US light bulb standards save billions for consumers but manufacturers seek a rollback

Trump administration will soon announce plans

Appliance Standards Awareness Project and American Council for an Energy-Efficient Economy

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Appendix A: A history of light bulb standards

This appendix describes the origins and structure of the federal law that established US light bulb standards, the actions that triggered the backstop, the markets' response to the federal law, related state and international standards, and the National Electrical Manufacturers Association's (NEMA) effort to avoid backstop implementation.

State standards lead to a two-stage federal standard with a "backstop"

In the mid-2000s, several states began to consider setting standards designed to make light bulbs more energy efficient. California acted first, setting initial standards in 2004. Several other states, including New York, began legislative proceedings to consider state standards, with Nevada enacting standards in mid-2007.

Manufacturers strongly prefer a single national standard rather than state-by-state requirements, and national standards offer the potential for larger savings. As a result, manufacturers worked with energy efficiency, consumer, and environmental advocates including ASAP and ACEEE, with input from state policy makers to develop recommendations for Congress. In 2007, Congress approved the first national light bulb standards and President Bush signed them into law, based on a joint recommendation. The enacted standards established a two-stage transition to energy-efficient light bulbs. Stage 1 applied only to "A-type" (the most common shape) incandescent light bulbs and required savings of 25 – 30% compared to traditional incandescent bulbs. This standard took effect over a three-year period starting in 2012.

For stage 2, Congress required the US Department of Energy (DOE) to conduct a public rulemaking to develop an improved standard. That new standard would not be limited to incandescent technology. Congress also required DOE to determine additional bulb shapes, sizes, and special categories that would be covered (42 U.S. Code 6295(i)(6)(A)(i)). But because DOE had a history of missing legal deadlines and to provide a firm efficiency-improvement target for manufacturers and other innovators, the law included a critical protective provision: a "backstop" standard. If DOE missed any of a series of legislatively required procedural steps, including a January 2014 deadline for initiating the rulemaking and a January 2017 deadline for a final rule, or failed to develop a standard that met a minimum savings threshold, then an automatic default standard would be triggered, with compliance required as of January 2020. The law set the minimum savings threshold at "savings that are greater than or equal to the savings from a minimum efficacy standard of 45 lumens per watt" (42 U.S. Code 6295(i)(6)(v)).[1] (A lumen is a unit for measuring light output.) The backstop standard, also 45 lumens per watt, could easily be met by CFLs and LEDs, but would require big but theoretically achievable improvements for incandescent technology.

The backstop is triggered and DOE expands the range of covered bulbs

DOE's failure to comply with two of the statute's required steps has triggered the backstop. First, DOE failed to initiate the rulemaking for general service incandescent lamps by January 1, 2014 due to an appropriations rider championed by Rep. Michael Burgess (R-Texas), who was opposed to light bulb standards. Second, DOE failed to complete a final rule by January 1, 2017.

Separate from those deadlines, DOE could not set a standard that meets the statute's savings threshold and still allows significant sales of currently available halogen light bulbs. For a standard to generate "savings that are greater than or equal to the savings from a minimum efficacy standard of 45 lumens per watt" and still permit sales of today's halogen light bulbs, which have much lower efficacy, the standard would have to make up for the less-efficient halogens by requiring that other bulb types (LEDs and CFLs) become more efficient than they would be without new standards. Because these bulb types already use a small fraction of the electricity used by a halogen bulb, standards that push them to be even better could compensate for only a few halogen bulb sales. Therefore, any proposed standard that considers each technology separately could not meet the savings threshold. That triggered the backstop in a third way.[2]

DOE did, however, fulfill its obligation to specify which bulbs would be covered by the 2020 standards. DOE's definitional rules apply the stage 2 standards to a wide range of light bulbs. In addition to A-type light bulbs, compliance with the 2020 standards is now required for reflector (cone-shaped bulbs used in recessed ceiling and track lighting fixtures), globe-shaped, 3-way, and a range of decorative bulbs such as candelabra-shaped ones. LED versions of all these light bulbs types are readily available (82 Federal Register 7276 and 7322).

The market responds to minimum standards

The 2007 law unleashed a wave of lighting innovation, focused first on improved incandescent and later on LED technology. At the time the law was enacted, improved incandescent bulbs using halogen gas inside the bulb and other refinements already existed but were expensive, costing about $5 each. In

[1] In its entirety, the backstop clause reads: ''(v) BACKSTOP REQUIREMENT.—If the Secretary fails to complete a rulemaking in accordance with clauses (i) through (iv) or if the final rule does not produce savings that are greater than or equal to the savings from a minimum efficacy standard of 45 lumens per watt, effective beginning January 1, 2020, the Secretary shall prohibit the sale of any general service lamp that does not meet a minimum efficacy standard of 45 lumens per watt."

