Small Network Equipment

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

Analysis *of* Standards Proposal for
Small Network Equipment

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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 small network equipment.

Network equipment consists of the devices whose primary purpose is to transport, route, switch or process network traffic (Lanzisera, Nordman, & Brown 2010). Small network equipment is network equipment that is intended to serve users in either small networks or a subset of a large network (EPA 2013a). Examples include cable modems that connect one's home to the internet or Wi-Fi routers that enable a family to share video, photos and other data among computers, game consoles, tablets and other devices within the home. There are approximately 27 million small network devices in use in California today, consuming a combined 1,700 gigawatt-hours per year (GWh/yr). Most small network equipment today draw the same amount of power when sitting idle as they do when transmitting large amounts of data at high rates.

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 the majority of residentially-focused small network equipment and a test and list requirement for emerging residential small network equipment (specifically fixed wireless devices) and small enterprise network equipment. We recommend that the proposed standard takes effect one year after adoption and addresses broadband access equipment and local network equipment.

17% of today's small network equipment can meet the proposed standards levels. Many cost-effective and technologically feasible opportunities to further reduce energy consumption beyond the proposed levels have been adopted or are under development by industry and researchers. Energy Efficient Ethernet (EEE) is utilized in small network equipment today. Wi-Fi and broadband power scaling technologies are emerging efficiency opportunities to enable devices to meet the proposed standard. The California IOUs estimate zero 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 nearly 93.5 GWh/yr for first year sales and over 438 GWh/yr savings in the year of entire stock turnover.[1] Energy savings in the year of stock turnover represent approximately 232,000 metric tons of equivalent carbon dioxide (metric ton of CO2e) savings per year. Adopting the recommended test and list requirement would enable California to gather data and monitor the energy use of small network equipment not covered by the mandatory standards. The adoption of the proposed small network

[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).

equipment standard is a cost effective means of helping California meet its long-term energy goals, climate initiatives and air quality guidelines.

2 Acronyms

ADSL – Asymmetric digital subscriber line
CAGR – Compound annual growth rate
CMTS – Cable Modem Termination Systems
CoC – Code of conduct
DOE – United States Department of Energy
DSL – Digital subscriber line
EC – European Commission
ECR – Energy Consumption Rating
EEE – Energy Efficient Ethernet
EPA – Environmental Protection Agency
FTTH – Fiber to the home
GWh – Gigawatt hour
IAD – Integrated access device
IEC – International Electrotechnical Commission
IP – Internet protocol
kWh – Kilowatt hour
LAN – Local area network
MIMO – Multi-input multi-output
NPV – Net present value
ONT – Optical network termination device
POTS – Plain old telephone system
SFP – Small form factor
SNE – Small network equipment
TEER – Telecommunications energy efficiency ratio
UEC – Unit energy consumption
WAN – Wide area network
VDSL – Very-high-bit-rate digital subscriber line

3 Product Description

3.1 Overview

Networked devices are increasingly common in our lives and our homes. In addition to accessing the internet on our home computers, we use other edge devices, such as televisions, tablets, smart phones and game consoles, to access web content. In California today, over 27 million small network devices support this type of information sharing. Network equipment consists of the devices whose primary purpose is to transport, route, switch, or process network traffic (Lanzisera, Nordman, & Brown 2010). Although the term network equipment is very broad in scope, this CASE report focuses on equipment that transmits network traffic and is typically (but not always) found in the home. We use ENERGY STAR®'s definition of small network equipment (EPA 2013a):

> Small network equipment is network equipment that is intended to serve users in either small networks or a subset of a large network. Small network equipment includes a) all network equipment with integral wireless capability and b) other network equipment meeting all of the following criteria:
>
> i. Designed for stationary operation;
>
> ii. Contains no more than eleven (11) wired physical network ports;
>
> iii. Primary configuration for operation outside of standard equipment racks;
>
> iv. Meets the definition of one or more of the product types defined below.[2]

We distinguish between two types of networks. A local area network (LAN) consists of network and edge devices that share information in a home or small business setting. A LAN typically includes one or more edge devices along with network devices such as switches, routers and access points.[3] Network devices such as modems connect the LAN to the wide area network (WAN). From the user's perspective, the WAN is the network beyond the walls of his or her home or small business.

The small network devices described in the product classes below draw two to tens of watts of power. In general, current small network equipment is always on and drawing full power. Thus typical unit energy consumption (UEC) of small network equipment ranges from approximately 20 to 200 kilowatt hours per year (kWh/yr).

3.2 Product Classes

We divide small network equipment into two categories of product classes: 1) broadband access equipment and 2) local network equipment (). DSL is digital subscriber line, ONT is optical network termination device, and IAD is integrated access device. The two primary types of DSL are Asymmetric digital subscriber line (ADSL) and Very-high-bit-rate digital subscriber line (VDSL).

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[2] We refer to these as product classes, as defined in Section 3.2.

[3] See Section 3.2 for a full description of product classes.

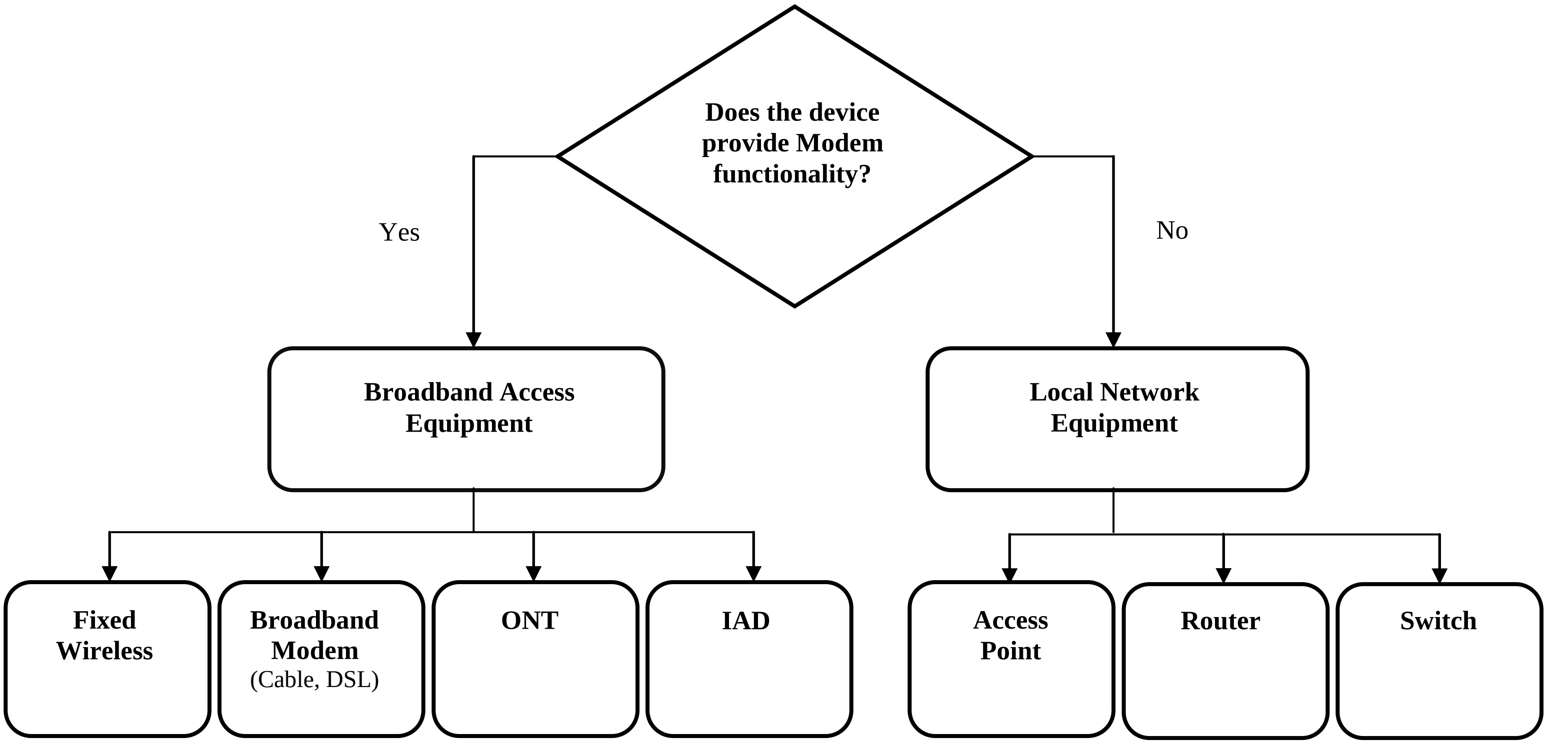

Figure 3.1 Classification of Residentially-focused Small Network Equipment Product Classes

Source: Modified from EPA (2013a, 2)

3.2.1 Broadband Access Equipment

Broadband Modem: A device that transmits and receives digitally-modulated analog signals over a wired or optical network as its primary function. The broadband modem category does not include devices with integrated router, switch, or access point functionality (EPA 2013a). A modem communicates with an internet service provider. A cable modem sends and receives broadband signals over the coaxial lines used by cable service providers to deliver pay TV service. A DSL modem does so over existing phone line infrastructure.

Figure 3.2 Example Broadband Modem

Source: Motorola (2012). Shown: 3360 High Speed DSL Modem for AT&T

Integrated Access Device (IAD): A network device with a modem and one or more of the following functions: network routing, multi-port Ethernet switching and/or access point functionality (EPA 2013a). Like modems above, an IAD communicates with either a cable or DSL service provider. Often IADs are marketed to consumers as gateways or broadband gateways.

Figure 3.3 Example Integrated Access Device

Source: NETGEAR (2012). Shown: CG3200 Cable Gateway for NETGEAR

Optical Network Termination Device (ONT): A modem or IAD that converts signals between an optical fiber connection and copper (wired) or wireless connections (Figure 3.4). ONTs are available in either desktop or building-mounted (EPA 2013a). Fiber to the home (FTTH) provides much higher data transfer speeds than DSL or cable service.

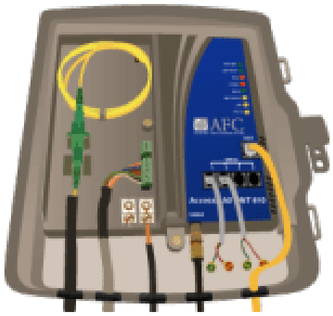

Figure 3.4 Example Optical Network Termination Device (ONT)

Source: Verizon (2012)

Fixed Wireless Broadband Access Device: A mains-powered device that enables broadband access via a wireless data connection. An example of one service provider implementing broadband via the cellular infrastructure is Clear (Clear 2013b).[4]

Figure 3.5 Example of Fixed Wireless Broadband Access Device

Source: (Clear 2013a)

3.2.2 Local Network Equipment

Router: A network device that determines the optimal path along which network traffic should be forwarded as its primary function (Figure 3.6). Routers assign IP addresses or recognize static IP addresses and forward packets from one network to another based on network layer information. Devices fitting this definition may provide both router functionality and wireless access capability (EPA 2013a). Most routers sold today are Wi-Fi routers with supplemental wired functionality.

[4] Fixed wireless represents only about 1.5% of fixed broadband subscribers (OECD 2013).

Figure 3.6 Example Router

Source: D-Link (2012c). Shown: DIR-835 Wireless N 750 Dual Band Router for D-Link

Access Point: A device that provides Institute of Electrical and Electronics Engineers (IEEE) 802.11 (Wi-Fi) connectivity to multiple clients as its primary function (EPA 2013a). An access point (Figure 3.7) extends the range of a wireless signal but does not assign IP addresses to networked devices and therefore cannot be used to connect multiple edge devices in the absence of a wired or wireless router. Many residential access points are referred to as range extenders.

Figure 3.7 Example Access Point

Source: D-Link (2012b). Shown: DAP-1525 Access Point MediaBridge for D-Link

Switch: A network device that forwards information to a specific device based on a destination address (Figure 3.8). Unlike a router, a switch does not assign a destination address. In general, a switch is used to extend a network's range or increase the number of devices that can connect with each other in the network.

Figure 3.8 Example Switch

Source: D-Link (2012a). Shown: DES-108 8-Port Fast Ethernet Metal Desktop Switch from D-Link.

3.2.3 Small Enterprise Network Equipment

In addition to the product classes outlined above, there is also small network equipment with 11 or fewer ports that is designed to primarily serve commercial markets. This equipment may be broadband access equipment or local network equipment, depending on functionality. This equipment is distinguished from the product classes outlined above based on one or more of the following characteristics:

- Device includes one or more modular network ports (e.g. small form factor pluggable) to allow expansion of the number of wired ports in use.
- Device is shipped without a power supply.
- Device requires a separate external access point controller for operation.

