from terrestrial, cable, satellite, broadband, or local networks, and providing video output.

"Cable Set-Top Box" means a set-top box whose primary function is to receive television signals from a broadband, hybrid fiber/coaxial, or community cable distribution system with Conditional Access (CA) or a set-top box capable of receiving cable service after installation of a CableCARD or other type of Conditional Access system.

"Satellite Set-Top Box" means a set-top box that receives and decodes video content as delivered from a service provider satellite network and that is not Cable.

"Internet Protocol (IP) Set-Top Box" means a set-top box whose primary function is to receive television/video signals encapsulated in IP packets and that is not Cable, Satellite, or Cable DTA.

"Over-the-top (OTT) Internet Protocol (IP) Set-Top Box" means an IP set-top box that does not receive signals from a Multichannel Video Programming Distributor (MVPD).

"Service Provider Internet Protocol (IP) Set-Top Box" means and IP set-top box that receives signals from a MVPD.

"Cable Digital Transport Adapter (DTA)" means a minimally-configured set-top box whose primary function is to receive television signals from a broadband, hybrid fiber/coaxial, or community cable distribution system.

"Thin-client / Remote" means a set-top box that can receive content over a Home Network Interface (HNI) from another set-top box, but is unable to interface directly to the Service Provider network.

"Advanced Video Processing" means the capability to encode, decode, and/or transcode audio/video signals in accordance with standards H.264/MPEG 4 or SMPTE 421M.

"CableCARD" means the capability to decrypt premium audio/video content and services and provide other network control functions via a plug-in conditional access module that complies with the ANSI/SCTE 28 HOST-POD Interface Standard.

"Digital Video Recorder (DVR)" means a set-top box feature that records television signals on a hard disk drive (HDD) or other non-volatile storage device integrated into the set-top box.

"Data Over Cable Service Interface Specification (DOCSIS®)" means the capability to distribute data and audio/video content over cable television infrastructure in accordance with the CableLabs® Data Over Cable Service Interface Specification.

"High Definition (HD) Resolution" means the capability to transmit or display video signals with a minimum output resolution of 1280×720 pixels in progressive scan mode at minimum frame rate of 59.94 fps (abbreviated 720p60) or a minimum output resolution of 1920×1080 pixels in interlaced scan mode at 29.97 fps (abbreviated 1080i30).

"Home Network Interface" means an interface with external devices over a local area network (e.g. Institute of Electrical and Electronics Engineers (IEEE) 802.11 (Wireless-Fidelity or Wi-Fi), Multimedia over Coax Alliance (MoCA), HomePNA alliance (HPNA), IEEE 802.3, HomePlug AV) that is capable of transmitting video content.

"MIMO Wireless Home Network Interface" means IEEE 802.11n/ac and related MIMO enabled WiFi functionality that supports more than one spatial stream in both send and receive (Antenna support is not relevant, thus the device must be 2 x n : 2 or better to fall under this definition).

"Multi-room" means the capability to provide independent live and/or real time transfer of audio/video content to multiple devices (2 or more clients) within a single family dwelling. This definition does not include the capability to manage gateway services for multi-subscriber scenarios

"Multi-stream" means a set-top box feature that may provide independent video content to one or more clients, one or more directly connected display devices, or a DVR. This definition does not include the capability to manage gateway services for multi-subscriber scenarios.

"On Mode" means the set-top box is connected to a mains power source. At least one principal function is activated and all principal functions are provisioned for use. The power consumption in On Mode may vary based on specific use and configuration.

"Sleep Mode" means a range of reduced power states where the set-top box is connected to a mains power source and is not providing any principal function. The set-top box may transition to On or Off Mode due to user action, internal signal, or external signal. The power consumed in this mode may vary based on specific use or configuration. If any principal function is activated while operating in this mode, the set-top box is assumed to transition to On Mode. Monitoring for user or network requests is not considered a principal function. The set-top box shall be able to transition from this mode to On Mode within 30 seconds to be considered in Sleep Mode.

"Deep Sleep State" means a power state characterized by reduced power consumption and more than 30 seconds required to return to full On Mode functionality.

"Auto Power Down (APD)" means a set-top box feature that monitors parameters correlated with the user activity or viewing. If the parameters collectively indicate that no user activity or viewing is occurring, the APD feature enables the set-top box to transition to Sleep or Off Mode.

"Principal Function" means functions necessary for selecting, receiving, decoding, decompressing, or delivering live or recorded audio/video content to a display device, local/remote recording device, or client. Monitoring for user or network requests is not considered a principal function for set-top boxes.