[2] DOE acknowledged the triggering of the backstop several times during the Obama administration (e.g., 81 Federal Register 14540, 82 Federal Register 7316, and its "Statement Regarding Enforcement of 45 LPW General Service Lamp Standard"), but has not confirmed those prior statements since President Trump took office.

response to the minimum standard, manufacturers developed a new generation of less-expensive halogen incandescent bulbs that comply with the stage 1 standards. These bulbs typically cost about $1.50 each. Compact fluorescent lamps (CFLs) offered consumers an even more efficient choice.

In 2007, colored LEDs were used in specialty lights like traffic signals or as indicator lights, but an LED that could cost effectively produce white light for general illumination did not yet exist. With the expectation of stronger standards in 2020, researchers ramped up work on white light LEDs, and soon a range of new and established lighting companies brought LEDs to market.[3] By 2014, LEDs started to take off in the marketplace, generally taking market share from CFLs. Figure A1 below shows the relative market share (i.e., sales) of conventional incandescent, halogen, CFL, and LED A-type light bulbs over time.

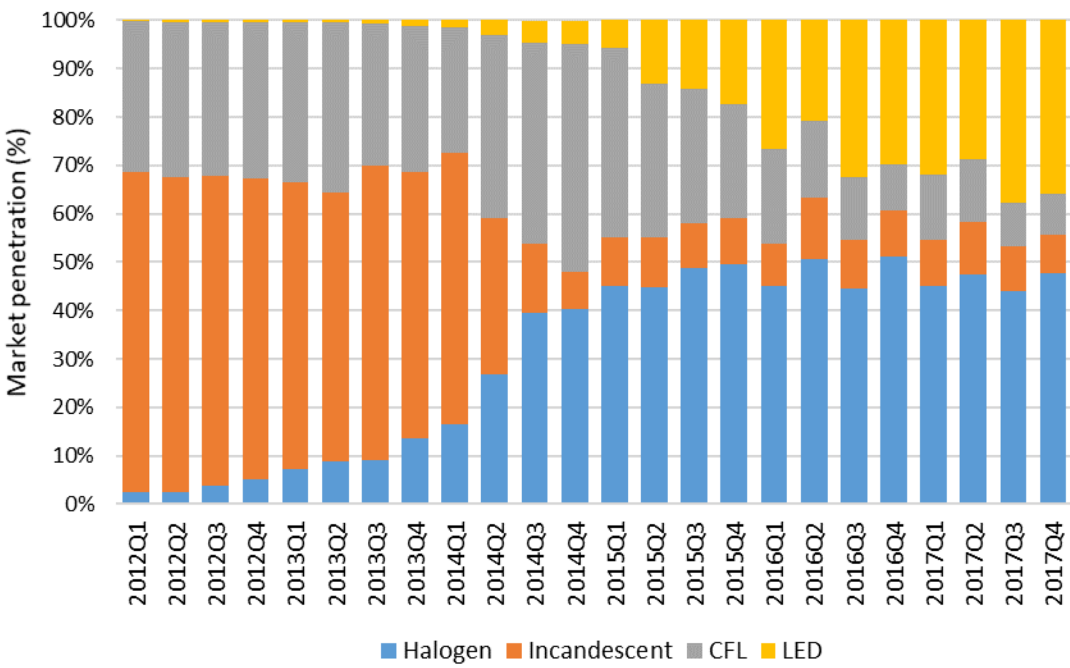

Figure A1. A-type bulb market share by technology. *Source:* National Electrical Manufacturers Association 2018.

As the figure shows, A-type halogen bulb sales started increasing in 2012 in response to the stage 1 standards but have plateaued since 2015. CFL market share reached its peak in 2014, but CFLs have since lost market share to LEDs. The A-type bulb market appears to have reached equilibrium since 2015; efficient bulbs (LEDs and CFLs) have about a 45% market share, and halogen and conventional incandescent market share has stabilized at about 55%. Because CFLs and LEDs last much longer than halogen and incandescent bulbs, the market share figures are not the same as the share of sockets with each technology type installed. An equal split of sales indicates that LEDs have a larger and growing share of sockets that contain an A-type bulb. (Similarly detailed data are not available for the bulb types

[3] The scientists who developed the technology enabling white light LEDs won the Nobel Prize in Physics in 2014 for work carried out in the 1990s. Over the past decade, DOE-funded research played a major role accelerating the advance of LED technology into market applications. A recent DOE brochure describes DOE's ongoing work: https://www.energy.gov/sites/prod/files/2017/01/f34/ssl-overview_oct2017.pdf

added for stage 2, but LED and CFL market share is generally much lower and conventional incandescent much higher for those bulb types.)