3.3 Scope of Products

We propose the California Energy Commission address two groups of small network equipment products with different policy approaches. For products where there is sufficient data available, we recommend mandatory energy efficiency performance standards. For the second group of products, we recommend the California Energy Commission require test and list to gather data.

The *scope* of products that we recommend for mandatory energy efficiency performance standards aligns scope with ENERGY STAR Version 1.0 Draft 3 (EPA 2013a). Small network equipment that meets one of the following equipment type definitions from Section 3.2 falls within the “mandatory energy efficiency performance standard scope”:

i. Broadband modem (Cable, DSL);
ii. Optical network termination device (ONT);
iii. Integrated access device (IAD);
iv. Router;
v. Switch; or
vi. Access point.

These product classes are the focus of the energy usage, market saturation and sales, savings potential, economic analysis and acceptance issues sections of this report, as these are the product classes that will enable energy savings to California rate payers.

We recommend the following products for test and list measures because there may be enough information available to enable a test procedure approach, but not enough data to support a standards level recommendation:

i. Small enterprise network equipment as defined in Section 3.2.3
ii. Fixed wireless broadband access device.

We recommend excluding large network equipment, which is significantly different from small residential and small enterprise networking equipment. Key technical differences require an alternate test procedure and possibly different approaches to efficiency metrics. Lastly, if a product has both network and set-top box functionality, then we categorize it as a set-top box.[5]

3.4 Additional Functionality

Small network equipment can be purchased with a variety of features and functions. Below we list the additional functions based on ENERGY STAR's approach:

Fast Ethernet (100Base-T): Fast Ethernet refers to data transfer speeds of 100 megabits per second (Mbit/s). 100Base-T is a collective term for Fast Ethernet standards that have transfer speeds of 100 Mbit/s.

Gigabit Ethernet (1000Base-T): Gigabit Ethernet refers to data transfer speeds of 1000 MBit/s, also described as 1 gigabit per second. 1000Base-T (also known as IEEE 802.3ab) is a standard for gigabit Ethernet over copper wiring.

Wi-Fi (802.11a/b/g/n): Wi-Fi allows an electronic device to exchange data wirelessly over a network. 802.11 is the family of specifications developed by the IEEE 802.11 committee which establishes standards for wireless Ethernet networks (WiFi Alliance 2012). 802.11 standards define the over-the-air interface between wireless clients and a base station, or access point that is physically connected to the wired network (WiFi Alliance 2012). The standard also includes data exchanged between two Wi-Fi-compliant devices.

Multi-input multi-output (MIMO) wireless home network interface (HNI): IEEE 802.11n/ac and related MIMO enabled Wi-Fi 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.[6]

Plain old telephone service: Traditional phone ports. RJ11/RJ14.

Energy Efficient Ethernet (EEE): IEEE 802.3az compliant Gigabit Ethernet ports reduce power draw when idling.

[5] We address set-top boxes with gateway functionality in the set-top box CASE report provided in a separate document.

[6] MIMO technology achieves higher data rates and greater reliability for the same transmit power through the use of a variety of techniques. Industry uses the TxR:S nomenclature to describe MIMO systems that support multiple spatial data streams. T represents the number of transmit antennas, R the number of receive antennas and S the number of spatial data streams. A 3x3:2 MIMO access point can transmit and receive 2 data streams on its 3 antennas. The majority of 802.11n clients available in the marketplace can transmit and receive 2 spatial streams. Source: Motorola (2009)

4 Manufacturing and Market Channel Overview

The overall market for small network equipment comprises component suppliers, hardware manufacturers and service providers, as well as other market actors such as distributors and retailers. Hardware manufacturers design and produce small network equipment across all product classes. Service providers offer subscribers access to the internet as part of a service package. Sometimes these packages also include pay-TV and telephone services (i.e. “triple play” packages).

The distribution channels for local network equipment and broadband access equipment vary. Figure 4.1 shows the primary distribution models for both local network equipment and broadband access equipment. Most consumers purchase local network equipment such as routers, switches and access points through traditional retail and e-tail channels. For broadband access equipment, however; service providers purchase small network equipment to supply to end consumers —often leasing out the equipment for a monthly fee. This is particularly common for devices that integrate multiple functions and connect directly to the service provider WAN, such as IADs.

Primary local network equipment distribution model for small network equipment

Primary broadband access equipment distribution model for small network equipment

Figure 4.1 Small Network Equipment Distribution Channels

The timeframe between new small network equipment product generations is typically 12 to 18 months (Infonetics 2012a). The fast-paced market for system-on-a-chip is driving rapid design cycles within small network equipment. Suppliers develop new system-on-chip solutions frequently. In many cases, the development cycles for suppliers’ reference designs are ahead of high-end small network equipment (Infonetics 2012a).

We provide additional small network equipment market information in the following tables. There are eight major manufacturers of broadband access equipment and five major manufacturers for local network equipment. Table 4.1 shows estimated U.S. manufacturer market share for broadband access equipment in 2011. Table 4.2 shows estimated U.S. manufacturer market share for local network equipment in 2011. Table 4.3 shows major internet service providers in the U.S. in 2013. While certain manufacturers and service providers may operate differently in California, we assume that California has a consistent market makeup as the rest of the country.

Table 4.1 Broadband Access Equipment Market Share by Units, 2011

Manufacturers	Market Share (%)
Pace	18
ARRIS	18
Motorola	13
NETGEAR	11
Cisco	9.2
ZyXEL	7.3
Ubee Interactive	5.8
Actiontec	5.1
Other	12

Source: Infonetics (2012b)
Note: percentages do not add to 100 due to independent rounding

Table 4.2 Local Network Equipment Market Share, 2011

Manufacturers	Market Share (%)
NETGEAR	27
Cisco	23
Belkin	17
Actiontec	10
D-Link	9.4
Other	13

Source: Infonetics (2012b)
Note: percentages do not add to 100 due to independent rounding

Table 4.3 Major U.S. Internet Service Providers, 2013

Service Provider	Subscribers (millions)
AT&T	17.8
Comcast	17.0
Time Warner	9.7
CenturyLink	6.5
Cox	6.0
Charter	5.5
Verizon	4.3

Source: ISP (2013)
Note: Fixed wireless represents only about 1.5% of fixed broadband subscribers (OECD 2013).
Note: This table represents U.S. major service providers but is not intended to account for the total number of broadband subscribers in the U.S.

5 Energy Usage

5.1 Test Methods

5.1.1 Current Test Methods

Although a number of technical standards related to various network technologies exist, there is a limited body of work on test procedures specific to measuring the energy use of network devices themselves. ENERGY STAR developed a small network equipment test procedure, building off test procedures for enterprise network equipment and other international procedures. We review these test procedures below, and conclude this section by recommending the ENERGY STAR test procedure with some additions.

ENERGY STAR

ENERGY STAR completed its small network equipment final draft test method in November 2012 (EPA 2012d). The test method measures three power states (where applicable):

> **Wide area network (WAN) measurement.** Measured power consumption in wired network – WAN test, at 1.0 kb/s;

Local area network (LAN) measurement. Measured power consumption in wired network – LAN test, half of available wired LAN ports populated, at 1.0 kb/s;

Wireless measurement. Measured power consumption in wireless network – LAN test, at 1.0 kb/s.[7]

The ENERGY STAR test method calculates the average power consumption (P_{AVG}) for the unit under test, the primary metric of the specification, using the following calculation:

$$P_{AVG} = \text{Average}\,[P_{WAN\_TEST},\ P_{LAN\_TEST},\ P_{WIRELESS\_TEST}]$$

Where:

- Average[x_i] = Average of terms (xi) applicable to the UUT;
- P_{WAN_TEST} = Measured power consumption in wired network – WAN test, at 1.0 kb/s (W);
- P_{LAN_TEST} = Measured power consumption in wired network – LAN test, half of available wired LAN ports populated, at 1.0 kb/s (W);
- $P_{WIRELESS\_TEST}$ = Measured power consumption in wireless network – LAN test, at 1.0 kb/s (W)

By averaging the power of the device in up to three operating modes, ENERGY STAR assigns equal importance and weight to each mode.

5.1.2 Other Test Procedures and Technical Standards

In 2009, The American National Standard for Telecommunications developed ATIS-0600015 (ANSI 2009) to help determine the energy efficiency of telecommunications equipment. The standards introduce the Telecommunications Energy Efficiency Ratio (TEER) as a measurement of network-element efficiency. The standards use a weighted approach for measuring energy consumption, uniformly quantifying a network component's ratio of "work performed" to energy consumed (IHS 2009). The scope of ATIS 0600015 addresses large, enterprise-class network equipment and is not directly applicable to small network equipment but useful as a resource (EPA 2009b).

The Energy Consumption Rating (ECR) Initiative is a framework for measuring the energy efficiency of network and telecom devices (ECR 2012). ECR developed its *Network and Telecom Equipment—Energy and Performance Assessment* (ECR 2010) which includes efficiency metrics, test procedure and measurement methodologies for network equipment. ECR's test procedure addresses measurement of typical power consumption of network equipment using a weighted power approach (EPA 2009b). Like that of ATIS-0600015, the scope of ECR (2010) addresses large, enterprise-class network equipment and may be useful as a resource but is not directly applicable to small network equipment (EPA 2009b).

The International Electrotechnical Commission's (IEC) standard, IEC 62301, specifies methods of measurement of electrical power consumption in standby mode(s) and other low power modes (e.g. off mode and network mode), as applicable (IEC 2011). The test voltage and power analyzer requirements from IEC62301 are often cited by the ENERGY STAR program (EPA 2009b).

[7] A wired Ethernet WAN port is connected for this measurement.

The European Commission *Code of Conduct on Energy Consumption of Broadband Equipment* (EC 2008) references the following test method: Technical Specification ETSI ES 102 533 *Environmental Engineering (EE); Measurement Methods and limits for Energy Consumption in Broadband Telecommunication Networks Equipment*.

Japan's Ministry of Economy, Trade and Industry (METI) developed a detailed test method, presented in Japan's Top Runner program documentation (Top Runner 2008), for small routers and Layer 2 (L2) switches that evaluates transmission efficiency (EPA 2009b).[8,9] Energy efficiency is evaluated in units of watts/bit/second.

5.1.3 Proposed Test Methods

The California IOUs recommend that the CEC adopt the ENERGY STAR small network equipment test procedure in conjunction with the proposed standard. The ENERGY STAR test procedure is the best choice because it includes procedures for measuring power for a wide range of small network product classes and because adoption of the ENERGY STAR approach enables us to have access to recent product test measurements and a vetted approach to efficiency metrics. Given the lack of specific configuration information available to distinguish among the different states outlined in the ENERGY STAR test procedure, we also recommend the ENERGY STAR P_{AVG} as the metric for the California standards. We also recommend the Energy Commission work with industry to develop test procedure modifications to support test and list of products outlined Section 3.2 of this document. Specifically, we recommend the following modifications to the ENERGY STAR test procedure:

- Add language that specifies the order of precedence of port type for modular ports to enable test and list of network equipment with one or more modular network ports (e.g. small form-factor pluggable (SFP)).
- Expand the scope and adjust the approach of the test procedure to include devices marketed and sold as enterprise network equipment that also meet one or more of the following additional criteria: a) is shipped without a power supply, or b) requires a separate external access point controller for operation.
- Consider test procedure approach needed to measure, for test and list purposes, fixed wireless broadband access equipment.

5.2 Baseline Energy Use Per Product

The California IOUs developed a small network equipment 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

Although the average number of ports connected to a small network device and the amount of data transfer through those ports is relatively unknown, the basic operating pattern of small network

[8] Japan created its Top Runner program in 1998 to improve the energy efficiency of its end-use products and to "develop the world's best energy-efficient products" (Kimura 2010). It is considered one of the major pillars of Japanese climate policy (Kimura 2010).

[9] Layer 2 switches work on Data-Link layer of Open Systems Interconnection Model. For more information see ISO/IEC 7498-1, available http://www.ecma-international.org/activities/Communications/TG11/s020269e.pdf.

equipment is fairly straightforward: the device is always powered on and ready to provide internet or network access (Urban, Tiefenbeck, & Roth 2011).[10] Prior studies (Lanzisera, Nordman, & Brown 2010; Roth, Ponoum, & Goldstein 2006) assume network devices are powered on 24 hours a day, 365 days a year with a constant power draw. We use this assumption in our analysis throughout the CASE report.