"Secondary Function" means functions that enable, supplement, or enhance a primary function including the activation or deactivation of a primary function by remote switch (e.g., remote control, internal sensor, and timer).

Section 1604. Test Method for Specific Appliances.

(x) Set-Top Boxes

Table X: Test Procedure for Set-Top Boxes

Test Protocol	Source
ENERGY STAR Draft 1, Version 4.1 Program Requirements for Set-top Boxes, Test Method with two additions*	https://energystar.gov/products/specs/sites/products/files/Draft%201%20Version%204%201%20STB%20Specification.pdf

*Two improvements to the existing ENERGY STAR test procedure are needed to enable verification of: (1) scheduled deep per the sleep modes section of CEA 2043, and (2) 15 minute auto power down after completion of maintenance/recording activities for cases where the set-top box was in Sleep mode before the activity. Language would need to be developed as part of the CEC workshop process.

Section 1605.3 State Standards for Non-Federally-Regulated Appliances.

(x) Set-Top Boxes

Effective [one year after adoption date], Set-Top Boxes shall not exceed the maximum unit energy consumption (UEC) allowance based on Table X below.

Table X: Standards for Set-Top Boxes, Energy Allowances for Base Functionality and Additional Functionality

Functionality	Energy Allowance (kWh/yr)
Base Functionality	
Cable	45
Satellite	50
Service Provider Internet Protocol (IP)	25
Over-the-top (OTT) Internet Protocol (IP)	10
Cable Digital Television Adapter	35
Thin-client / Remote	10
Additional Functionality	
Advanced Video Processing	8
CableCARD	15
Digital Video Recorder (DVR)	36
DOCSIS®	15
High Definition (HD)	16
Home Network Interface	8
MIMO WiFi HNI	$N_{2.4\text{ GHz}} + 2 \text{ X } N_{5\text{ GHz}}$ Where: N is the number of spatial streams at the given frequency
Multi-room	40
Multi-stream – Cable/Satellite	8
Multi-stream – Internet Protocol (IP)	6

Equation:

$$AEC - Incentive_{Scheduled\ Deep\ Sleep} \leq AEC_{Spec\ Max} = AEC_{Base\ Max} + \sum AEC_{Addl\_i}$$

$$\text{where } Incentive_{Scheduled\ Deep\ Sleep} = (P_{Sleep\ APD} - P_{Scheduled\ Deep\ Sleep}) \text{ x } Duration_{Scheduled\ Deep\ Sleep}$$

If a set-top box does not have APD, then substitute $P_{Sleep\ Manual}$ for $P_{Sleep\ APD}$

In addition, Set-Top Boxes shall meet the following secondary criteria:

Maintenance Activities. Products that have exited Sleep mode or Deep Sleep state and completed maintenance or other user-requested activities shall automatically return to Sleep mode or Deep Sleep state in less than 15 minutes.

Auto Power Down (APD). Products that offer an APD feature shall meet the following requirement:

> Products shall be deployed by the service provider with APD enabled by default, with APD to occur after a period of inactivity less than or equal to 4 hours.

Deep Sleep. Products that offer a Deep Sleep state shall meet the following requirements:

iv. For a power state to qualify as a Deep Sleep, measured power consumption (P_{DEEP_SLEEP}) shall be less than or equal to 15 percent of the power draw in On mode (as measured per the ENERGY STAR test procedure for "Watching Live TV" [PTV]), or 3.0 watts, whichever is greater. In addition, the set-top box must have default settings that include a scheduled deep sleep of up to 4 hours.

v. For set-top boxes with a user interface, a means of manually activating Deep Sleep shall be accessible to the end user via a clearly marked button or switch on the remote control and/or the front face of the set-top box. This is in addition to the scheduled deep sleep requirement.

vi. If Deep Sleep capability is enabled in the as-deployed default product configuration, an override function may be provided to allow the end-user to disable Deep Sleep functionality.

Energy Efficiency Ethernet. Products that include an Ethernet port shall be EEE-certified.

11.3 Implementation Plan

The expected implementation for this standards proposal is for the CEC to proceed with its appliance standards rulemaking authority, from pre-rulemaking and rulemaking through adoption, and for manufacturer compliance upon effective date.

