Pay-Television In-Home Equipment: National Energy Consumption, Savings Potential, and Policy Barriers and Opportunities

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ABSTRACT

One hundred million homes subscribe to pay-television in the U.S., requiring approximately 240 million pay-television set-top boxes. The energy use, energy savings opportunities and policy challenges of these devices is the primary focus of this paper. We developed a set-top box energy model using recent market and energy use data to estimate historical and future energy use. Both national and per-household energy use has increased over time, primarily because of the growing number of set-top boxes per subscriber household. Nearly 11 coal power plants are required in the U.S. to power today's pay-television set-top boxes (33 TWh/year). Per-household energy use has nearly tripled from 120 kWh a decade ago to almost 325 kWh today, costing subscribers $4 billion/year. Fortunately, there are a variety of energy savings opportunities that align with the four primary variables that determine set-top box energy consumption for a subscriber household: on mode power levels, sleep mode power levels, duty cycle, and network architecture. We estimate that the savings potential associated with these opportunities is 30–50%. Characteristics of the pay-television industry present unique policy challenges and opportunities.

Introduction

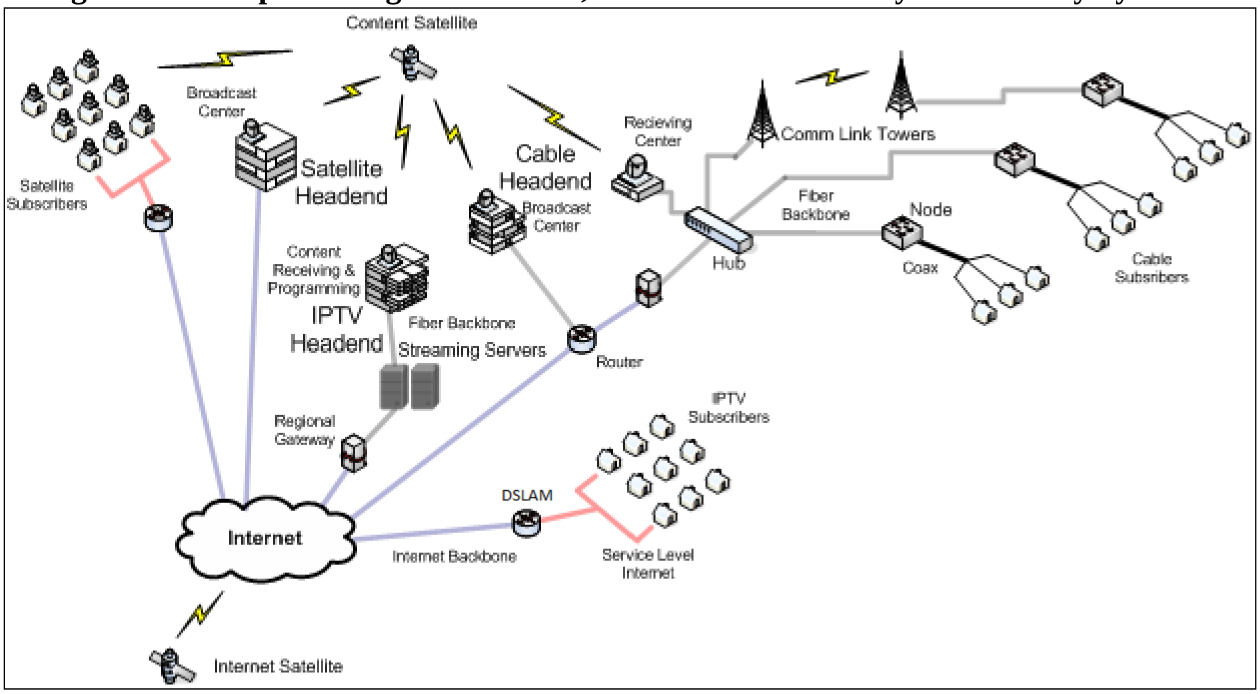
Pay-television (i.e. "pay-TV") set-top boxes allow subscribers to access video content from distribution networks on their television. The main elements of these distribution networks are (1) regional or national headend facilities that receive video signals from content providers and splice-in local programming and advertisements and (2) land-based or satellite-based network equipment that transports encrypted signals from these headends to pay-TV households. There are approximately 240 million pay-TV set-top boxes installed in 100 million U.S. subscriber households by cable, telecommunications (telco) and satellite service providers. U.S. pay-TV households have an average of 2.5 pay-TV set-top boxes to serve an average of three TVs (SNL/Kagan 2012; Nielsen 2011). In this paper, we focus on set-top box energy use, energy savings opportunities and policy challenges and opportunities.