5.2.2 Unit Energy Consumption

The UEC of a small network device is a function of power levels and duty cycle. For this analysis, we used a public list of power and features data provided by manufacturers and NRDC to ENERGY STAR in support of the development of their small network equipment specification. Using the published ENERGY STAR dataset (EPA 2013b), we calculated UEC assuming that the average power of a device is represented by the ENERGY STAR P_{AVG} metric. We used the average because we lack sufficient information to stipulate a more specific weighting of user device configuration. After determining the proposed standard level (Section 5.4), we calculated UEC for the average non-compliant and compliant device in each product class. Table 5.1 shows the average UEC for non-qualifying small network equipment in 2013, categorized by product class.

Table 5.1 Average Energy Use for Non-Compliant Products[11]

Product Class		Average Power Draw (W)[a]	Average Unit Electricity Consumption (kWh/yr)	Range of Unit Electricity Consumption (kWh/yr)
Broadband Access Equipment	Broadband Modem, Cable	6.7	59	53-68
	Broadband Modem, ADSL	5.4	47	35-59
	ONT	7.1	62	44-81
	IAD Cable	8.0	70	49-96
	IAD ADSL	7.3	64	43-98
	IAD VDSL	10.8	95	75-133
Local Network Equipment	Access Point	6.2	54	18-133
	Router	7.8	68	40-124
	Switch	6.9	61	10-204

[a] Using P_{AVG} metric described in Section 5.1.1

[10] In addition, most small network equipment automatically turns on when plugged into a power source.

[11] The test and list group values are unknown.

5.3 Efficiency Measures

In general, each new generation of network equipment benefits from advances in the silicon manufacturing process that enable increased silicon efficiency. These advancements enable next generation silicon tends to use less power to deliver the same function when compared to current technology. These advancements and refinements help support reduced power use overall. Additional improvements in power conversion efficiency in both internal and external power supplies used to power small networking equipment are another cross-cutting opportunity to improve efficiency.

In addition to these broad opportunities for all small networking equipment, there are additional emerging opportunities to improve efficiency of small networking equipment functionality, including:

- Wired LAN functionality efficiency improvement
- Wi-Fi LAN functionality improvement
- Broadband access device efficiency improvement

Lastly, through network proxy there are opportunities for small network equipment to support reduced energy use of other devices on a network, such as printers and computers.

Wired LAN functionality improvement

IEEE 802.3az Energy Efficient Ethernet (EEE) is the primary means for achieving power scaling in devices with wired LAN functionality. Ratified in 2010, EEE enables Ethernet ports and system components to enter a sleep mode called low power idle (LPI) in between data packets when transmitting at less than maximum data rate and both ends of the network link support have EEE enabled. EEE does this without impacting the performance of consumer computing applications. Industry expects near term savings from first generation EEE devices to be 5 to 20 percent of system power at low data rate. Next generation network silicon, designed with power islands, voltage scaling and other power saving approaches, could possibly save up to 80 percent of system power (Cisco 2011). These savings may more than offset the increase in power draw resulting from the market shift to gigabit per second Ethernet devices.

Illustrated in Figure 5.1, EEE allows the networking device to use less power when not transferring data. The device wakes up to the fastest interface when traffic comes in, and is able to transfer the data in a matter of microseconds. Even at considerable average data transfer rate, the low power idle time can be milliseconds, meaning that the device would be in low power idle 99.9% of the time. This saves significant energy.

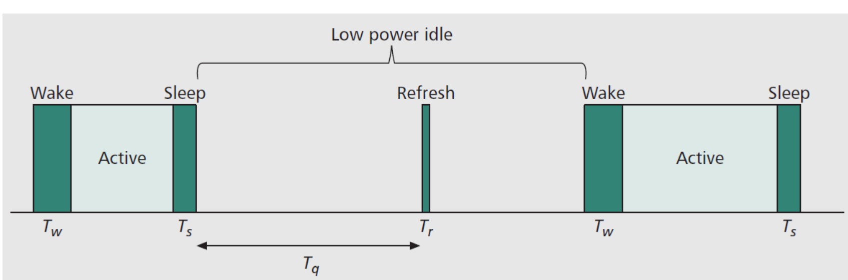

Figure 5.1 Sleep Schedule for Devices with EEE

Source: Christensen et al. (2010, 51).

To benefit from EEE, the devices on both ends of an Ethernet connection, for example a router and a computer, must have EEE enabled. If an EEE-capable router is connected to one EEE-capable computer and another computer without EEE enabled, the router port connected to the EEE computer will scale power to use, and the port connected to the other PC will not scale power to use. Manufacturers enable EEE by default on most compliant network devices. However, EEE was not default-enabled on half of the EEE-capable computers we tested.[12] Moreover, it is difficult to find the software setting to enable it. We confirmed in our lab that network devices that had EEE drew less power when transferring data with EEE enabled and more power when transferring data with EEE disabled.

Wi-Fi LAN functionality

Wi-Fi power scaling technologies are emerging as well. IEEE 802.11ac, a recently ratified Wi-Fi standard targeted at providing a high quality media sharing experience within the home, delivers data rates measured in gigabits per second at lower power for equivalent data rates to 802.11n. 802.11ac does this through the use of more efficient encoding mechanisms, and the ability to transmit more data with fewer transmission chains (i.e., transmitter and antennae) (WildPackets 2012).

Proprietary power scaling technologies also exist. One manufacturer, Trendnet, has introduced a suite of energy saving features, labeled Green Wi-Fi, that can reportedly save energy by enabling Wi-Fi routers to a) operate at reduced power when no Wi-Fi clients are connected, b) reduce their signal strength when connected clients are in close range, and c) enter a low power states between packets without affecting performance. Trendnet reports that their Green Wi-Fi products use 66 percent less power when unassociated with a Wi-Fi client and 53 percent less when connected but not transferring data (TRENDnet 2011).

Figure 5.2 illustrates the power break-down when comparing an inefficient router to a future router with similar functionality that incorporates next generation wired and Wi-Fi power scaling. We assume a typical use case where the router is on and connected to a broadband modem through the wide area network (WAN) Ethernet port, to one idle Ethernet client, perhaps a printer, through the local area network (LAN) port, and to one or more Wi-Fi clients that are not actively transferring content. In other words the home network is ready to use but not actively doing anything at the moment.

[12] None of these computers were ENERGY STAR qualified.

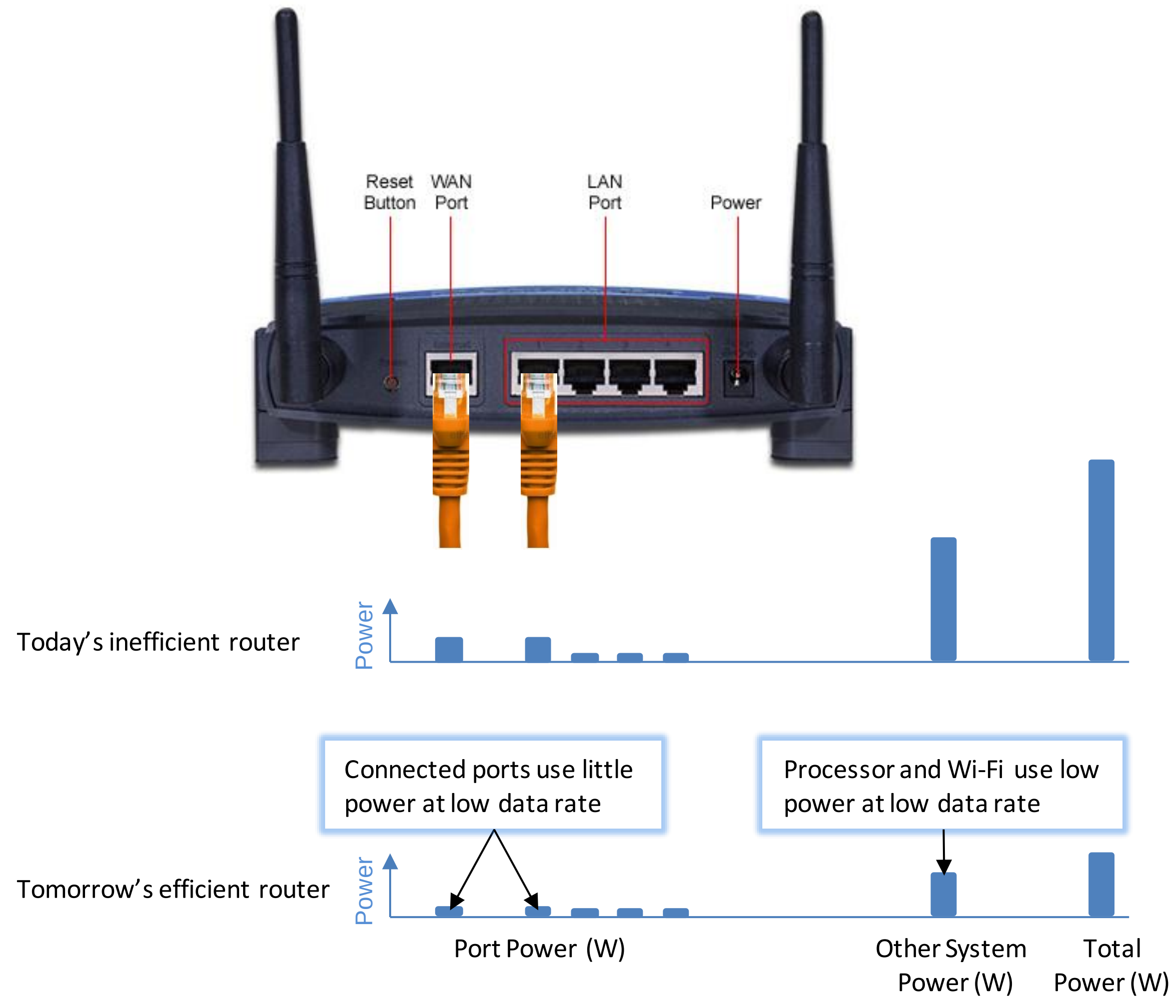

Figure 5.2 Conceptual savings example

Broadband access functionality

Technologies focused on enabling power scaling of broadband access functionality of cable and DSL broadband access functionality are under development. Although not widely deployed today, these technologies have significant potential for energy reduction of small network equipment in the future.

As part of its energy efficiency initiative, the cable industry has published a paper on power scaling implementations for cable modems (CableLabs® 2013). In basic terms, this paper proposes an approach that would enable cable modems to:

- Enter low power (i.e., 1 channel upload and 1 channel download (1x1)) mode if a modem is transmitting <= 1.5 Mbps downstream (minimum needed to stream a Netflix movie) for more than 5 minutes, and
- Exit 1x1 mode if a modem needs to transmit >= 2 Mbps downstream for more than 2 seconds.

The report (CableLabs® 2013) did not estimate wake latency, but it does recognize that wake time would have to be short in order to meet user needs. The report estimates that modems could spend 80% in low power mode. User behavior is not the only factor in determining when modems enter low power mode. The central cable modem termination systems (CMTSs) are unable to support simultaneous wake in response to a large number of modems, so each service provider would develop policies that maximize the use of low power mode while guarding against a scenario where the CMTSs are flooded by modem wake (i.e., provisioning) events.

There has also been research on sleep modes for DSL broadband functionality (Kamitsos et al. 2011; Bonetto et al. 2012).

In summary, the efficiency opportunities in this section would impact the following small network equipment product classes proposed for minimum energy performance standards (Table 5.2).