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Appendix A: Additional Market Data

Table A.1 California estimated stock and sales for set-top boxes, 2013-2023, Ecova analysis of SNL Kagan (2012)

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
in millions											
STOCK											
Cable	10.31	10.52	10.58	11.13	11.44	11.67	11.95	12.28	12.63	12.85	13.16
Satellite	11.34	11.43	11.50	11.74	11.82	11.92	12.05	12.20	12.34	12.46	12.59
IP	3.79	4.25	4.70	5.21	5.68	6.14	6.61	7.09	7.57	8.03	8.51
Cable DTA	4.36	4.60	4.57	3.89	3.50	3.15	2.83	2.55	2.30	2.07	1.86
Thin Client	0.19	0.34	0.51	0.73	0.90	1.09	1.29	1.47	1.66	1.85	2.04
	2013	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
in millions											
SALES											
Cable	2.01	1.90	1.71	2.13	2.07	2.01	2.06	2.14	2.22	2.15	2.24
Satellite	2.66	2.65	2.65	3.00	2.73	2.76	2.87	2.91	2.92	2.90	2.97
IP	0.88	0.93	0.99	1.09	1.12	1.17	1.24	1.30	1.36	1.41	1.48
Cable DTA	0.91	0.79	0.58	0.57	0.49	0.30	0.15	0.00	0.00	0.00	0.00
Thin Client	0.09	0.17	0.22	0.28	0.25	0.31	0.33	0.34	0.38	0.39	0.42

Note: As explained in Section 6.1.1, sales are equal to the sum of replacement set-top boxes and new set-top boxes attributable to subsciber growth.

Table A.2 California estimated stock and sales for set-top boxes, 2013-2023, including sub-class, Ecova analysis of SNL Kagan (2012)

in millions		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
STOCK												
Cable	SD	3.61	3.24	2.94	2.70	2.36	2.04	1.74	1.45	1.14	0.82	0.52
	SD-DVR	0.40	0.38	0.34	0.33	0.30	0.28	0.25	0.23	0.21	0.18	0.15
	HD	3.39	3.89	4.20	4.73	5.30	5.74	6.19	6.68	7.18	7.63	8.11
	HD-DVR	2.91	3.02	3.09	3.37	3.48	3.62	3.76	3.92	4.10	4.22	4.38
Cable - DTA		4.36	4.60	4.57	3.89	3.50	3.15	2.83	2.55	2.30	2.07	1.86
Sat	SD	5.23	4.94	4.64	4.18	3.88	3.59	3.23	2.88	2.54	2.23	1.88
	HD	3.38	3.62	3.84	4.41	4.63	4.88	5.23	5.58	5.92	6.20	6.54
	DVR	2.73	2.87	3.02	3.15	3.31	3.45	3.59	3.74	3.88	4.03	4.17
Telcom	HD	2.88	3.23	3.53	3.92	4.27	4.60	4.95	5.30	5.65	5.99	6.34
	HD-DVR	0.91	1.02	1.18	1.29	1.41	1.54	1.66	1.79	1.91	2.04	2.17
Thin Clients		0.19	0.34	0.51	0.73	0.90	1.09	1.29	1.47	1.66	1.85	2.04
in millions		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
SALES												
Cable	SD	0.49	0.45	0.41	0.37	0.34	0.30	0.25	0.22	0.18	0.14	0.10
	SD-DVR	0.05	0.05	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.02
	HD	0.96	0.92	0.80	1.06	1.16	1.11	1.17	1.26	1.34	1.35	1.43
	HD-DVR	0.50	0.48	0.45	0.66	0.53	0.57	0.60	0.63	0.67	0.63	0.69
Cable - DTA		0.91	0.79	0.58	0.57	0.49	0.30	0.15	0.00	0.00	0.00	0.00
Sat	SD	1.09	1.05	0.99	0.93	0.84	0.78	0.72	0.65	0.58	0.51	0.45
	HD	0.89	0.91	0.94	1.34	1.10	1.18	1.32	1.40	1.45	1.47	1.58
	DVR	0.68	0.69	0.72	0.73	0.79	0.80	0.83	0.86	0.89	0.92	0.95
Telcom	HD	0.67	0.71	0.70	0.83	0.84	0.87	0.92	0.97	1.02	1.05	1.10
	HD-DVR	0.21	0.22	0.28	0.26	0.28	0.30	0.32	0.34	0.34	0.37	0.38
Thin Clients		0.09	0.17	0.22	0.28	0.25	0.31	0.33	0.34	0.38	0.39	0.42

Note: As explained in Section 6.1.1, sales are equal to the sum of replacement set-top boxes and new set-top boxes attributable to subsciber growth.