This paper starts with a technical overview of the pay-TV content delivery system, which influences set-top box energy use. It then presents a national set-top box energy use model using recent market data for stock and sales and energy use data from a variety of previous field measurement studies. We provide a brief comparison to other set-top box energy analyses and present a number of energy savings scenarios. Lastly, we identify several policy challenges and opportunities for reducing the energy use of set-top boxes and pay-TV content delivery.

Technical Background

The pay-TV content delivery system consists of a complex network of communications channels, network gear and edge devices, like set-top boxes, that deliver video content from TV content providers to subscribers. This section provides an overview of the three primary national content distribution networks then describes fiber-to-the-premises (FTTP) technology and in-home, multi-room set-top box networks. The three major types of pay-TV delivery systems are cable, satellite and Internet Protocol TV (IPTV) (Figure 1).

Figure 1. Conceptual Diagram of Cable, Satellite and IPTV Pay-TV Delivery Systems



Cable

For cable networks, content providers generally transmit television content via satellite link to headend equipment, which adds local programming and commercials and sends the signal via fiber optic cable to neighborhood nodes, which transmit content via coaxial cable to approximately 250–500 subscriber households within a residential neighborhood. In a household that subscribes to multiple services, the coaxial cable runs through a cable splitter to both (1) a broadband access device like a cable modem or integrated access device (IAD), which provides internet and voice over IP (VOIP) telephone service, and (2) pay-TV set-top boxes, which can tune both TV channel broadcasts and two-way internet protocol (IP) data flow to include software and electronic program guide (EPG) updates and video-on-demand (VOD) movies and pay-per-view content streamed from media servers. The set-top boxes operate independently of the cable modem or IAD, which is not the case for IPTV.

IPTV

IPTV networks use existing broadband networks, typically those built by telcos, such as AT&T, to deliver content from a headend via fiber optic cable to a digital subscriber line access multiplexor (DSLAM), which acts like a cable node. DSLAMs transmit, in many cases, via twisted-pair telephone cable to in-home IADs, which provide broadband access to the subscriber's computer network and provide IP-based video content to the home's IPTV set-top boxes. These set-top boxes use less energy than either cable or satellite set-top boxes, but an IAD, which commonly uses 4–14 watts (EPA 2012), is a required part of the home set-top box network. The IAD's role in an IPTV set-top box network adds little or no incremental energy consumption for those homes who had subscribed to telco broadband before subscribing to IPTV.[1]

Satellite

Satellite service providers procure content from content providers, and transmit it via satellite and fiber link to national headend facilities. Satellite providers also set-up over-the-air antennas to receive free local broadcast content, which they transmit via fiber link to their headend facilities. These local channels are often broadcast regionally via spot beams, which allow reuse of downlink frequencies. Satellite subscribers receive signals via roof or window-mounted satellite dishes, commonly 18" in diameter, that focus the satellite transmission onto an outdoor unit (ODU), which commonly consists of three low-noise block down converters (LNBs), each of which consumes 1–2 watts to receive signals from a unique satellite position, and an embedded RF switch, which consumes 1–2 watts to package the signals from the LNBs onto a separate coaxial cable for each set-top box, up to a total of three (Dish) or four (DirecTV) set-top boxes. Thin-client, multi-room configurations require only one cable to feed content to the digital video recorder (DVR) server. Dish set-top boxes share the ODU power load equally through the coaxial cables that feeds signals to them from the ODU; while an external power supply powers the DirecTV ODU. Assuming 85% power supply efficiency, a three-LNB ODU uses about 9 watts continuously.[2]