Table 5.2 Technological opportunities for improving small network equipment power use

Product Class		**Core silicon improvements and power supply**	**Power scaling of wired LAN functionality (EEE)**	**Power Scaling of Wi-Fi LAN functionality**	**Power scaling of broadband access functionality**
Broadband Access Equipment	Broadband Modem, Cable	Yes	Yes		Yes
	Broadband Modem, ADSL	Yes	Yes		Yes
	ONT	Yes	Yes	Maybe, depending on function	
	IAD Cable	Yes	Yes	Maybe, depending on function	Yes
	IAD ADSL	Yes	Yes	Maybe, depending on function	Yes
	IAD VDSL	Yes	Yes	Maybe, depending on function	Yes
Local Network Equipment	Access Point	Yes	Yes	Yes	
	Router	Yes	Yes	Maybe, depending on function	
	Switch	Yes	Yes		

Network Proxy

A network connection proxy is an "entity that maintains network presence for a sleeping higher-power host" (Ecma International 2012, 3). This technology allows a device, such as a computer or router, to go to sleep without losing network connectivity. To do so, the proxy intercepts any message sent to the edge device and decides whether to discard the message, reply to the message or wake the computer up to decide what to do (Jimeno, Christensen, & Nordman 2008). As a result, the proxy allows the host to sleep longer, increasing energy savings. Network connection proxying has two key advantages over its predecessor, wake-on-LAN technology. First, proxying does not require other devices in a LAN to know that a given device is sleeping. Second, proxying works across both LAN and WAN devices. Ecma International, a non-profit standards organization, approved the ProxZzzy™ standard for sleeping hosts in February 2010, including instructions for handling EEE, which allows the technologies to operate together. In its Version 5.2 specification for computers, ENERGY STAR adopted proxying as a functional allowance (EPA 2012a).

5.4 Standards Case Energy Use per Product

The California IOUs propose to establish limits on power draw of devices using the same framework and metrics as the draft ENERGY STAR Version 1.0 program requirements for small network equipment (EPA 2013a). We considered international policies in addition to the ENERGY STAR framework, and selected ENERGY STAR as a starting point for a number of reasons:

- Other international programs, such as Japan's Top Runner and South Korea's e-Standby program are not as comprehensive in scope as the ENERGY STAR Program. The European Code of Conduct approach is more comprehensive, but there are no U.S. data available for these additional product classes on which to base a proposal. Europe's Lot 26 requirement is much broader than ENERGY STAR, but it establishes horizontal power levels across all products that have a network standby mode, and thereby delivers less energy savings for product classes that are able to achieve lower standby power levels than other product categories.
- The ENERGY STAR program was developed for the U.S. market, and so is best suited for adoption in California.
- The ENERGY STAR approach has been vetted by U.S. industry stakeholders and was recently developed with the best available data.

The proposed standard includes a maximum power allowance for (i) base functionality and (ii) additional functionalities of the unit. The maximum average power (P_{AVG_MAX}) for the unit under test, its total power allowance, is determined using the following equation:

$$P_{AVG\_MAX} = P_{BASE} + \sum_{i=1}^{n} P_{ADDi}$$

Where:

P_{BASE} = Base power allowance (W) from Table 5.2Table 5.3

P_{ADDi} = The power allowance (W) as specified in Table 5.4 for each feature present in the device, for a total of n such allowances.

Average power of a given device is calculated using the ENERGY STAR formula:

$$P_{AVG} = \text{Average}\,[P_{WAN\_TEST}, P_{LAN\_TEST}, P_{WIRELESS\_TEST}]$$

Where:

P_{WAN_TEST} = Measured power consumption in wired network – WAN test, at 1.0 kb/s (W);

P_{LAN_TEST} = Measured power consumption in wired network – LAN test, half of available wired LAN ports populated, at 1.0 kb/s (W);

$P_{WIRELESS\_TEST}$ = Measured power consumption in wireless network – LAN test, at 1.0 kb/s (W)

Comparing the average power (P_{AVG}) of a small network product to its total power allowance (P_{AVG_MAX}) determines its qualification with the standard (i.e. it cannot exceed P_{AVG_MAX}).

We propose levels within the ENERGY STAR framework that are different and generally more stringent than ENERGY STAR. ENERGY STAR selects its levels largely based on 25 percent market penetration, whereas we propose levels based on maximizing the cost-effective energy savings to California ratepayers. The levels proposed:

- Have a near zero incremental cost (see "Economic Analysis Section 8.1").
- Enable products with the newest features to comply. Products that comply with the proposed standard are, in general, slightly higher featured than non compliant products.
- Allow a slightly higher power adder relative to ENERGY STAR for Wi-Fi 802.11n/ac
- Enable approximately 17 percent of the products tested meet the proposed standard levels.

The proposed standard level in each product class can be met with current, market-available technology. Expected widespread adoption of energy efficient Ethernet in small networking equipment will facilitate compliance with the proposed standard. Neither improved Wi-Fi, nor broadband power scaling outlined in the efficiency measures (section 5.3) are required to meet the proposed standard although these technologies would support efficient improvements for products.

Table 5.3 Proposed Base Power Allowances

Product	Proposed CASE Level
	P_{BASE} (watts)
Broadband Modem, Cable	5.7
Broadband Modem, ADSL	3.5
ONT	3.4
IAD – Cable	4.0
IAD – ADSL	4.2
IAD – VDSL	6.9
Access Point	1.5
Router	3.0
Switch	0.1

Table 5.4 Proposed Additional Functions Power Allowances

Function	Proposed CASE Level P_{ADD} (watts)	Notes
Fast Ethernet (100Base-T)	0.1	Allowance applied once per port present in the UUT.
Gigabit Ethernet (1000Base-T)	0.2	Allowance applied once per port present in the UUT.
Wi-Fi (802.11a/b/g/n)	0.3	Allowance applied once for the UUT for availability of Wi-Fi connectivity.
Wi-Fi (802.11n per receive chain)	0.1	Allowance applied to total number of 2.4 GHz and 5.0 GHz 802.11n receive chains. Only applicable for products that ship with simultaneous dual band Wi-Fi enabled.
Wi-Fi (802.11ac per receive chain)	1.9	Allowance applied to 5.0 GHz 802.11ac receive chains only. Only applicable for products that ship with simultaneous dual band Wi-Fi enabled.
Plain old telephone service (RJ11/RJ14)	0.3	Allowance applied once per port, up to a maximum of two ports.
EEE	0.2	Applied to each EEE capable Gigabit port

5.4.1 Secondary Standards Criteria

Although not included in savings estimates in this proposal, the CEC could create an additional incentive for external proxy as done in the ENERGY STAR small network equipment specification (EPA 2013a). The maximum savings associated with this incentive would only be realized if all devices on the network are able to operate according to the protocol.[13] The ENERGY STAR specification includes different levels of incentives depending on the different levels of external proxy.[14]

In addition to the mandatory standard, we also propose the CEC adopt a test and list requirement for small enterprise network equipment and fixed wireless broadband access devices. Descriptions of these product classes can be found in section 3.2.

5.4.2 Standards Case Unit Energy Consumption

For each product class, we calculated average UEC for devices compliant with the proposed standard by averaging P_{AVG} of all devices in ENERGY STAR's published dataset (EPA 2013b) tested that meet the proposed allowances presented in section 5.4. Power draw of the average compliant product is as much as 5 W less than that of the average non-compliant product.

[13] In other words, savings from network proxy are achieved when both the network and the edge device support external proxy capabilities and these capabilities are enabled.

[14] For key definitions related to network proxy, see Appendix D.

Table 5.5 Average Energy Use for Compliant Products

Product Class		Average Power Draw (W)	Average Unit Electricity Consumption (kWh/yr)	Range of Unit Electricity Consumption (kWh/yr)
Broadband Access Equipment	Broadband Modem, Cable	5.7	50	50*
	Broadband Modem, DSL	3.5	30	30*
	ONT	3.8	33	26-39
	IAD Cable	3.6	32	25-38
	IAD ADSL	4.8	42	42*
	IAD VDSL	8.1	70	67-74
Local Network Equipment	Access Point	1.8	16	16*
	Router	5.2	46	15-85
	Switch	1.9	16	8-27

[a] Using P_{AVG} metric described in Section 5.1.1
*single product

6 Market Saturation & Sales

6.1 Current Market Situation

In the U.S., the vast majority of homes with broadband internet receive it through cable, DSL or FTTH. These technologies vary in speed and geographical availability. In California, there are over 10 million households with broadband internet service (Figure 6.1), each requiring at least one piece of small network equipment to service the home.

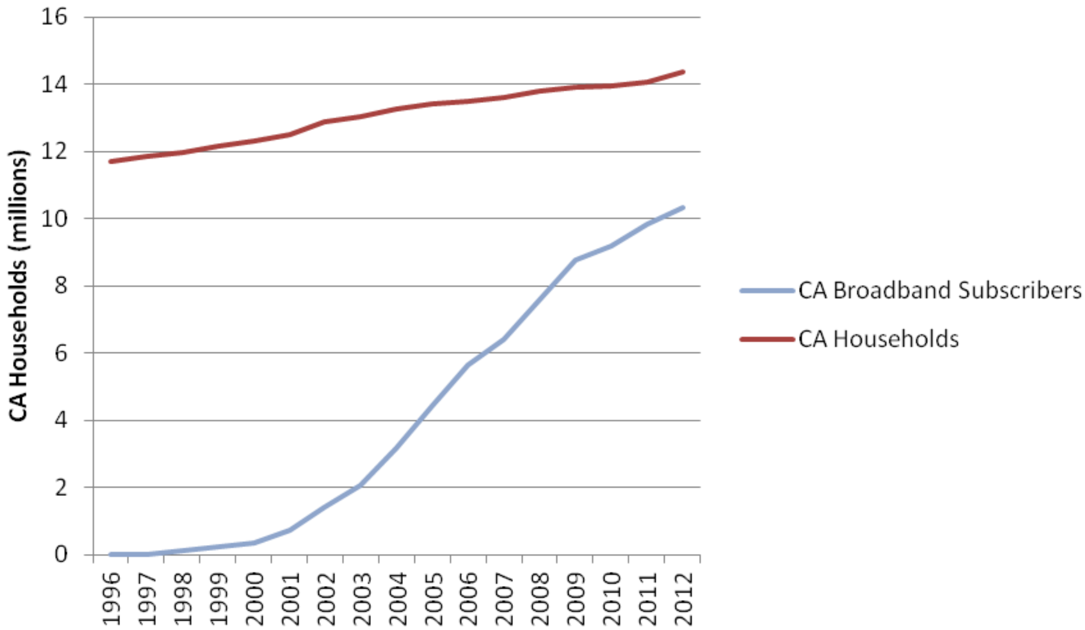

Figure 6.1 California Trends in Broadband Subscribers, 1996-2012

Source: Ecova analysis of OECD (2012) and U.S. Census (2012). We scale national data to California by a factor of 0.12, based on the ratio of California population to U.S. (U.S. Census 2012).

Below we summarize four primary trends occurring in the small network equipment market:

- **Increased fiber optic installations**. Fiber optics are replacing DSL and competing with cable internet service providers. Fiber optic cable all or part way to the home offers faster connections to subscribers compared with standard copper phone cables. More geographic locations, mainly metropolitan areas, now offer fiber technology.
- **Integration of discrete networking products**. IADs are growing in popularity. For example, instead of standalone modems, service providers are more frequently supplying customers with a single IAD device that also incorporates Wi-Fi, Ethernet, and VoIP phone services.
- **Movement away from wired devices**. Sales of wired local network equipment are dropping while sales of wireless local network equipment continue to increase.
- **Emergence of fixed wireless technology**. Wireless broadband technologies like WiMAX enable internet service providers to serve both mobile clients and fixed wireless customers with broadband access speeds on par with ADSL. WiMAX combines the performance of Wi-Fi with the range and quality of service of a carrier-grade cellular technology (WiMAX 2013). While WiMAX and related technologies are broadly used to connect laptops and other mobile edge devices to the network, fixed implementations are much less common representing 1.5% of total fixed broadband connections worldwide (OECD 2013).

6.1.1 Baseline Case

The California IOUs developed a small network equipment 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 5.2.2 for information covering the energy aspects of the model).

We obtained U.S. sales and sales forecast data for each product class from Infonetics (Infonetics 2012b, 2013) for 2005-2016. We estimate sales for 2017-2020 by continuing Infonetic's sales trends, using a best-fit (least squares) linear regression forecast. The forecast returns a prediction of a future value based on existing values provided. In other words, we assume that growth in sales will continue in a similar fashion from 2017-2020 as it did from 2005-2016. In addition, not all devices sold are used. Lanzisera, Nordman, and Brown (2010) estimate that about 5 percent of devices purchased are held in reserve or otherwise not powered. Following their reasoning, we assume that 95 percent of devices sold are powered and used by subscribers. Because 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).[15] Supplemental market data in provided in Appendix A in this report.

Table 6.1 shows estimated California sales for small network equipment in 2013. These devices make up the cohort of small network equipment requiring compliance with the proposed standard after effective date. The energy use data and assumptions of these new devices are explained in Section 7.1.

[15] We chose to scale based on CA population rather than number of CA households, assuming that the number of small network equipment devices existing in CA is dependent more on population than number of households.