Table A.3 U.S. estimated stock and sales for set-top boxes, 2013-2023, Ecova analysis of SNL Kagan (2012)

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
in millions											
STOCK											
Cable	85.88	87.69	88.18	92.75	95.34	97.28	99.59	102.32	105.21	107.08	109.68
Satellite	94.48	95.23	95.81	97.83	98.50	99.35	100.41	101.66	102.83	103.80	104.92
IP	31.60	35.40	39.20	43.39	47.30	51.15	55.11	59.09	63.05	66.94	70.89
Cable DTA	36.33	38.37	38.11	32.39	29.15	26.24	23.61	21.25	19.13	17.21	15.49
Thin Client	1.56	2.80	4.27	6.11	7.47	9.12	10.72	12.23	13.85	15.41	16.97
	2013	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
in millions											
SALES											
Cable	16.72	15.80	14.21	17.72	17.26	16.77	17.13	17.81	18.46	17.89	18.67
Satellite	22.18	22.05	22.10	24.99	22.75	22.99	23.92	24.26	24.34	24.15	24.77
IP	7.36	7.75	8.23	9.09	9.34	9.76	10.35	10.87	11.35	11.77	12.32
Cable DTA	7.59	6.57	4.80	4.76	4.05	2.50	1.25	0.00	0.00	0.00	0.00
Thin Client	0.72	1.43	1.82	2.37	2.12	2.59	2.74	2.85	3.16	3.28	3.49

Note: As explained in Section 6.1.1, sales are equal to the sum of replacement set-top boxes and new set-top boxes attributable to subsciber growth.

Table A.4 U.S. estimated stock and sales for set-top boxes, 2013-2023, including sub-class, Ecova analysis of SNL Kagan (2012)

in millions		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
STOCK												
Cable	SD	30.06	27.03	24.53	22.52	19.69	17.00	14.54	12.09	9.51	6.86	4.37
	SD-DVR	3.36	3.13	2.87	2.75	2.52	2.31	2.10	1.91	1.71	1.49	1.29
	HD	28.25	32.38	35.00	39.43	44.14	47.86	51.61	55.64	59.85	63.60	67.54
	HD-DVR	24.21	25.14	25.77	28.04	28.99	30.13	31.35	32.68	34.14	35.13	36.47
Cable - DTA		36.33	38.37	38.11	32.39	29.15	26.24	23.61	21.25	19.13	17.21	15.49
Sat	SD	43.56	41.15	38.68	34.87	32.37	29.93	26.93	24.00	21.16	18.54	15.65
	HD	28.19	30.15	31.99	36.74	38.58	40.67	43.55	46.52	49.31	51.67	54.49
	DVR	22.73	23.93	25.14	26.21	27.56	28.75	29.93	31.14	32.36	33.59	34.77
Telcom	HD	24.02	26.90	29.40	32.65	35.55	38.35	41.23	44.15	47.12	49.95	52.85
	HD-DVR	7.58	8.50	9.80	10.74	11.75	12.80	13.87	14.93	15.93	16.99	18.05
Thin Clients		1.56	2.80	4.27	6.11	7.47	9.12	10.72	12.23	13.85	15.41	16.97
in millions		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
SALES												
Cable	SD	4.12	3.76	3.38	3.07	2.82	2.46	2.12	1.82	1.51	1.19	0.86
	SD-DVR	0.44	0.42	0.39	0.36	0.34	0.32	0.29	0.26	0.24	0.21	0.19
	HD	8.03	7.66	6.67	8.80	9.64	9.24	9.73	10.48	11.17	11.23	11.90
	HD-DVR	4.13	3.96	3.77	5.49	4.46	4.76	4.99	5.25	5.55	5.25	5.73
Cable - DTA		7.59	6.57	4.80	4.76	4.05	2.50	1.25	0.00	0.00	0.00	0.00
Sat	SD	9.10	8.71	8.23	7.74	6.97	6.47	5.99	5.39	4.80	4.23	3.71
	HD	7.45	7.60	7.87	11.15	9.18	9.81	11.01	11.68	12.10	12.22	13.16
	DVR	5.63	5.74	6.00	6.10	6.59	6.71	6.93	7.20	7.44	7.70	7.90
Telcom	HD	5.60	5.89	5.86	6.92	6.98	7.24	7.67	8.08	8.49	8.72	9.14
	HD-DVR	1.77	1.86	2.37	2.16	2.36	2.52	2.67	2.79	2.86	3.06	3.18
Thin Clients		0.72	1.43	1.82	2.37	2.12	2.59	2.74	2.85	3.16	3.28	3.49

Note: As explained in Section 6.1.1, sales are equal to the sum of replacement set-top boxes and new set-top boxes attributable to subsciber growth.

Appendix B: Energy Use and Savings Analysis Using Changing Compliance Rates Over Time

In this section, we calculate an alternative non-standards case energy use scenario assuming a changing compliance rate over time. We estimated a compliance rate in this alternative non-standards case based on our assessment of the future adoption of high efficiency options for each year's sales until stock turnover.[40] See Section 6.2 for more detail on the future adoption of high efficiency options. California energy use and savings estimates resulting from this alternative scenario are shown below. In either scenario, the proposed standards are cost effective.