With LEDs' improving performance and declining prices, manufacturers stopped investing in improved halogen technology. One manufacturer, Venture Lighting, brought to market a halogen bulb with efficiency significantly above the stage 1 standards in 2013, but could not gain wide distribution. With manufacturers and retailers ramping down the marketing of CFLs, once compliance with the 2020 standards begins, LEDs will likely dominate the market for the range of bulbs covered by stage 2 standards. LED technology enables a broad array of choices in lighting color, controllability, and bulb shapes. LEDs can be built into traditional bulb shapes as well as flat panels, enabling new light fixture designs. They also offer the potential for a range of innovative features not possible with other technologies. Some recent LED bulbs can be controlled by the user's smart phone to change colors or dim (without the need of a dimmer switch) and even incorporate a speaker to play music. Others advertise light color changes that can mimic the progression of daylight, intended to support healthy sleep patterns. New innovations may be around the corner (CNET 2018).

State and international standards are moving forward

In general, federal standards for a product preempt state standards. However, the 2007 law included a special provision allowing California to implement light bulb standards in 2018 if DOE failed to adhere to required procedural steps, the same condition that triggered the backstop. California adopted state standards in 2008, anticipating that the backstop might be triggered, and the obligation to comply with the state standards began on January 1, 2018.

In 2017, Vermont enacted the backstop standard into state law as a protective measure, covering the same range of bulbs as the stage 2 standards. If DOE attempts to remove any bulb types from the federal standard, and hence from federal preemption, the state can enforce its standards. Bills in other states include similar protective provisions.

Internationally, European Union standards will complete the phaseout of halogen light bulbs on September 1, 2018. Canada adopted the US stage 1 standards and has begun the process for adopting the next stage. Standards are also pending in Australia. Recently, the United Nations, in collaboration with Signify/Philips Lighting and Natural Resources Defense Council, completed model regulations intended for use in developing countries that phase out conventional incandescent and halogen bulbs. These model regulations require efficiency levels stronger than the US stage 2 standards (UN Environment 2018).

NEMA's opposition to backstop implementation

NEMA, which represents light bulb manufacturers, has opposed DOE's conclusion that the backstop has been triggered and compliance will be required beginning in 2020. Under NEMA's alternative legal interpretation, DOE can still complete the rulemaking that was due by January 2017, meet the minimum savings threshold, and avoid implementing the backstop (NEMA 2016; NEMA 2017). NEMA sued DOE after the 2017 definitional rules were published and reached a settlement with the Department in summer 2017. That settlement does not mention the backstop standard, but it implies that DOE still has to decide whether to issue new standards for incandescent bulbs, which would illegally roll back the backstop if they set minimum efficiency at less than 45 lumens per watt. It also says that DOE may reassess the January 2017 definitions, presumably for the purpose of removing all or some of the newly added bulb types from the scope of standards. In addition, the settlement requires DOE to issue a supplemental notice of proposed rulemaking for LED bulb standards only and consider updated standards for CFLs, implying that DOE may regulate light bulbs based on the technology used for producing illumination (NEMA v. DOE 2017). The settlement agreement provides DOE with an opportunity to attempt to implement NEMA's interpretation of the law.

Manufacturers, represented by NEMA, also brought suit against California, arguing that DOE had met procedural requirements and thus California could not implement state standards. (As noted, these are the same procedural requirements that, if not met, trigger the backstop.) A federal court ruled against NEMA, allowing California's standards to take effect on January 1, 2018. The court rejected NEMA's arguments that the backstop had not yet been triggered (NEMA v. CEC 2017). NEMA subsequently dropped its suit and manufacturers

What's next?

DOE is scheduled to complete a supplemental proposed rule for light bulb standards later in 2018. This proposed rule will likely reveal any new legal strategies from the Department. A final rule will likely follow in 2019. If the final rule denies the applicability of the 2020 backstop or narrows the range of bulbs covered, that action would violate the 2007 law, as well as the anti-backsliding provision of the national appliance standards law, which prohibits DOE from weakening standards. Almost assuredly, those potential DOE actions or others to undermine the 2020 standards would lead to lawsuits against DOE. While manufacturers and retailers must comply with the backstop as of January 1, 2020, lawsuits may be unresolved until late 2019 or even later, creating significant uncertainty for manufacturers and retailers. In addition, the federal law includes a special provision empowering state Attorneys General to enforce light bulb standards. Whether or not DOE denies the applicability of the backstop, individual states may seek to enforce the backstop against retailers and manufacturers that fail to comply (42 U.S. Code 6304).