Table 6.1 Estimated California Sales, 2013

Product Class		Annual Sales (units)	Source
Broadband Access Equipment	Broadband Modem, Cable	730,000	Infonetics (2012b)
	Broadband Modem, ADSL	4,900	
	ONT	200,000	
	IAD Cable	1,000,000	
	IAD ADSL	780,000	
	IAD VDSL	150,000	
Local Network Equipment	Access Point	200,000	Infonetics (2013)
	Router	2,200,000	Infonetics (2012b)
	Switch	140,000	Infonetics (2013)
	Total	**5,400,000**	

We scale US sales estimates to CA based on 0.12 population factor (U.S. Census 2012).
VDSL IAD sales estimates include estimates for VDSL modems.

We estimate California stock (i.e. installed-base) for each product class based on Infonetics sales data (Infonetics 2012b, 2013). In order to estimate stock for California in 2013, we multiply the sales data for each product class shown in Table 6.1 by a 5-year design life estimate.[16] In general, we observe relatively minimal change in overall market growth over the past five years based on analysis of Infonetics sales data (Infonetics 2012b, 2013).

Table 6.2 shows estimated California stock for small network equipment in 2013.

[16] We explain design life estimates in more detail in Section 8.2.

Table 6.2 Estimated California Stock, 2013

Product Class		Stock (units)	Notes and Source
Broadband Access Equipment	Broadband Modem, Cable	3,600,000	Based on sales estimate from Infonetics (2012b) shown in Table 6.1, multiplied by 5-year design life.
	Broadband Modem, ADSL	24,000	
	ONT	1,000,000	
	IAD Cable	5,100,000	
	IAD ADSL	3,900,000	
	IAD VDSL	750,000	
Local Network Equipment	Access Point	980,000	Based on sales estimate from Infonetics (2013) shown in Table 6.1, multiplied by 5-year design life.
	Router	11,000,000	Based on sales estimate from Infonetics (2012b) shown in Table 6.1, multiplied by 5-year design life.
	Switch	710,000	Based on sales estimate from (Infonetics 2013) shown in Table 6.1, multiplied by 5-year design life.
	Total	**27,100,000**	

Table 6.3 shows growth rates for small network equipment sales. We calculate compound annual growth rate (CAGR) for sales from 2009-2012 (Infonetics 2012b, 2013). Over this period, sales of cable and ADSL modems, ADSL IADs, and routers decline, while that of cable and VDSL IADs increase. In general, we observe a shift from ADSL devices to VDSL devices (which offer faster data transmission than ADSL) based on analysis of Infonetics (2012b). ONT growth remains flat during the analysis period.

Table 6.3 California Compound Annual Growth Rate (CAGR) for Sales of Small Network Equipment, 2009–2012

Product Class		CAGR (%) 2009-2012
Broadband Access Equipment	Broadband Modem, Cable	-1%
	Broadband Modem, ADSL	-70%
	ONT	0%
	IAD Cable	11%
	IAD ADSL	-2%
	IAD VDSL	2%
Local Network Equipment	Access Point	n/a
	Router	-1%
	Switch	n/a

Source: Ecova analysis of Infonetics (2012b, 2013)
CAGR for Access Points and Switches unavailable for these years

6.1.2 High Efficiency Options

Current high efficiency options for small network equipment vary by manufacturer and product class. Because market share data for high efficiency options were not available, we estimated compliance rates (i.e. products meeting the standard level) for each product class in 2013 based on the compliant/non-compliant ratio of our analysis. Table 6.4 shows estimated proposed standard compliance rate for sales of new small network equipment in 2013. An estimated 17 percent of sales of new small network equipment in 2013 meet the proposed standard levels.

Table 6.4 California Proposed Standard Compliance Rates for 2013 Sales

Product Class		Compliance Rate (%)
Broadband Access Equipment	Broadband Modem, Cable	13%
	Broadband Modem, DSL	17%
	ONT	11%
	IAD Cable	25%
	IAD ADSL	11%
	IAD VDSL	25%
Local Network Equipment	Access Point	8%
	Router	18%
	Switch	24%
	Total[a]	**17%**

[a] Weighted by 2013 sales estimates based on analysis of data from Infonetics (2012b, 2013)

6.2 Future Market Adoption of High Efficiency Options

Small network equipment may integrate several energy-saving improvements in the coming months and years. ENERGY STAR's specification (EPA 2013a) is in its third draft at the time of this report with a planned effective date of summer 2013. The specification provides incentive for manufacturers to reduce energy use of small network devices. Products with power saving technology (e.g. EEE) are already on the market, and the market share of these devices may increase once the ENERGY STAR specification is finalized. This may create high market penetration of ENERGY STAR product in the switch category. Other categories may benefit from improved silicon, and possibly power scaling for wireless, but changing compliance over time will likely be slower than for switches.

Although market trends may reduce energy use, the proposed standard will help California achieve greater energy savings for the following reasons:

- Service providers distribute most broadband access equipment to consumers. The consumer has little if any ability to choose an energy efficient device in this distribution channel. Given this lack of choice, consumers have less opportunity to drive the market to ENERGY STAR labeled devices. That market driver will be dependent upon service providers.

- To realize savings from EEE, both the network device and the edge device(s) it is connected to must have EEE enabled. A mandatory standard will support widespread adoption of EEE in network devices, increasing the savings associated with EEE-enabled edge devices.
- A mandatory standard would require manufacturers to reduce energy use of all small network equipment beyond the currently proposed ENERGY STAR levels.
- A mandatory standard may encourage the development of new energy saving technologies.

7 Savings Potential

7.1 Statewide California Energy Use

The California IOUs developed a small network equipment 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 energy use data are applied to market data to estimate statewide California energy use.

Beginning in 2013, the model calculates the new cohort of small network equipment purchased in a given year using estimated California sales data presented in Table 6.1 and described in Section 6.1.[17] The estimated energy use of each new annual cohort of small network equipment is a variable mix of devices that are compliant and non-compliant with the proposed standard. Our analysis model utilizes power and energy data from ENERGY STAR (EPA 2013b) to determine the estimated energy use of compliant and non-compliant small network devices used to inform statewide energy use:

1. **Compliant small network devices.** These are small network equipment already compliant with the proposed standard today.[18] Table 5.5 shows the average UEC of compliant small network equipment. The UEC of compliant small network equipment does not change over time. However, the share of annual sales of compliant small network equipment *increases* over time. This varies for each product class based on market trends and industry initiatives.
2. **Non-compliant small network devices.** These are small network devices that do not comply with the proposed standard today. Table 5.1 shows the average UEC of non-compliant small network equipment. The UEC of non-compliant small network equipment does not change over time. However, the share of annual sales of non-compliant small network equipment *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 small network equipment in California consumes a combined 1,700 GWh/year and today's annual sales of small network equipment consume an estimated 340 GWh/year. Table 7.1 shows current energy use for estimated sales and stock in 2013. The UEC for each product category was multiplied by the appropriate sales or stock

[17] It is important to note that sales data is the primary driver in determining future, statewide energy use of small network equipment after 2013. Market data for today's stock, on the other hand, is generally used to provide a snapshot of today's estimated energy of small network equipment installed-base.

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

data in each year (from Table 6.1 and Table 6.2) to generate the energy use estimates shown in Table 7.1.

Table 7.1 California Statewide Baseline Energy Use – Current Year

Product Class		Annual Sales (2013)		For Entire Stock[b] (2013)	
		Coincident Peak Demand (MW)[a]	Annual Energy Consumption (GWh/yr)	Coincident Peak Demand (MW)	Annual Energy Consumption (GWh/yr)
Broadband Access Equipment	Broadband Modem, Cable	5.2	42	26	210
	Broadband Modem, ADSL	0.027	0.22	0.13	1.1
	ONT	1.5	12	7.5	60
	IAD Cable	7.7	62	38.5	310
	IAD ADSL	6.7	54	33	270
	IAD VDSL	1.7	13	8.3	66
Local Network Equipment	Access Point	1.3	10	6.3	50
	Router	17	139	86	700
	Switch	0.88	7.1	4.4	36
	CA Total	**42.2**	**340**	**211**	**1700**

[a] 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).

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 small network equipment 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 **6.4**.[19] The estimated UEC of small network equipment in the non-standards case scenario is comprised of a mix of non-compliant (Table 5.1) and compliant (Table 5.5) UEC estimates.

Our second scenario models the energy use of California small network equipment 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 small network equipment is 100% compliant with the proposed standard. Starting in 2016, we use the compliant small network equipment UEC estimates from Table 5.5 for each new cohort of small network equipment in the standards case scenario.

For both scenarios, we use an analysis period of 2016-2020 based on design life and expected stock turnover.[20] We use the same market data for both scenarios, with sales data being the primary input. We estimate that entire stock turnover will take place in the last year of this analysis period, starting in 2020.

Below we present the estimated statewide energy use findings of this scenario analysis. Table 7.2 shows the estimated energy use of small network equipment in California for the non-standards case, for both first full calendar year sales (2016) and year of entire stock turnover (2020). Our findings indicate that should California not adopt small network equipment energy conservation standards, estimated California energy use of small network equipment stock will be 1710 GWh/yr and draw 213 MW at peak demand in year of stock turnover (Table 7.2).

Table 7.3 shows the estimated energy use of small network equipment 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 small network equipment stock will be 1,180 GWh/yr and draw 147 MW at peak demand in year of stock turnover (Table 7.3).

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. Estimated statewide savings are presented and discussed in more detail in the next section (Section 7.2).

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[19] In Appendix C, 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 C. In either scenario, the standard recommendations are cost-effective.

[20] 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 7.2 California Statewide Non-Standards Case Energy Use - After Effective Date

Product Class		For First-Year Sales		Year of Stock Turnover	
		Coincident Peak Demand (MW)[a]	Annual Energy Consumption (GWh/yr)	Coincident Peak Demand (MW)	Annual Energy Consumption (GWh/yr)
Broadband Access Equipment	Broadband Modem, Cable	7.7	62	44	350
	Broadband Modem, DSL	0.025	0.20	0.098	0.79
	ONT	1.5	12	9.0	73
	IAD Cable	7.9	64	43	349
	IAD ADSL	5.2	42	27	220
	IAD VDSL	2.9	23	16	127
Local Network Equipment	Access Point	0.97	7.8	4.1	33
	Router	15	120	67	540
	Switch	0.54	4.4	2.02	16.3
	CA Total	**41.6**	**335**	**213**	**1,710**

[a] 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 7.3 California Statewide Standards Case Energy Use - After Effective Date

Product Class		For First-Year Sales		Year of Stock Turnover [a]	
		Coincident Peak Demand (MW)[a]	Annual Energy Consumption (GWh/yr)	Coincident Peak Demand (MW)	Annual Energy Consumption (GWh/yr)
Broadband Access Equipment	Broadband Modem, Cable	6.7	54	38	310
	Broadband Modem, DSL	0.018	0.14	0.068	0.54
	ONT	0.87	7.0	5.1	41
	IAD Cable	4.13	33.2	22.6	182
	IAD ADSL	3.6	29	19	150
	IAD VDSL	2.3	18	13	100
Local Network Equipment	Access Point	0.30	2.4	1.3	10
	Router	11	85	48	380
	Switch	0.18	1.5	0.67	5.4
	CA Total	**28.5**	**230**	**147**	**1,180**

[a] 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 during year of entire stock turnover on projected stock in 2020. Our findings indicate that should California adopt the proposed standard, estimated California energy savings are 105 GWh/yr for first-year sales of new small network equipment and 532 GWh/yr in year of entire stock turnover.

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

Product Class		For First-Year Sales		Year of Stock Turnover[b]	
		Coincident Peak Demand Reduction (MW)	Annual Energy Savings (GWh/yr)	Coincident Peak Demand Reduction (MW)	Annual Energy Savings (GWh/yr)
Broadband Access Equipment	Broadband Modem, Cable	1.02	8.2	5.8	47
	Broadband Modem, DSL	0.0079	0.064	0.03	0.25
	ONT	0.674	5.4	3.9	32
	IAD Cable	3.782	30	21	170
	IAD ADSL	1.658	13	8.6	70
	IAD VDSL	0.571	4.6	3.2	25
Local Network Equipment	Access Point	0.674	5.4	2.9	23
	Router	4.312	35	20	160
	Switch	0.363	2.9	1.34	10.8
	CA Total	**13.1**	**105**	**66.0**	**532**

[a] 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).