Table B.1 California Statewide Baseline Energy Use – Current Year

Product Class	Annual Sales (2013)		Entire Stock (2013)	
	Coincident Peak Demand (MW)[b]	Annual Energy Consumption (GWh/yr)	Coincident Peak Demand (MW)	Annual Energy Consumption (GWh/yr)
Cable	40	330	220	1800
Satellite	44	360	180	1400
Internet Protocol[a]	10	80	46	370
Cable Digital Television Adapter	5.8	47	28	230
Thin Client / Remote	0.54	4.4	1.3	10
Total	**101**	**813**	**473**	**3810**

[a] Service provider Internet Protocol (IP) set-top boxes only. Over-the-top IP set-top boxes excluded from this analysis.
[b] Peak demand values calculated by multiplying GWh by a 0.92 kW/MWh load factor ratio from the 'Miscellaneous' category in Table 3 from Brown and Koomey (2003).

Table B.2 California Statewide Non-Standards Case Energy Use - After Effective Date

Product Class	For First-Year Sales		Year of Stock Turnover	
	Coincident Peak Demand (MW)[b]	Annual Energy Consumption (GWh/yr)	Coincident Peak Demand (MW)	Annual Energy Consumption (GWh/yr)
Cable	39	320	240	2000

[40] The non-standards case scenario presented in Section 7.1, however, assumes no change in the compliance rate over time.

Satellite	40	330	180	1500
Internet Protocol[a]	11	91	94	760
Cable Digital Television Adapter	3.0	25	10	83
Thin Client / Remote	1.7	14	13	110
Total	**95.7**	**771**	**544**	**4380**

[a] Service provider Internet Protocol (IP) set-top boxes only. Over-the-top IP set-top boxes excluded from this analysis.
[b] Peak demand values calculated by multiplying GWh by a 0.92 kW/MWh load factor ratio from the 'Miscellaneous' category in Table 3 from Brown and Koomey (2003).

Table B.3 California Statewide Standards Case Energy Use - After Effective Date

Product Class	For First-Year Sales		Year of Stock Turnover	
	Coincident Peak Demand (MW)[b]	Annual Energy Consumption (GWh/yr)	Coincident Peak Demand (MW)	Annual Energy Consumption (GWh/yr)
Cable	33	260	220	1800
Satellite	31	250	150	1200
Internet Protocol[a]	9.2	74	78	630
Cable Digital Television Adapter	2.5	20	10	81
Thin Client / Remote	1.4	11	13	100
Total	**76.9**	**620**	**470**	**3790**

[a] Service provider Internet Protocol (IP) set-top boxes only. Over-the-top IP set-top boxes excluded from this analysis.
[b] Peak demand values calculated by multiplying GWh by a 0.92 kW/MWh load factor ratio from the 'Miscellaneous' category in Table 3 from Brown and Koomey (2003).

Table B.4 Estimated California Statewide Energy Savings with Standards Case - After Effective Date

Product	For First-Year Sales	Year of Stock Turnover

Class	Coincident Peak Demand Reduction (MW)	Annual Energy Savings (GWh/yr)	Coincident Peak Demand Reduction (MW)	Annual Energy Savings (GWh/yr)
Cable	6.6	53	25	200
Satellite	9.3	75	31	250
Internet Protocol[a]	2.1	17	17	140
Cable Digital Television Adapter	0.57	4.6	0.33	2.7
Thin Client / Remote	0.30	2.4	0.69	5.5
Total	**18.5**	**151**	**73.7**	**594**

[a] Service provider Internet Protocol (IP) set-top boxes only. Over-the-top IP set-top boxes excluded from this analysis.

Table B.5 Estimated California Statewide Greenhouse Gas Savings for Standards Case

Product Class	Annual GHG Savings for First-Year Sales (metric ton of CO2e/yr)	Annual GHG Savings in Year of Stock Turnover (metric ton of CO2e/yr)
Cable	23,000	89,000
Satellite	33,000	110,000
Internet Protocol[a]	7,200	59,000
Cable Digital Television Adapter	250	1,200
Thin Client / Remote	130	2,400
Total	**63,500**	**260,000**

[a] Service provider Internet Protocol (IP) set-top boxes only. Over-the-top IP set-top boxes excluded from this analysis.
Assumes 4.37 X 10^{-7} MMT of CO2e per MWh of electricity savings based on assumptions for GHG emissions reduction in CA ARB (2008, I-24).