Fiber-To-The-Premises (FTTP) Technology

Some cable and IPTV networks use fiber optic cable to connect the node or DSLAM to the home. These FTTP configurations, which support extensive channel line-ups and high broadband throughput rates, often require an externally-mounted optical network terminal (ONT), which commonly draws a continuous 3–8 watts (EPA 2012), for both broadband network access and pay-TV reception. Customer premise equipment (CPE) in FTTP networks commonly includes an IAD that supports broadband, telephone and TV (i.e. *triple play*) services. While ONTs represent incremental *in-home* energy consumption relative to copper-based networks, some studies argue that FTTP systems, also known as passive optical networks (PONs), consume considerably less energy than wired networks (Baliga et al. 2009).

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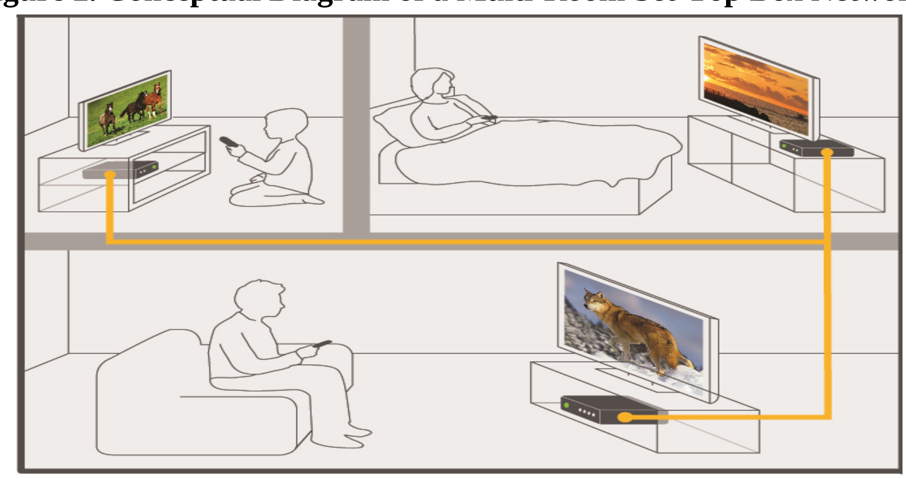
[1] 80% of U.S. homes have broadband access (OECD 2012; U.S. Census 2011).
[2] ODUs are not included in our energy use model for this paper.

Multi-Room Configurations

Figure 2 depicts a multi-room configuration in which a DVR server, located in the downstairs living space in this example, provides content for two client set-top boxes in the upstairs bedrooms. The subscriber can program and view recordings from any room using the multi-room configuration. In the simplest case, the multi-room server maintains a direct connection with the headend and has enough tuners, four in this scenario, to record one show while providing independent video streams to the primary TV and each of the thin-client set-top boxes, which support second and third TVs. This configuration uses much less energy and is more convenient to program than one in which each TV has its own DVR. Current DirecTV DVRs have five tuners, can serve to clients or record up to five live shows at once, and can serve recorded content to up to 15 thin clients. In the rare case that a subscriber requires more than five live streams at once, s/he would need a second DVR server to feed a separate multi-room network. A second approach used by the cable industry involves providing hybrid clients that have the ability to program and play content from the DVR server and that also have their own cable TV tuners that communicate directly with the headend. This configuration, in principle, makes the multi-room network more scalable because each client comes with the needed additional tuner or tuners; however, since today's cable tuners do not power-down effectively, hybrid clients have higher barriers to effective power management implementation.[3] It remains to be seen which approach will achieve lower energy consumption per household for comparable functionality. IPTV multi-room networks are similar except that they require a gateway device or IAD to provide the connection with the IPTV headend. Some multi-room networks have the ability to stream content from the DVR server to IP devices such as internet-enabled TVs, blu-ray players, game consoles, iPads, computers, and smart phones. All of these technologies are designed with the goal of providing viewers with the content they want, when and where they want it.