7.3 Other Benefits and Penalties

By encouraging the use of EEE, this standard could enable energy savings in other devices (discussed in Section 5.3), assuming those devices support EEE and are enabled. The second is network proxy, discussed immediately below. If an incentive is given for network proxy, this would result in further energy savings outside of the regulated small network equipment.

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 for local and state governments from the purchase of more efficient products as a result of the proposed standard are dependent on the volume of products purchased.

8 Economic Analysis

8.1 Incremental Cost

California IOU research reveals a number of trends related to incremental cost of the proposed standards. These include:

- One or more units in the publically-available ENERGY STAR dataset (EPA 2013b) meet the proposed standard in each product class (Broadband Cable Modem, Broadband DSL Modem, IAD ADSL, ONT, IAD Cable, IAD VDSL, Access Point, Router and Switch). MIMO, Wi-Fi, and plain old telephone system (POTS) functionality and gigabit data transfer are all represented in the units that meet or exceed the proposed standard.
- We found the retail prices of 45 of the products studied in NRDC (2013). There does not appear to be any correlation in price of compliant versus noncompliant products. This indicates that the incremental cost is near zero.
- Interviews with manufacturers indicate that silicon to support energy efficient Ethernet and Wi-Fi power scaling is expected to have significant market share in 2014, even in the absence of any mandatory efficiency standards. In addition, the addition of EEE in networking silicon does not increase the size or cost of the silicon. The software that handles power management in 802.11ac requires additional processing power and memory, but the desire to reduce power for mobile wireless devices is driving the adoption of 802.11ac and its power management features.[21]
- No incremental cost information for efficiency improvements was supplied by industry during the invitation to participate (ITP) process.

For all of these reasons, we conclude that the incremental cost of the proposed standard to California ratepayers is zero.

8.2 Design Life

The California IOU statewide codes and standards team used a design life of 5 years for all small network equipment. This rough approximation is based on input from discussions with Infonetics and market actors and is driven by product obsolescence than product failure.

[21] Based on phone interviews with leading manufacturers, June 2013.

Table 8.1 Design Life by Product Class

Product Class		Design Life (years)
Broadband Access Equipment	Broadband Modem, Cable	5
	Broadband Modem, DSL	5
	ONT	5
	IAD Cable	5
	IAD ADSL	5
	IAD VDSL	5
Local Network Equipment	Access Point	5
	Router	5
	Switch	5

Source: (Infonetics 2012a)

8.3 Lifecycle Cost / Net Benefit

We evaluated the costs and benefits of small network equipment 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 8.2). We assumed no additional costs, such as increased maintenance costs, in calculating total per unit benefits. We also excluded expected benefits such as GHGs and network proxy.

Using the per-unit lifecycle benefit, Table 8.2 shows the NPV for first year sales after the standard is enacted and total NPV by entire stock turnover. The NPV of the proposed small network equipment standard, based on the projected first year sales in 2016, is $89.9 million. The cumulative total net present value of the proposed standard by entire stock turnover in 2020 is nearly $470 million. Our analysis indicates the proposed standard is cost-effective. The large NPVs are driven by the large number of small network devices in use in California and the large lifecycle benefit to cost ratios resulting from significant electricity savings and zero incremental cost. There is no expected negative impact on California economy or revenue.

Table 8.2 Costs and Benefits Per Unit for Qualifying Products

Product Class	Design Life (years)	Lifecycle Costs per Unit (Present Value $)			Lifecycle Benefits per Unit (Present Value $)		
		Incremental Cost	Add'l Costs[a]	Total PV Costs	Energy Savings[b]	Add'l Benefits[c]	Total PV Benefits
Broadband Modem, Cable	5	-	-	-	7	-	7
Broadband Modem, DSL	5	-	-	-	14	-	14
ONT	5	-	-	-	25	-	25
IAD Cable	5	-	-	-	33	-	33
IAD ADSL	5	-	-	-	19	-	19
IAD VDSL	5	-	-	-	20	-	20
Access Point	5	-	-	-	33	-	33
Router	5	-	-	-	19	-	19
Switch	5	-	-	-	37	-	37

PV = Present Value

[a] We assume no additional costs.

[b] 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

[c] We assume no additional benefits.

Table 8.3 Lifecycle Costs and Benefits for Qualifying Products

Product Class		Lifecycle Benefit / Cost Ratio[a]	Net Present Value ($)[bd]		
			Per Unit	For First Year Sales	Total Until Entire Stock Turnover [c]
Broadband Access Equipment	Broadband Modem, Cable	Near infinite	7	7,000,000	41,000,000
	Broadband Modem, DSL	Near infinite	14	54,000	210,000
	ONT	Near infinite	25	4,600,000	28,000,000
	IAD Cable	Near infinite	33	26,000,000	150,000,000
	IAD ADSL	Near infinite	19	11,000,000	61,000,000
	IAD VDSL	Near infinite	20	3,900,000	22,000,000
Local Network Equipment	Access Point	Near infinite	33	4,600,000	20,000,000
	Router	Near infinite	19	30,000,000	140,000,000
	Switch	Near infinite	37	2,500,000	9,500,000
			Total	**89,900,000**	**469,000,000**

[a] Total present value benefits divided by total present value costs. Since we assume zero costs, this is near infinite.
[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

The existing small network equipment supply chain can be utilized to bring more efficient products to market. Only iterative improvements are needed to existing product design. In addition, and as discussed in Section 5.3, new technical standards will be in place to support further reductions of small network equipment power levels, including:

- Network traffic power scaling to reduce wired port power (EEE or 802.3az). IEEE ratified this standard in 2010.
- Network traffic power scaling to reduce wireless connection power (WiFi 802.11ac). IEEE plans to ratify this standard in early 2014.

Additional efficiency improvements to non-port related functions, including power supply efficiency, silicon improvements, etc. are also opportunities to reduce base power of small networking equipment. All of these technological advances, which are expected in coming months, will use existing channels within the marketplace.

9.2 Existing Standards

The most substantial market influence in the U.S. is the forthcoming small network equipment EPA ENERGY STAR program. The EPA takes a comprehensive approach to addressing the energy use of the most common types of small network equipment, including provisions for both broadband access equipment and local network equipment. Although the U.S. Department of Energy (DOE) issued a proposed determination that included small network equipment (DOE 2011), to date, the DOE has focused on a rulemaking for set-top boxes. Outside the U.S., the E.U. Code of Conduct addresses a broad array of small network devices with published targets for low power modes and standard modes. In addition, Japan Top Runner and the Korean e-standby program have policies that cover certain products within small network equipment (small routers, and home gateways, respectively).

9.2.1 ENERGY STAR Voluntary Specification

The U.S. EPA launched its development of an ENERGY STAR specification for small network equipment on October 23, 2009 (EPA 2009a, 2009b). Draft test procedure and specification criteria have gone through multiple revisions and received feedback from a variety of stakeholders. EPA released Draft 1 Version 1.0 of its Small Network Equipment Specification, including a draft test method, on February 28, 2012 (EPA 2012b). EPA published Draft 2 Version 1.0 and the final test procedure in November 2012 (EPA 2012c, 2012d). In early 2012, EPA assembled a dataset on the energy performance of small network equipment from which to establish draft eligibility criteria for the Version 1.0 ENERGY STAR Small Network Equipment specification. EPA published Draft 3 of this dataset in May 2013 (EPA 2013b), which we use for this CASE Report. As detailed in section 3.2, the Draft 3 Version 1.0 ENERGY STAR Small Network Equipment specification covers (i) broadband access equipment, including broadband modems, ONT devices and IAD, and (ii) local network equipment, including routers, switches and access points.

The draft program requirements are based on a maximum power allowance for (i) base functionality and (ii) additional functionalities of the unit, as detailed in Appendix B (EPA 2013a).

9.2.2 U.S. Department of Energy Rulemaking

Starting in 2011, DOE has 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). Since that time, DOE has undertaken the following activity:

- 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).
- 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.
- May to October 2012: DOE temporarily suspended rulemaking activity to allow industry and energy efficiency advocates come to a non-regulatory agreement. No agreement was reached within this time period.
- March 2013: DOE released a notice of data availability (NODA) (DOE 2013) focused on a cost and efficiency analysis for set-top boxes only (not including small networking equipment).

Recent activity by DOE has focused primary on set-top boxes. DOE has given verbal indications in public forums that they are not actively pursuing small network equipment standards at this time. DOE's timing on next steps for this product category, or if any will be taken at all, is currently unclear. If passed, the standard would then take effect five years after the publication of the final rule. This timeline would give California the opportunity to achieve significant savings ahead of a federal compliance requirement.

9.2.3 Other Standards

EU Code of Conduct

In 2008, the European Commission (EC) established a Code of Conduct (CoC) for broadband equipment based on "expectations that broadband equipment will contribute considerably to the electricity consumption of households in European Community in the near future" (EC 2008, 2). Version 4, Tier 2 of the CoC (EC 2011) is currently in effect, which proposes power limits through 2014. The CoC aims to target reduced energy consumption of broadband communication equipment without hampering the fast technological developments and the service provided. As part of the CoC, signatories agree to provide the EC information concerning the power consumption of the equipment covered by the CoC they produce, specify, buy, or install. The CoC scope is more comprehensive than the scope of products covered in this proposal. For additional details see (Table B.1 in Appendix B).

Japan Top Runner

Japan created its Top Runner program in 1998 to improve the energy efficiency of its end-use products (Kimura 2010). The Top Runner program sets a power target for active-mode for each product class based on the best-in-class product in the current market. When the majority of the industry achieves the target, the market is reanalyzed and a new target level is set. Top Runner has a scope that is less comprehensive than the scope of this standard proposal and published its criteria in 2008. Table B.3 in Appendix B: summarizes the levels for the small network equipment included in Japan's Top Runner Program. The terms used in the Japanese policy are given in the table with the California IOU (and ENERGY STAR) definitions shown in italics to enable cross-referencing. Scope of the policy includes: switches, WiFi routers, ADSL modems, and ADSL IADs.

South Korea e-Standby

South Korea's e-Standby labeling program allows devices meeting the given criteria (Appendix B:) to put the smiling "Energy Boy" logo on packaging. Devices that fail to comply must put a one-inch warning label on the packaging stating that the device fails to comply with e-Standby. Currently, the e-Standby program covers cable modems and all varieties of IAD (KEMCO 2012). For more details, see Appendix B:.

9.3 Stakeholder Positions

We summarize select stakeholder positions in response to potential California standards for small network equipment below. We use responses to CEC's ITP in the 2013 Appliance Efficiency Rulemaking as the basis for these summaries.[22]

- ENERGY STAR and other voluntary measures are sufficient
- The technology is changing too fast to regulate
- The Federal Cable Act preempts CEC from imposing energy standards
- Small network equipment and set-top boxes are different products classes and would require different test procedures, so CEC should not include small network equipment in rulemaking
- CEC did not follow due process for including small network equipment
- Data indicate there is a large spread in efficiency among similarly functional products, indicating regulation would save significant energy
- Marginal electricity prices should be used, which are generally higher than average prices, justifying greater efficiency
- Many new efficient technologies are on the horizon
- Power factor correction could save additional energy at near zero incremental cost
- Incremental cost for energy efficiency would be near zero, therefore significant energy savings would be feasible and cost-effective

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.

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

10.2 Air Quality

This proposed measure is estimated to reduce total criteria pollutant emissions in California by 91,500 lbs/year in 2020, after stock turnover, as shown in Table 10.1 due to 532 GWh in reduced end user electricity consumption with an estimated value of $4,384,400. 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 F (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	14,656	$17,460	$127,948
NOx	49,987	$17,460	$436,388
SOx	5,254	$18,300	$48,073
PM2.5	21,603	$349,200	$3,771,963
Total	91,500		**$4,384,400**

10.3 Greenhouse Gases

Table 10.2 shows the first year and stock turnover GHG savings and the range of the societal benefits as a result of the standard. By stock turnover in 2020, this standard would save 232,000 metric tons of CO2e, equal to between roughly $12 million and $37 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 F: 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 ($)	Value of Stock Turnover GHG Savings - high ($)
46,000	232,000	12,300,000	36,700,000

11 Recommendations

11.1 Recommended Standards Proposal

The California IOU codes and standards team recommends that the CEC adopt:

i. A mandatory energy efficiency standard for residentially-focused small network equipment product classes

ii. A test and list requirement for small enterprise and fixed wireless broadband access devices.