Table B.8.4 Costs and Benefits Per Unit for Qualifying Products

Product Class	Non-DVR or DVR (if applicable)	Design Life (years)	Lifecycle Costs per Unit (Present Value $)			Lifecycle Benefits per Unit (Present Value $)		
			Incremental Cost	Add'l Costs[b]	Total PV Costs	Energy Savings[c]	Add'l Benefits[d]	Total PV Benefits
Cable	non-DVR	8	9.58	0.00	9.58	46.12	0.00	46.12
	DVR	8	29.55	0.00	29.55	46.02	0.00	46.02
Satellite	non-DVR	5	9.17	0.00	9.17	19.29	0.00	19.29
	DVR	5	27.12	0.00	27.12	31.54	0.00	31.54
Internet Protocol[a]	non-DVR	8	4.29	0.00	4.29	39.91	0.00	39.91
	DVR	8	21.57	0.00	21.57	66.59	0.00	66.59
Cable Digital Television Adapter		8	0.00	0.00	0.00	9.25	0.00	9.25
Thin Client / Remote		8	7.34	0.00	7.34	31.28	0.00	31.28

PV = Present Value

[a] Service provider Internet Protocol (IP) set-top boxes only. Over-the-top IP set-top boxes excluded from this analysis.

[b] We assume no additional costs.

[c] Calculated using the CEC's average statewide present value (2012 $) statewide energy rates that assume a 3% discount rate. http://www.energy.ca.gov/2012_energypolicy/documents/index.html

[d] We assume no additional benefits.

Table B.8.5 Lifecycle Costs and Benefits for Qualifying Products

Product Class	non-DVR or DVR (if applicable)	Lifecycle Benefit / Cost Ratio	Net Present Value ($)[b]		
			Per Unit	For First Year Sales	Total Until Stock Turnover[c]
Cable	non-DVR	4.8	36.54	31,000,000	260,000,000
	DVR	1.6	16.47	6,900,000	52,000,000
Satellite	non-DVR	2.1	10.12	21,000,000	180,000,000
	DVR	1.2	4.42	2,300,000	18,000,000
Internet Protocol[a]	non-DVR	9.3	35.62	18,000,000	160,000,000
	DVR	3.1	45.02	7,000,000	70,000,000
Cable Digital Television Adapter		n/a	9.25	3,200,000	8,400,000
Thin Client / Remote		4.3	23.94	4,100,000	39,000,000
Total				**93,400,000**	**785,000,000**

[a] Service provider Internet Protocol (IP) set-top boxes only. Over-the-top IP set-top boxes excluded from this analysis.
[b] Positive value indicates a reduced total cost of ownership over the life of the appliance.
[c] This calculation assumes a constant NPV for each year's sales until stock turnover.

Appendix C: Criteria Pollutant Emissions and Monetization

C.1 Criteria Pollutant Emissions Calculation

To calculate the statewide emissions rate for California, the incremental emissions between CARB's high load and low load power generation forecasts for 2020 were divided by the incremental generation between CARB's high load and low load power generation forecast for 2020. Incremental emissions were calculated based on the delta between California emissions in the high and low generation forecasts divided by the delta of total electricity generated in those two scenarios. This emission rate per MWh is intended to provide a benchmark of emission reductions attributable to energy efficiency measures that could help achieve the low load scenario instead of the high load scenario. While emission rates may change somewhat over time, 2020 was considered a representative year for this measure.

C.2 Criteria Pollutant Emissions Monetization

Avoided ambient ozone precursor and fine particulate air pollution benefits were monetized based on avoided control costs rather than damage costs due to the availability of emission control cost-effectiveness thresholds, as well as challenges in quantifying a specific value for damages per ton of pollutants.

Two sources of data for cost-effectiveness thresholds were evaluated. The first is Carl Moyer cost-effectiveness thresholds for ozone precursors and fine particulates (CARB 2011a, CARB 2013a and 2013b). The Carl Moyer program has provided incentives for voluntary reductions in criteria pollutant reductions from a variety of mobile combustion sources as well as stationary agricultural pumps that meet specified cost-effectiveness cut-offs.

The second is the San Joaquin Valley UAPCD Best-Available Control Technology ("BACT") cost-effectiveness thresholds study. Pollution reduction technologies that are not yet demonstrated in practice (in which case they are required without a cost-effectiveness evaluation) can be required at new power plants and other sources if technologically feasible and within cost-effectiveness thresholds. San Joaquin Valley UAPCD conducted a state-wide study as the basis for updating their BACT thresholds in 2008.