Figure 2. Conceptual Diagram of a Multi-Room Set-Top Box Network



[3] The National Cable and Telecommunications Association (NCTA) has publicly committed to develop technologies that enable more effective cable system power management.

Methodology

We developed a national set-top box energy use model using recent market data and energy use data from a variety of previous field measurement studies. The analysis focused on pay-TV set-top boxes, which serve nearly 240 million of the approximately 350 million TVs in use nationally (Urban, Tiefenbeck, & Roth 2011), 300 million of which are in pay-TV households. We focus on this subset of set-top boxes because they make-up approximately 90% of total energy consumption of all set-top boxes and because they consume near full-power regardless of whether or not the subscriber is watching or recording a show or has pressed the power button. Two-thirds of pay-TV energy consumption occurs when the subscriber is neither watching nor recording a show. National set-top box stock data used in our analysis is from SNL/Kagan (2012) for 2006–2012. Pre-2006 stock values represent extrapolations of SNL/Kagan (2012) and market assumptions used by NRDC (2011).

Table 1. U.S. Pay-TV Set-Top Box Stock, Millions of Units, 2002–2012

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Cable	50.9	50.8	50.4	50.2	50.8	59.6	65.1	70.1	74.5	79.2	82.5
Cable - IP	-	-	-	-	-	-	-	-	-	-	2.6
Cable - DTA	-	-	-	-	-	-	6.2	12.3	18.5	27.2	32.9
Satellite	47.4	53.6	62.2	68.7	74.3	79.4	82.2	84.1	88.9	91.3	92.9
Telco	-	-	0.08	0.11	0.76	3.6	8.7	14.4	19.3	23.3	27.7
Total	**98**	**104**	**112**	**119**	**126**	**143**	**162**	**181**	**201**	**221**	**239**

Sales values are calculated by multiplying the replacement rate by the set-top box stock of the previous year, then adding the net number of new boxes (i.e. growth in stock). We assume the following replacement rates: 12.5% for cable, cable-IP and cable-DTAs, 20% for satellite, 12.5% for telco set-top boxes. We use unit energy consumption (UEC) values from field measurement studies conducted for the Natural Resources Defense Council (NRDC 2011) and the California Energy Commission's Public Interest Energy Research (PIER) program (Porter, Moorefield, & May-Ostendorp 2006). We use duty cycle figures, 11.5 hours in on mode and 12.5 hours in sleep mode, from Urban, Tiefenbeck, & Roth (2011). Using these data, we calculate the total energy use of pay-TV set-top boxes as a function of stock, power levels, and duty cycle.