A test and list of requirement supports California's ability to understand energy implications of small network equipment beyond the current proposed scope of the energy performance standards. In addition, the proposed test and list requirement enables future evaluation of the need for possible additional energy performance requirements. The framework proposed for the mandatory standard, including the product classes and P_{AVG} metric, has been vetted by U.S. industry stakeholders as part of the ENERGY STAR program development process. Analysis of the small network equipment market justifies the cost-effectiveness of the proposed maximum power allowances for base and adder functionality for each product class. 17 percent of products in today's market can meet the standard with no incremental cost, including some products with the latest functionality offerings. With this proposal, California ratepayers can save 94 GWh or $155 million on their utility bills in the first year, with a total measure savings of 1,700 GWh for 2016-2020, the equivalent of nearly $800 million.

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) Small network equipment which meets the respective product type definition in Section 1602.

Section 1602. Definitions.

"Network equipment" means a device whose primary function is to pass Internet Protocol (IP) traffic among various network interfaces/ports.

"Small network equipment" means network equipment that is intended to serve users in either small networks or a subset of a large network. Small network equipment includes a) all network equipment with integral wireless capability and b) other network equipment meeting all of the following criteria:

a) Designed for stationary operation;

b) Contains no more than eleven (11) wired Physical Network Ports;

c) Primary configuration for operation outside of standard equipment racks;

d) Meets the definition of one or more of the Product Types defined in Section 1602

"Broadband Modem" means a device that transmits and receives digitally-modulated analog signals over a wired or optical network as its primary function. The broadband modem category does not include devices with integrated router, switch, or access point functionality.

"Integrated Access Device (IAD)" means a network device with a modem and one or more of the following functions: network routing, multi-port Ethernet switching and/or access point functionality.

"Optical Network Termination Device (ONT)" means a modem or IAD that converts signals between an optical fiber connection and copper (wired) or wireless connections.

"Fixed Wireless Broadband Access Device" means a device that is mains powered and enables broadband access receiving information via a wireless data connection.

"Router" means a network device that determines the optimal path along which network traffic should be forwarded as its primary function. Routers assign IP addresses or recognize static IP addresses and forward packets from one network to another based on network layer information. Devices fitting this definition may provide both router functionality and wireless access capability.

"Access Point" means a device that provides Institute of Electrical and Electronics Engineers (IEEE) 802.11 (Wi-Fi) connectivity to multiple clients as its primary function. An access point extends the range of a wireless signal but does not assign IP addresses to networked devices and therefore cannot be used to connect multiple edge devices in the absence of a wired or wireless router.

"Switch" means a network device that forwards information to a specific device based on a destination address. Unlike a router, a switch does not assign a destination address.

"Enterprise small network equipment" has one or more of the following characteristics:

- Device includes one or more modular network ports (e.g. small form factor pluggable) to allow expansion of the number of wired ports in use.
- Device is shipped without a power supply.
- Device requires a separate external access point controller for operation.

"Fast Ethernet (100Base-T)" means data transfer speeds of 100 megabits per second (Mbit/s). 100Base-T is a collective term for Fast Ethernet standards that have transfer speeds of 100 Mbit/s.

"Gigabit Ethernet (1000Base-T)" means data transfer speeds of 1000 MBit/s, also described as 1 gigabit per second. 1000Base-T (also known as IEEE 802.3ab) is a standard for gigabit Ethernet over copper wiring.

"Wi-Fi (802.11a/b/g/n)" means functionality allowing an electronic device to exchange data wirelessly over a network. 802.11 is the family of specifications developed by the IEEE 802.11 committee which establishes standards for wireless Ethernet networks.

"Multi-Input Multi-Output (MIMO) Wireless HNI" means IEEE 802.11n/ac and related MIMO enabled Wi-Fi 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.

"Plain Old Telephone Service" means traditional phone ports. RJ11/RJ14.

"Energy Efficient Ethernet (EEE)" means a technology standard, IEEE 802.3az, that enables compliant Gigabit Ethernet ports to reduce power draw when idling.

"On Mode" means the product is connected to a power source, is ready to use, and is providing one or more primary functions.

"Idle State" means the product is in On Mode and the data rate is 0 kb/s.

"Low Data Rate" means the product is in On Mode and traffic is passed across ports at 1.0 kb/s (0.5 kb/s in each direction) as defined in the test procedure.

"High Data Rate" means the product is in On Mode and traffic is passed across ports at a selected reference rate as defined in the test procedure.

Section 1604. Test Method for Specific Appliances.

(x) Small network equipment

Table X: Test Procedure for Small Network Equipment

Test Protocol	**Source**
ENERGY STAR Final Draft, Rev. November 2012, Test Method for Small Network Equipment with three additions*	https://energystar.gov/products/specs/sites/products/files/ES_SNE_Final_Draft_Test_Method_Nov2012.pdf

* We recommend the following modifications to the ENERGY STAR test procedure: (1) add language that specifies the order of precedence of port type for modular ports to enable test and list of network equipment with one or more modular network ports (e.g. Small Form-factor Pluggable (SFP)), (2) expand the scope and adjust the approach of the test procedure to include devices marketed and sold as enterprise network equipment that also meet one or more of the following additional criteria: a) is shipped without a power supply, or b) requires a separate external access point controller for operation, and (3) consider test procedure approach needed to measure, for test and list purposes, fixed wireless broadband access equipment.

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

(x) Small network equipment

Small network equipment that meets one of the following equipment type definitions from Section 1602 falls within the "mandatory energy efficiency performance standard scope":

i. Broadband modem (Cable, DSL);

ii. Optical network termination device (ONT);

iii. Integrated access device (IAD);

iv. Router;

v. Switch; or

vi. Access point.

Small network equipment that meets one of the following equipment type definitions from Section 1602 falls within the "test and list scope":

i. Small enterprise network equipment as defined in section 1602

ii. Fixed wireless broadband access device.

Effective [one year after adoption date], small network equipment in the test and list scope shall be tested and the results reported. In addition, small network equipment in the mandatory energy efficiency performance standard scope shall not exceed the maximum power (watts) allowance based on Table X and Table X below. The proposed standard includes a maximum power allowance for (i) base functionality and (ii) additional functionalities of the unit. The maximum average power (P_{AVG_MAX}) for the unit under test, its total power allowance, is determined using the following equation:

$$P_{AVG\_MAX} = P_{BASE} + \sum_{i=1}^{n} P_{ADDi}$$

Where:

- P_{BASE} = Base power allowance (W) from Table X
- P_{ADDi} = The power allowance as specified in Table X for each feature present in the device, for a total of n such allowances.

Average power of a given device is calculated using the ENERGY STAR formula:

$$P_{AVG} = \text{Average}\ [P_{WAN\_TEST}, P_{LAN\_TEST}, P_{WIRELESS\_TEST}]$$

Where:

- P_{WAN_TEST} = Measured power consumption in Wired Network – WAN test, at 1.0 kb/s (W);
- P_{LAN_TEST} = Measured power consumption in Wired Network – LAN test, half of available wired LAN ports populated, at 1.0 kb/s (W);
- $P_{WIRELESS\_TEST}$ = Measured power consumption in Wireless Network – LAN test, at 1.0 kb/s (W)

Comparing the average power (P_{AVG}) of a small network product to its total power allowance (P_{AVG_MAX}) determines its qualification with the standard (i.e. it cannot exceed P_{AVG_MAX}).

Table X: Standards for Small Network Equipment, Power Allowances for Base Functionality

Product	**P_{BASE} (watts)**
Broadband Modem, Cable	5.7
Broadband Modem, ADSL	3.5
ONT	3.4
IAD – Cable	4.0

IAD – ADSL	4.2
IAD – VDSL	6.9
Access Point	1.5
Router	3.0
Switch	0.1

Table X: Standards for Small Network Equipment, Power Allowances for Additional Functionality

Function	P_{ADD} (watts)	Notes
Fast Ethernet (100Base-T)	0.1	Allowance applied once per port present in the UUT.
Gigabit Ethernet (1000Base-T)	0.2	Allowance applied once per port present in the UUT.
Wi-Fi (802.11a/b/g/n)	0.3	Allowance applied once for the UUT for availability of Wi-Fi connectivity.
Wi-Fi (802.11n per Receive Chain)	0.1	Allowance applied to total number of 2.4 GHz and 5.0 GHz 802.11n receive chains. Only applicable for products that ship with simultaneous dual band Wi-Fi enabled.
Wi-Fi (802.11ac per Receive Chain)	1.9	Allowance applied to 5.0 GHz 802.11ac receive chains only. Only applicable for products that ship with simultaneous dual band Wi-Fi enabled.
Plain Old Telephone Service (RJ11/RJ14)	0.3	Allowance applied once per port, up to a maximum of two ports.
EEE	0.2	Applied to each EEE capable Gigabit port

Section 1606. Filing by Manufacturers; Listing of Appliances in Database.

[TBD – In subsequent comments to the CEC, we plan to provide more specific recommendations for Table X requirements in Section 1606 for small enterprise and fixed wireless broadband access devices]

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

The first table below shows sales data for small network equipment in California, and the second in the United States.

Table A.1 California estimated sales for small network equipment, 2013-2020, Ecova analysis of (Infonetics 2012b, 2013)

	2013	2014	2015	2016	2017	2018	2019	2020
SALES								
Broadband Modem, Cable	727,987	840,234	959,446	1,076,868	873,690	1,285,066	1,393,613	1,502,159
Broadband Modem, ADSL	4,890	4,743	4,696	4,602	4,696	3,757	2,817	1,878
Integrated Access Device, Cable	1,028,072	1,019,059	1,058,940	1,054,251	1,143,637	1,168,853	1,194,070	1,219,286
Integrated Access Device, ADSL	776,141	725,460	685,753	659,850	755,362	741,317	727,273	713,229
Integrated Access Device, VDSL	150,089	202,168	234,342	259,298	258,095	282,298	306,501	330,704
Optical Network Termination Device (ONT)	204,743	203,485	197,961	211,025	238,156	249,229	260,301	271,374
Access Point	196,588	180,861	166,392	153,081	140,834	129,568	119,202	109,666
Router	2,171,587	2,105,975	2,000,557	1,860,685	1,767,384	1,678,775	1,594,620	1,514,695
Switch	142,963	121,518	103,291	87,797	74,627	63,433	53,918	45,831

Table A.2 U.S. estimated sales for small network equipment, 2013-2020, Ecova analysis of (Infonetics 2012b, 2013)

	2013	2014	2015	2016	2017	2018	2019	2020
SALES								
Broadband Modem, Cable	6,066,557	7,001,950	7,995,387	8,973,897	7,280,748	10,708,885	11,613,440	12,517,995
Broadband Modem, ADSL	40,749	39,527	39,131	38,349	39,131	31,305	23,479	15,653
Integrated Access Device, Cable	8,567,266	8,492,159	8,824,503	8,785,422	9,530,306	9,740,443	9,950,580	10,160,717
Integrated Access Device, ADSL	6,467,845	6,045,504	5,714,612	5,498,749	6,294,682	6,177,645	6,060,608	5,943,571
Integrated Access Device, VDSL	1,250,746	1,684,736	1,952,847	2,160,818	2,150,793	2,352,483	2,554,173	2,755,863
Optical Network Termination Device (ONT)	1,706,193	1,695,704	1,649,672	1,758,542	1,984,634	2,076,906	2,169,177	2,261,448
Access Point	1,638,235	1,507,176	1,386,602	1,275,674	1,173,620	1,079,730	993,352	913,884
Router	18,096,559	17,549,793	16,671,308	15,505,705	14,728,199	13,989,790	13,288,502	12,622,458
Switch	1,191,357	1,012,653	860,755	731,642	621,896	528,611	449,320	381,922

Appendix B: Allowance Levels of Voluntary Market Programs and Mandatory Standards

B.1 Draft 3 Energy Star Provisions

The average power consumption (P_{AVG}) for the unit under test is first determined using the following calculation:

$$P_{AVG} = \text{Average}\ [P_{WAN\_TEST} + P_{LAN\_TEST} + P_{WIRELESS\_TEST}]$$

Where:

- $\text{Average}[x_i]$ = Average of terms (xi) applicable to the UUT;
- P_{WAN_TEST} = Measured power consumption in wired network – WAN test, at 1.0 kb/s (W);
- P_{LAN_TEST} = Measured power consumption in wired network – LAN test, half of available wired LAN ports populated, at 1.0 kb/s (W);
- $P_{WIRELESS\_TEST}$ = Measured power consumption in wireless network – LAN test, at 1.0 kb/s (W)

The maximum average power (PAVG_MAX) for the unit under test, its total power allowance, is determined using the following equation:

$$P_{AVG\_MAX} = P_{BASE} + \sum_{i=1}^{n} P_{ADDi}$$

Where:

- P_{BASE} = Base power allowance (W) from XX
- P_{ADDi} = The power allowance as specified in XX for each feature present in the device, for a total of n such allowances.