This CASE report relies primarily on the Carl Moyer thresholds due to their state-wide nature and applicability to combustion sources[41]. In addition, the Carl Moyer fine particulate values for fine particulate apply to combustion sources with specific health impacts, while BACT thresholds include both combustion sources and dust. The Carl Moyer values are somewhat more conservative for ozone precursors than San Joaquin Valley UAPCD BACT thresholds, and significantly higher for fine particulate[42].The Carl Moyer program does not address sulfur oxides, however, thus the San Joaquin BACT thresholds were used for this pollutant.

Price reports for California Emission Reduction Credit (ERCs, i.e. air pollution credits purchased to offset regulated emission increases) for 2011 and 2012 were also compared to the values selected in this CASE report. For each pollutant there is a wide range of ERC values per ton that are both higher and lower than the values per ton used in this CASE report [CARB 2011b and 2012]. Due to wide variability and low trading volumes, ERC values were evaluated for comparative purposes only.

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[41] Further evaluation of the qualitative impacts of combustion fine particulate emissions from power generation and transportation sources may be beneficial.

[42] We note that both the Carl Moyer and San Joaquin Valley UAPCD BACT cost-effectiveness thresholds for fine particulates fall within the wide range of fine particulate ERC trading prices in California in 2011 and 2012.

Appendix D: Greenhouse Gas Valuation Discussion

The climate impacts of pollution from fossil fuel combustion and other human activities, including the greenhouse gas effect, present a major risk to global economies, public health and the environment. While there are uncertainties of the exact magnitude given the interconnectedness of ecological systems, at least three methods exist for estimating the societal costs of greenhouse gases: 1) the Damage Cost Approach 2) the Abatement Cost Approach and 3) the Regulated Carbon Market Approach. See below for more details regarding each approach.

D.1 Damage Cost Approach

In 2007, the U.S. Court of Appeals for the Ninth Circuit ruled that the National Highway Transportation Traffic Safety Administration (NHTSA) was required to assign a dollar value to benefits from abated carbon dioxide emissions. The court stated that while there are a wide range of estimates of monetary values, the price of carbon dioxide abatement is indisputably non-zero. In 2009, to meet the necessity of a consistent value for use by government agencies, the Obama Administration established the Interagency Working Group on the Social Cost of Carbon to establish official estimates (Johnson and Hope).

The Interagency Working Group primarily uses estimates of avoided damages from climate change which are valued at a price per ton of carbon dioxide, a method known as the damage cost approach.

D.1.1 Interagency Working Group Estimates

The Interagency Working Group SCC estimates, based on the damage cost approach, were calculated using three climate economic models called integrated assessment models which include the Dynamic Integrated Climate Economy (DICE), Policy Analysis of the Greenhouse Effect (PAGE), and Climate Framework for Uncertainty, Negotiation, and Distribution (FUND) models. These models incorporate projections of future emissions translated into atmospheric concentration levels which are then translated into temperature changes and human welfare and ecosystem impacts with inherent economic values. As part of the Federal rulemaking process, DOE publishes estimated monetary benefits using Interagency Working Group SCC values for each Trial Standard Level considered in their analyses, calculated as a net present value of benefits received by society from emission reductions and avoided damages over the lifetime of the product. The recent U.S. DOE Final Rulemaking for microwave ovens contains a Social Cost of Carbon section that presents the Interagency Working Group's most recent SCC values over a range of discount rates (DOE 2013) as shown in Table D.1. The two dollar per metric ton of values used in this CASE report were taken from the two highlighted columns, and converted to 2013 dollars.

Table D.1 Social Cost of CO_2 2010 – 2050 (in 2007 dollars per metric ton of CO_2)

Discount Rate	5.0%	3.0%	2.5%	3.0%
Year	Avg	Avg	Avg	95th
2010	11	33	52	90
2015	12	38	58	109
2020	12	43	65	129
2025	14	48	70	144
2030	16	52	76	159
2035	19	57	81	176
2040	21	62	87	192
2045	24	66	92	206
2050	27	71	98	221

Source: Interagency Working Group on Social Cost of Carbon, United States Government, 2013

The Interagency Working Group decision to implement a global estimate of the SCC rather than a domestic value reflects the reality of environmental damages which are expected to occur worldwide. Excluding global damages is inconsistent with U.S. regulatory policy aimed at incorporating international issues related to resource use, humanitarian interests, and national security. As such, a regional SCC value specific to the Western United States or California specifically should be at similarly inclusive of global damages. Various studies state that certain values may be understated due to the asymmetrical risk of catastrophic damage if climate change impacts are above median predictions, and some estimates indicate that the upper end of possible damage costs could be substantially higher than indicated by the IWG (Ackerman and Stanton 2012, Horii and Williams 2013).