Table 2. Average Unit Energy Consumption of Stock, kWh, 2002–2012

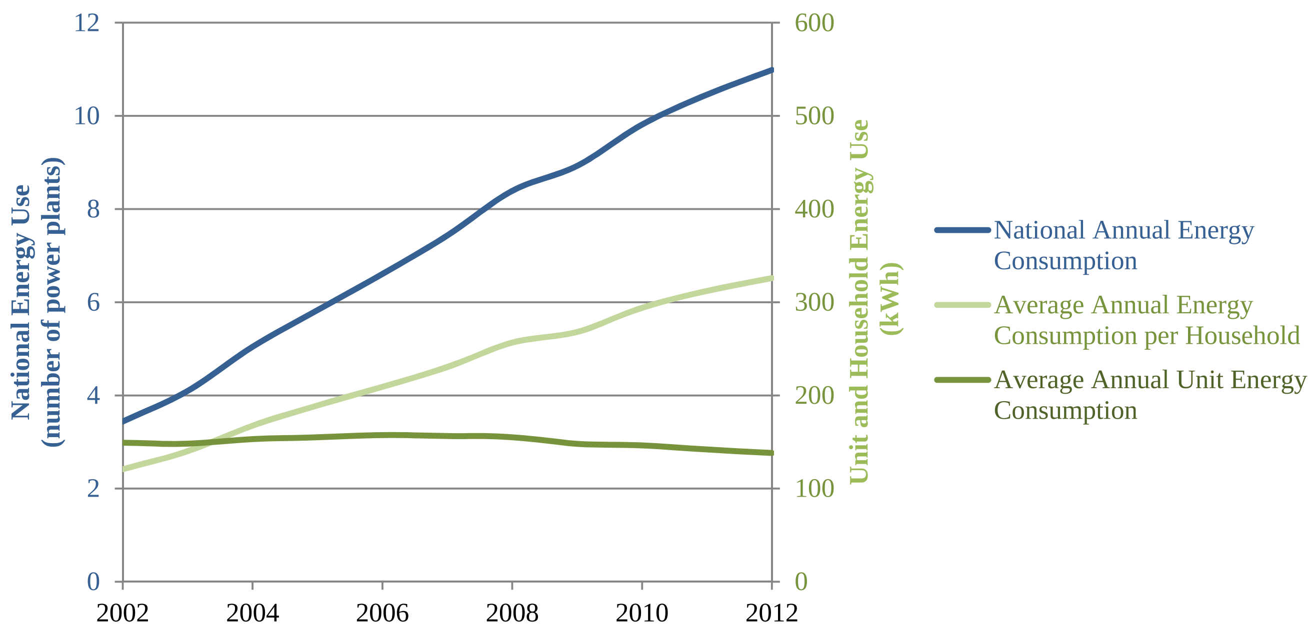
		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Cable	SD	143	142	140	138	137	135	133	132	130	130	130
	SD-DVR	243	241	238	236	233	231	229	226	224	223	223
	HD	203	200	197	194	191	188	185	182	179	179	175
	HD-DVR	358	348	338	328	318	308	298	288	279	277	275
Cable - IP	Client	-	-	-	-	-	-	-	-	-	90	88
	HD	-	-	-	-	-	-	-	-	-	-	109
	DVR	-	-	-	-	-	-	-	-	-	165	161
Cable - DTA		-	-	-	-	-	-	39	39	39	39	39
Satellite	SD	143	137	130	124	117	111	104	98	91	89	85
	HD	203	196	190	183	176	170	163	156	150	143	133
	DVR	358	351	344	337	330	323	316	309	301	294	281

		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Telco	HD	-	-	87	87	87	87	87	87	87	86	84
	HD-DVR	-	-	142	142	142	142	142	142	142	141	139

Annual Energy Use and Savings Potential Estimates

Pay-TV set-top boxes use 33 TWh/year—equivalent to more than 11 coal power plants—costing subscribers $4 billion/year.[4,5] Average pay-TV set-top box annual energy consumption (AEC) per household is up from about 120 kWh a decade ago to almost 325 kWh today, an increase driven primarily by the growing number of set-top boxes per subscriber household. Today's average pay-TV home pays about $40/year just to power set-top boxes. Figure 3 shows U.S. pay-TV set-top box energy consumption trends at the per-unit, per-household and national levels. Our results indicate that average UEC values for each device class have decreased in recent years. However, pay-TV subscribers have upgraded to higher-power device classes (e.g. HD-DVR) over the same timeframe. Increases in the number of set-top boxes per home and the number of pay-TV households in the U.S. have driven up both household and national energy consumption.

Figure 3. U.S. Pay-TV Annual Energy Consumption, 2002–2012



[4] We use the Rosenfeld unit to calculate coal plant equivalency through this paper, for both energy use and energy savings. A Rosenfeld is the equivalent of displacing a 500 megwatt (MW) existing coal plant operating at a 70% capacity factor with 7% transmission and distribution (T&D) losses. Displacing such a plant for one year would save 3 billion kWh/year at the meter and reduce emissions by 3 million metric tons of carbon dioxide (CO_2) per year as described in Koomey (2010).

[5] We assume a national residential electricity price of 11.49 cents per kWh, based on EIA (2012).

Comparison to Other Studies

Table 3 compares results from a number of previous set-top box energy use studies. We focus on the key differences between our results with those presented in the most recent analysis, conducted by Urban, Tiefenbeck, & Roth (2011).