Table B.1 ENERGY STAR Base Power Allowances

Product Type	P_{BASE} (watts) Version 1.0	P_{BASE} (watts) Version 2.0
Broadband Modem – Cable	5.7	TBD
Broadband Modem – ADSL	4.0	
Broadband Modem – ONT	4.4	
IAD – Cable	6.1	
IAD – ADSL	5.5	
IAD – VDSL	7.5	
Router	3.1	
Switch	0.6	
Access Point	2.0	

Table B.2 ENERGY STAR Additional Functional Adders

Feature	P_{BASE} (watts) Version 1.0	Notes
Fast Ethernet (100Base-T)	0.1	Allowance applied once per port present in the UUT.
Gigabit Ethernet (1000Base-T)	0.3	Allowance applied once per port present in the UUT.
Wi-Fi (802.11a/b/g/n)	0.7	Applied once for the UUT for availability of Wi-Fi connectivity.
802.11n per Receive Chain	0.2	Allowance applied to total number of 2.4 GHz and 5.0 GHz 802.11n receive chains. Only applicable for products that ship with simultaneous dual band Wi-Fi enabled.
802.11ac per Receive Chain	1.3	Allowance applied to 5.0 GHz 802.11ac receive chains only. Only applicable for products that ship with simultaneous dual band Wi-Fi enabled.
Plain Old Telephone Service (RJ11/RJ14)	0.5	Allowance applied once per port, up to

Comparing the Average Power Consumption (P_{AVG}) of a small network product to its total power allowance (P_{AVG_MAX}) determines its qualification with the specification (i.e. it cannot exceed P_{AVG_MAX}).

B.2 EU Code of Conduct Details

The scope of the EU CoC is more comprehensive the scope of this proposal for California. Additional products in the EU CoC include: Wireless Customer Premise Equipment (CPE) (WiMAX, 3G and LTE), DSL CPE powered by USB, powerline adapters, alternative LAN technologies (HPNA, MoCA) adapters, Optical LAN adapter, ATA / VoIP gateway, VoIP telephone, and print server. We lack U.S. power measurement data in support the breadth of products covered by the EU CoC.

B.3 Japan's Top Runner Program Details

The table below summarizes the levels for the small network equipment included in Japan's Top Runner Program. The terms used in the Japanese policy are given in the table with the California IOU (and ENERGY STAR) definitions shown in italics to enable cross-referencing. Scope of the policy includes: Switches, WiFi Routers, ADSL modems, and ADSL IADs.

Table B.3 Top Runner Specification for small network equipment

	LAN Interface (active mode)			
WAN Interface	**Connection**	**Ethernet (*Switch*)**	**With VoIP**	**With wireless (*WiFi Router*)**
	Ethernet	4.0W	5.5W	2.4GHz Singleband: Power Limit = (.1*X2)+3.9 5GHz Singleband: Power Limit = (.15*X5)+3.9 Both (dualband): Power Limit = (.1*X2)+(.15*X5) + 5.1 *X2: 2.4Ghz output power density (mW/MHz)* *X5: 5GHz output power density (mW/MHz)*
	ADSL	7.4W *(ADSL Modem)*	7.4W *(ADSL Modem)*	8.8W *(ADSL AID (Gateway))*

Source: Top Runner (2008)

B.4 South Korea's e-Standby Program Details

Below are details of South Korea's allowances for small network equipment. Scope of the e-Standby program includes cable modems and all IAD.

Table B.4 Functional Allowances in South Korea's e-Standby Program

Additional Functionality (excluding base functions and VoIP phones)	Functional Allowance in Sleep-mode
LAN port (up to 8)	0.25W
Wireless Functionality	1.0W
WAN port	0.5W
Optical port	0.5W
PLC port (similar to HomePlug in United States)	0.5W
USB port	0.5W
RS485 port	0.5W
RS232 port	0.5W
Default time to sleep: ≤ 10 minutes	
Base Sleep Power Limit: 10 watts	
Maximum Sleep Power Limit: 16 watts	

[a] Sleep is tested by connecting a traffic generator, but not transmitting. In other words, the device has been idle for 10 minutes.
Source: KEMCO (2012)

Appendix C: 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.[23] 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 C.1 California Statewide Baseline Energy Use – Current Year

Product Class		Annual Sales (2013)		For Entire Stock (2013)	
		Coincident Peak Demand (MW)[a]	Annual Energy Consumption (GWh/yr)	Coincident Peak Demand (MW)	Annual Energy Consumption (GWh/yr)
Broadband Access Equipment	Broadband Modem, Cable	5.2	42	26	210
	Broadband Modem, ADSL	0.027	0.22	0.13	1.1
	ONT	1.5	12	7.5	60
	IAD Cable	7.7	62	38.5	310
	IAD ADSL	6.7	54	33	270
	IAD VDSL	1.7	13	8.3	66
Local Network Equipment	Access Point	1.3	10	6.3	50
	Router	17	139	86	700
	Switch	0.88	7.1	4.4	36

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

CA Total	**42.2**	**340**	**211**	**1700**

[a] 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 C.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)[a]	**Annual Energy Consumption (GWh/yr)**	**Coincident Peak Demand (MW)**	**Annual Energy Consumption (GWh/yr)**
Broadband Access Equipment	Broadband Modem, Cable	7.6	61	43	350
	Broadband Modem, DSL	0.025	0.20	0.093	0.75
	ONT	1.5	12	8.4	68
	IAD Cable	7.5	60	40	318
	IAD ADSL	5.1	41	26	210
	IAD VDSL	2.8	22	15	123
Local Network Equipment	Access Point	0.93	7.5	3.8	31
	Router	14	116	64	510
	Switch	0.39	3.1	1.20	9.7
CA Total		**40.1**	**324**	**201**	**1620**

[a] 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 C.3 California Statewide Standards Case Energy Use - After Effective Date

Product Class		For First-Year Sales		Year of Stock Turnover	
		Coincident Peak Demand (MW)[a]	Annual Energy Consumption (GWh/yr)	Coincident Peak Demand (MW)	Annual Energy Consumption (GWh/yr)
Broadband Access Equipment	Broadband Modem, Cable	6.7	54	38	310
	Broadband Modem, DSL	0.018	0.14	0.068	0.54
	ONT	0.87	7.0	5.1	41
	IAD Cable	4.13	33.2	22.6	182
	IAD ADSL	3.6	29	19	150
	IAD VDSL	2.3	18	13	100
Local Network Equipment	Access Point	0.30	2.4	1.3	10
	Router	11	85	48	380
	Switch	0.18	1.5	0.67	5.4
CA Total		**28.5**	**230**	**147**	**1180**

[a] 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 C.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)	Annual Energy Savings (GWh/yr)	Coincident Peak Demand Reduction (MW)	Annual Energy Savings (GWh/yr)
Broadband Access Equipment	Broadband Modem, Cable	0.93	7.5	4.9	39
	Broadband Modem, DSL	0.0071	0.057	0.03	0.21
	ONT	0.617	5.0	3.3	27
	IAD Cable	3.333	27	17	140
	IAD ADSL	1.520	12	7.4	59
	IAD VDSL	0.503	4.1	2.6	21
Local Network Equipment	Access Point	0.633	5.1	2.6	21
	Router	3.848	31	16	130
	Switch	0.207	1.7	0.53	4.3
CA Total		**11.6**	**93.5**	**54.3**	**438**

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

Product Class		Annual GHG Savings for First-Year Sales (metric tons of CO_2e/yr)	Annual GHG Savings Year of Stock Turnover (metric tons of CO_2e/yr)
Broadband Access Equipment	Broadband Modem, Cable	3000	17000
	Broadband Modem, DSL	25	91

	ONT	2200	12000
	IAD Cable	12000	59000
	IAD ADSL	5400	26000
	IAD VDSL	1800	9000
Local Network Equipment	Access Point	2200	9000
	Router	14000	57000
	Switch	730	1900
CA Total		**40900**	**191000**

Assumes 0.437 metric tons of CO_2e per MWh of electricity savings based on assumptions for GHG emissions reduction in CA ARB (2008, I-24).

Table C.6 Costs and Benefits Per Unit for Qualifying Products

Product Class	Design Life (years)	Lifecycle Costs per Unit (Present Value $)			Lifecycle Benefits per Unit (Present Value $)		
		Incremental Cost	Add'l Costs[a]	Total PV Costs	Energy Savings[b]	Add'l Benefits[c]	Total PV Benefits
Broadband Modem, Cable	5	-	-	-	7	-	7
Broadband Modem, DSL	5	-	-	-	14	-	14
ONT	5	-	-	-	25	-	25
IAD Cable	5	-	-	-	33	-	33
IAD ADSL	5	-	-	-	19	-	19
IAD VDSL	5	-	-	-	20	-	20
Access Point	5	-	-	-	33	-	33
Router	5	-	-	-	19	-	19

Switch	5	-	-	-	37	-	37

PV = Present Value

[a] We assume no additional costs.

[b] 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

[c] We assume no additional benefits.

Table C.7 Lifecycle Costs and Benefits for Qualifying Products

Product Class		**Lifecycle Benefit / Cost Ratio**[a]	**Net Present Value ($)**[b]		
			Per Unit	For First Year Sales	Total Until Entire Stock Turnover [c]
Broadband Access Equipment	Broadband Modem, Cable	Near infinite	7	6,400,000	35,000,000
	Broadband Modem, DSL	Near infinite	14	49,000	180,000
	ONT	Near infinite	25	4,300,000	24,000,000
	IAD Cable	Near infinite	33	23,000,000	120,000,000
	IAD ADSL	Near infinite	19	10,000,000	52,000,000
	IAD VDSL	Near infinite	20	3,500,000	18,000,000
Local Network Equipment	Access Point	Near infinite	33	4,400,000	18,000,000
	Router	Near infinite	19	26,000,000	110,000,000
	Switch	Near infinite	37	1,400,000	3,700,000
			Total	**7,990,000**	**385,000,000**

[a] Total present value benefits divided by total present value costs. Since we assume zero costs, this is near infinite.

[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 D: Definitions for Network Proxy

This appendix includes additional definitions for network proxy. We use definitions from ENERGY STAR's specification for small network equipment, Draft 3 Version 1.0 (EPA 2013a)

Full Network Connectivity: The ability of an end point device to maintain network presence while in sleep mode or another low power mode (LPM) of equal or lower power consumption and intelligently wake when further processing is required (including occasional processing required to maintain network presence). Presence of the end point device, its network services and applications is maintained even though the end point device is in a LPM. From the vantage point of the network, an end point device with full network connectivity that is in LPM is functionally equivalent to an idle end point device with respect to common applications and usage models. Full network connectivity in is not limited to a specific set of protocols but can cover applications installed after initial installation. Also referred to as "network proxy" functionality and as described in the Ecma-393 standard.

i. Network Proxy - Base Capability: To maintain addresses and presence on the network while in LPM, the system handles IPv4 ARP and IPv6 NS/ND.

ii. Network Proxy - Full Capability: While in LPM, the system supports base capability, remote wake, and service discovery/name services.

iii. Network Proxy - Remote Wake: While in LPM, the system is capable of remotely waking upon request from outside the local network. Includes base capability.

iv. Network Proxy - Service Discovery/Name Services: While in LPM, the system allows for advertising host services and network name. Includes base capability.

External Proxy Capability: The ability of an SNE device to maintain full network connectivity on behalf of an end point device. Must include an implementation of a standard protocol for communicating between the end point device and the SNE device. Note: A known such protocol is mDNS. Waking the sleeping end point device is typically accomplished by Wake-127 On-LAN, a wireless equivalent, or some other directed traffic.

Appendix E: Criteria Pollutant Emissions and Monetization

E.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.

E.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[24]. 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[25].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

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

[25] 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.

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.

Appendix F: 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.

F.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.

F.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 F.1. The two $ per metric ton of values used in this CASE report were taken from the two highlighted columns, and converted to 2013 dollars.

Table F.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).

F.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 F.2 below.

Table F.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 ($/MTC$0_2$eq).
3. Arizona Climate Change Advisory Group, *Climate Change Action Plan*, August 2006, ($/MTC$0_2$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.

F.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.

F.4 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.

F.4.1 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.