D.2 Abatement Cost Approach

Abating carbon dioxide emissions can impose costs associated with more efficient technologies and processes, and policy-makers could also compare strategies using a different by estimating the annualized costs of reducing one ton of carbon dioxide net of savings and co-benefits. The cost of abatement approach could reflect established greenhouse gas reduction policies and establish values for carbon dioxide reductions relative to electricity de-carbonization and other measures. (While recognizing the potential usefulness of this method, this report utilizes the IWG SCC approach and we note that the value lies within the range of abatement costs discussed further below.)

The cost abatement approach utilizes market information regarding emission abatement technologies and processes and presents a wide-range of values for the price per ton of carbon dioxide. The California Air Resources Board data of the cost-effectiveness of energy efficiency measures and emission regulations would provide one source of potential data for an analysis under this method. To meet the AB 32 target, ARB has established the "Cost of a Bundle of Strategies Approach" which includes a range of cost-effective strategies and regulations (CARB 2008b). The results of this approach within the framework of the Climate Action Team Macroeconomic Analysis are provided for California, Arizona, New Mexico, the United States, and a global total identified in that same report, as shown in Table D.2 below.

Table D.2 Cost-effectiveness Range for the CAT Macroeconomic Analysis

Exhibit 3: Cost-effectiveness Range for the CAT Macroeconomic Analysis, Selected States, United States, Global -

State	Cost-effectiveness Range $/ ton CO_2eq	Tons Reduced MMtCO_2e/yr	Percent of BAU
California 2020 (CAT[1], CEC[2])	- 528 to 615	132	22
Arizona[3] 2020	- 90 to 65	69	47
New Mexico[4] 2020	- 120 to105	35	34
United States (2030)[5]	-93 to 91	3,000	31
Global Total (2030)	-225 to 91	26,000	45

Source:
1. Climate Action Team Updated Macroeconomic Analysis of Climate Strategies, Presented in the March 2006 Climate Action Team Report, September 2007.
2. California Energy Commission, *Emission Reduction Opportunities for Non-CO2 Greenhouse Gases in California*, July 2005, ICF ($/MT$CO_2$eq).
3. Arizona Climate Change Advisory Group, *Climate Change Action Plan*, August 2006, ($/MT$CO_2$eq).
4. New Mexico Climate Change Advisory Group, Final Report, December 2006.
5. McKinsey & Company, *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?* December 2007.
6. The McKinsey Quarterly, McKinsey & Company, *A Cost Curve for Greenhouse Gas Reduction*, Fall 2007.

Source: CARB 2008b

Energy and Environmental Economics (E3) study defines the cost abatement approach more specifically as electricity de-carbonization and is based on annual emissions targets consistent with existing California climate policy. Long-term costs are determined by large-scale factors such as electricity grid stability, technological advancements, and alternative fuel prices. Near-term costs per ton of avoided carbon could be$200/ton in the near-term (Horii and Williams 2013), thus as noted earlier the value used in this report may be conservative.

D.3 Regulated Carbon Market Approach

Emissions allowance markets provide a third potential method for valuing carbon dioxide. Examples include the European Union Emissions Trading System and the California AB32 cap and trade system as described below. Allowances serve as permits authorizing emissions and are traded through the cap-and-trade market between actors whose economic demands dictate the sale or purchase of permits. In theory, allowance prices could serve as a proxy for the cost of abatement. However, this report does not rely on the prices of cap-and-trade allowances due to the vulnerability of the allowance market to external fluctuations, and the influence of regulatory decisions affecting scarcity or over-allocation unrelated to damages or abatement costs.

D.3.1 European Union Emissions Trading System

The European Union Emissions Trading System (EU ETS) covers more than 11,000 power stations, industrial plants, and airlines in 31 countries. However, the market is constantly affected by over-supply following the 2008 global recession and has seen prices drop to dramatic lows in early 2013, resulting in the practice of "back-loading" (delaying issuances of permits) by the European parliament. At the end of June 2013, prices of permits dropped to $5.41/ton, a price which is well below damage cost estimates and sub-optimal for encouraging innovative carbon dioxide emission abatement strategies.

D.3.2 California Cap & Trade

In comparison, California cap-and-trade allowance prices were reported to be at least $14/ton in May of 2013, with over 14.5 million total allowances sold for 2013 (CARB 2013b). However, cap-and-trade markets are likely to cover only subsets of emitting sectors of the industry covered by AB 32. In addition, the market prices of allowances are determined only partly by costs incurred by society or industry actors and largely by the stringency of the cap determined by regulatory agencies and uncontrollable market forces, as seen by the failure of the EU ETS to set a consistent and effective signal to curb carbon dioxide emissions.