- Urban, Tiefenbeck, & Roth (2011) assume lower satellite set-top box stock than in SNL/Kagan (2012) based on input from a satellite service provider. We use the unaltered stock estimate from SNL/Kagan (2012).
- Urban, Tiefenbeck, & Roth (2011) assume higher satellite stock power levels than we do, likely because of different stock turnover assumptions or older box power level assumptions.

Table 3. Summary of Previous Studies and Energy Consumption Calculations

Year	Units (millions)	Power (W)		UEC (kWh/yr)	AEC (TWh/yr)	Source
		On	Sleep			
Cable						
2010	93	19	17	155	14.4	*This study*
2010	87	18	17	150	13.0	Urban, Tiefenbeck, & Roth (2011)
2008	52	–	–	173	9.0	Sanchez et al. (2010)
2006	77	16	15	134	10.0	Roth & McKenney (2007)
2003	35	16	16	140	4.9	NRDC (2005)
2003	–	–	23	–	–	Davis Energy Group (2004)
2003	65	23	22	–	–	Amann (2004)
2000	49	13	11	103	5.0	Rosen, Meier, & Zandelin (2001)
Satellite						
2010	89	18	16	146	13.0	*This study*
2010	76	14	12	112	8.5	Urban, Tiefenbeck, & Roth (2011)
2008	51	–	–	206	10.5	Sanchez et al. (2010)
2006	70	15	14	129	9.0	Roth & McKenney (2007)
2003	32	–	–	–	–	NRDC (2005)
2003	–	–	16	–	–	Davis Energy Group (2004)
2003	32	18	17	–	–	Amann (2004)
2000	13	17	16	140	1.9	Rosen, Meier, & Zandelin (2001)
Telco						
2010	19	12	11	99	1.9	*This study*
2010	16	14	12	115	1.8	Urban, Tiefenbeck, & Roth (2011)
2008	3	–	–	164	0.5	Sanchez et al. (2010)

Source: Table was modified from Urban, Tiefenbeck, & Roth (2011) to include our analysis.

Energy Savings

To illustrate the magnitude of opportunities to reduce set-top box energy consumption, we break down today's base case energy use by device category—DVR, receiver, client, and DTA—where IPTV set-top boxes are clients (Table 4). We then present a calculated savings analysis associated with a few scenarios, all grounded in the current number of pay-TV households and televisions served.

Table 4. 2012 Base Case: Energy Use Estimates by Set-Top Box Type

	On			Sleep			UEC	Units	AEC	Power Plants
	Watts	Hours	kWh/yr	Watts	Hours	kWh/yr	kWh/yr	Millions	TWh/yr	
DVRs	33	11.5	138	31	12.5	142	280	55	15	5
Receivers	13	11.5	55	12	12.5	55	110	148	16	5.4
Clients	11	11.5	46	9	12.5	41	87	2	0.2	0.1
DTAs	4.5	11.5	18	4.4	12.5	20	39	33	1.3	0.4
U.S. Total								**239**	**33**	**11**

There are many technologies and practices in discussion today with high technical savings potential. If we reduce sleep mode power levels for all set-top boxes to 5 watts, consistent with the stated goal of the cable industry (NCTA 2011), then we would save the equivalent of 4.2 coal power plants. We recognize that satellite and telco have not set such a goal.

With a ubiquitous 5 watt sleep mode, each 1 hour reduction of on mode time would save 0.3 coal power plants.[6] The average U.S. household watches approximately 8–9 hours of TV per day (Nielsen 2011). Since multi-room DVRs must be on when recording shows or when thin-client set-top boxes are in use, it may be difficult to achieve average on mode times of less than 11.5 hours. However, we should target less than 11.5 hours for non-DVR set-top boxes. There are several means to achieving improved duty cycles. Although many service providers program their set-top box remote controls to simultaneously power on and off both the set-top box and the TV at the press of a button, sometimes the set-top box and TV get out of synch such that the TV turns off when the set-top box turns on. Service providers could work with other consumer electronics industry market actors to address this problem. One possible means for addressing this issue is to update the High-Definition Multimedia Interface (HDMI) specification to require a standard way for set-top boxes to know the power state of the TV. Today's HDMI spec has an optional means for doing this called Consumer Electronics Control (CEC) that manufacturers have implemented in proprietary ways.

If we develop a scenario in which a) each of today's roughly 100 million subscribers owns a DVR that uses 27 and 5 watts in on and sleep modes and b) all additional set-top boxes are thin-clients with power levels comparable to Apple TV (2.1 and 0.2 watts in on and sleep), then we would save the equivalent of 6 coal power plants relative to the base case even though we have added DVR capability to tens of millions of households.

It would save the equivalent of one coal power plant if satellite providers would auto-power-down their DVRs to 5 watts.[7] Whereas cable and telco providers can store rich program guide content in the cloud, satellite service providers cannot count on their subscribers having broadband access, so satellite providers continually update guide data on the hard drive, preventing DVR power down. One savings approach would be for satellite providers to offer cloud guides to broadband connected clients. One industry representative estimated that 75% of subscribers had broadband and 20% of their set-top boxes were connected to broadband.

Cable and telco systems might use less total energy if they streamed content from the cloud as opposed to storing it on local DVRs. This *network DVR* model would increase the

[6] This does not apply to Cable-DTAs.

[7] Assuming a technical potential savings of converting today's entire stock of satellite DVRs to devices with 5 watt sleep capability.

energy consumption of datacenter and network equipment while reducing in-home energy consumption. Streaming content would involve a complex assessment of equipment utilization and marginal vs. average energy consumption. To put this discussion into perspective, if we divide the total energy consumed by the internet by the total volume of data transmitted, we get about 2 kWh/GB (Taylor & Koomey 2008). Since a Netflix movie requires the transmission of about 1.5 GB of data, the average energy consumption associated with this data transmission is equivalent to running a 1,000 watt hair blow-dryer for 3 hours. Average energy consumption is high because the utilization of network equipment is generally just a few percentage points (Lanzisera, Nordman, & Brown 2010). With today's always-on network equipment, it costs society a lot of energy to have an internet but not much marginal energy to transmit additional data given that network equipment power levels do not scale with the rate of data transmitted. Commercial and residential network equipment uses 18 TWh/year on a national scale (Lanzisera, Nordman, & Brown 2010), far less than the 33 TWh/year used by today's set-top boxes. It is clear that network gear that effectively scales power to throughput would save a significant amount of energy.

Policy Challenges and Opportunities

Unique characteristics of the pay-TV industry present several challenges for energy efficiency policymakers. First, large pay-TV service providers develop, install and manage the configuration of set-top box application software, which can determine how much energy a set-top box consumes when deployed at the subscriber's household. In many ways pay-TV service providers do more specification definition, software development and device configuration than computer manufacturers like Dell do for laptops, which most computer OEMs source from turn-key hardware vendors like Compal, Quanta and Wistron. These vendors, known as original design manufacturers (ODMs), design, verify, manufacture, and ship laptops and they provide warranty and service support on behalf of computer OEMs, which manage the brand, product marketing and sales of laptop computers. By developing and in some cases installing set-top box application software, large service providers act like manufacturers. They play a critical role in determining how much energy set-top boxes consume, which can change over time as service providers update software, change set-top box configuration settings, or offer new features that alter usage patterns. This distinction presents a challenge for policymakers, who have historically addressed device manufacturers and retailers with policy tools. Second, subscribers have little influence over what set-top box they get. They can typically choose between one cable, two satellite, and sometimes one telco service provider. Subscribers can then choose a subscription package, after which the service provider deploys either a refurbished, older set-top box or unused, new set-top box chosen by their procurement team. The consumer has little influence over what set-top box is deployed.

There are several implications associated with these two challenges. First, policymakers should carefully evaluate whether or not to develop energy efficiency policies that regulate the service provider instead of the set-top box manufacturer. This issue raises several questions, for example how to include stand-alone set-top boxes like TiVo and over-the-top (OTT) video streaming set-top boxes like Apple TV that are primarily sold through retail channels as opposed to deployed by a service provider. Second, electric utility program offices will find it difficult to develop traditional incentive programs because of the difficulty in attributing energy savings to their efforts. This is difficult because large service providers make set-top box procurement decisions on a national scale, so incentive dollars associated with regional efficiency improvements from one or even a few utility territories combined may not suffice to offset the cost to the service modifying its national-scale procurement or development decisions. Third, it is important—but difficult to accomplish with today's policy tools—to verify that deployed set-top boxes continue to meet minimum efficiency levels over time. Fourth, policymakers should keep system-wide energy implications in mind when deploying device-level policy tools. The U.S. Environmental Protection Agency (EPA) did this when they developed ENERGY STAR specification levels for multi-room DVRs. Fifth, policymakers should take a look at the global policy and legal framework in place for the pay-TV industry. For example, policymakers should review legal barriers to efficient network DVR implementation. Today's interpretation of copyright law, which requires service providers to store individual copies of shows for each subscriber, increases the cost and energy consumption of network DVR implementations. Service providers would benefit from reduced capital depreciation and operational and maintenance expenses resulting from a shift to network DVR. The dollar cost and association greenhouse gas emissions of hot-swapping a failed drive at a datacenter are much lower than driving a van to a subscriber's household to replace a failed DVR and bringing the unit back to the shop for repair and redeployment. Moreover, cloud content storage and transmission likely draws less marginal energy than DVR use, especially in an environment, like today's, where DVRs always draw near full power. The benefit of utilizing network DVRs is an important area for future research.

While there are many challenges, the pay-TV industry has several unique attributes that can lead to opportunities for policymakers and further research. Trained technicians have access to homes, service providers have frequent communication with subscribers, and they have data about set-top box stock, replacement, and configuration. They also know when set-top boxes are powered down, and they control the video distribution system. This creates several opportunities. First, the efficiency community could collaborate with service providers to understand the energy consumption of customer premise equipment, including set-top boxes, network gear and auxiliary equipment like satellite dish electronics. Service providers could provide information about stock and configuration while adding features to set-top boxes that would enable participating subscribers to report usage data to researchers. Second, service providers could work with industry associations to develop and implement standards that would enable set-top boxes to know the power state of the TV they serve and of other connected consumer electronics devices in order to improve set-top box duty cycle. Service provider technicians could configure home entertainment centers to take advantage of such capabilities and train subscribers what role they can play in reducing energy consumption. And third, service providers can work with their infrastructure and set-top box supply chains to develop new cloud video streaming and in-home, client-server architectures that provide exceptional viewing experiences with reduced greenhouse gas emissions.

Conclusions

We developed a national set-top box energy use model using recent market and energy use data to estimate historical and future set-top box energy use. Both national and per-household energy use have increased over time, primarily because of the growing number of set-top boxes per subscriber household. Nearly 11 coal power plants are required in the U.S. to power today's pay-TV set-top boxes. Per-household energy use has nearly doubled from 150 kWh a decade ago to almost 350 kWh today. Fortunately, it is possible in the near term to save energy cost effectively in four different ways: reducing on mode power levels, reducing sleep mode power levels, reducing the amount of time boxes spend in higher-power modes, and shifting where recording and playback occur within the network. We estimate that the savings potential associated with these opportunities is 30-50%, depending primarily on how effectively service providers develop and deploy the technologies and practices necessary to achieve effective power scaling and to move to more efficient video distribution architectures. Set top boxes have proven particularly challenging to improve relative to other electronic products like televisions, computers, and power supplies. The split financial incentives to save energy among manufacturers, service providers, and final users create daunting market barriers to pursuing purely voluntary market approaches like labeling and utility rebates. Likewise, the rapid technological innovation in networks threatens to overtake the secure content distribution models built by cable and satellite service providers over a period of decades. A rapid shift to more efficient boxes and means of secure data transfer would strand billions of dollars of their assets. However, we find these challenges surmountable with good program design, readily available information about product efficiency differences, and the integration of appropriately structured and targeted mandatory efficiency standards. The value of the resulting energy savings may be small at the individual box or household level, but it is enormous in total, and entirely worthy of continued pursuit by the market transformation community.

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