Appendix B: Detailed national results

Annual electricity savings from the light bulb standards grow from 68 billion kWh in 2020, reducing consumer electricity bills by $10 billion, to about 140 billion kWh in 2025, worth $22 billion in savings. Annual savings grow as more and more bulbs in use comply with stage 2 standards. Accounting for both stage 1 and stage 2 standards, cumulative electricity savings reach more than 4 trillion kWh through 2050, worth about $665 billion in consumer bill savings (expressed in constant 2017 dollars but without discounting). Table B1 provides the annual electricity and electricity bill savings in 2020 and 2025, as well as cumulative savings through 2050 due to the standards. The table separates stage 2 savings into savings from A-type bulbs and from five categories of bulb types included in the expanded scope of coverage. As detailed in the methodology (appendix D), all of these estimates take into account the share of sockets that would contain compliant bulbs even in the absence of standards.

Table B1. Annual electricity and electricity bill savings in 2020 and 2025 and cumulative savings through 2050 from the light bulb standards

		Annual savings in 2020		Annual savings in 2025		Cumulative savings through 2050	
		Electricity (billion kWh)	Electricity bills (billion 2017 $)	Electricity (billion kWh)	Electricity bills (billion 2017 $)	Electricity (billion kWh)	Electricity bills (billion 2017 $)
Stage 1	A-type	42.5	6.2	50.3	7.9	2,018	323
Stage 2	A-type	5.9	0.9	10.8	1.7	314	51
	Reflector	11.1	1.6	41.1	6.3	855	134
	MR	1.8	0.2	6.1	0.9	152	22
	Decorative	5.1	0.7	28.3	4.4	702	114
	Globe	0.5	0.1	3.0	0.5	83	13
	Misc. A-type	1.3	0.2	2.9	0.5	59	10
Stage 2 total		25.7	3.6	92.1	14.2	2,166	343
Total		**68**	**10**	**142**	**22**	**4,184**	**666**

Table B2. Annual emissions reductions in 2020 and 2025 and cumulative reductions through 2050 from the light bulb standards

		Annual emissions reductions in 2020			Annual emissions reductions in 2025			Cumulative emissions reductions through 2050		
		NOx (thous. tons)	SO2 (thous. tons)	CO2 (MMT)	NOx (thous. tons)	SO2 (thous. tons)	CO2 (MMT)	NOx (thous. tons)	SO2 (thous. tons)	CO2 (MMT)
Stage 1	A-type	10.9	12.1	18.3	11.8	14.3	20.9	476	614	811
Stage 2	A-type	1.5	1.7	2.5	2.5	3.1	4.5	73	94	125
	Reflector	2.8	3.2	4.8	9.6	11.7	17.1	199	255	343
	MR	0.4	0.5	0.8	1.4	1.7	2.5	35	45	61
	Decorative	1.3	1.4	2.2	6.7	8.1	11.8	163	210	280
	Globe	0.1	0.1	0.2	0.7	0.8	1.2	19	25	33
	Misc. A-type	0.3	0.4	0.6	0.7	0.8	1.2	14	18	24
Stage 2 total		6.6	7.3	11.1	21.6	26.2	38.4	502	647	866
Total		**18**	**19**	**29**	**33**	**40**	**59**	**978**	**1,261**	**1,677**

Figure B1 shows the breakdown of cumulative electricity bill savings. (The breakdowns of cumulative electricity savings and emissions reductions are very similar to the electricity bill savings breakdown.) Cumulatively, the stage 2 standards account for slightly more than half of the total bill savings from the light bulb standards. The vast majority of savings achieved by stage 2 is the result of the expanded scope of light bulbs covered. Savings from the expanded scope are especially large because these market segments were unaffected by stage 1. As a result, unlike with A-type bulbs, very inexpensive and inefficient conventional incandescent bulbs retain significant market share absent standards. A-type light bulbs contribute a significant but smaller share of stage 2 savings. In stage 1, a significant portion of the A-type bulb market has already shifted to long-lived CFLs and LEDs. We assume that trend will continue, which results in 90% of the in-use stock of A-type bulbs being LEDs by 2030 even without the stage 2 standards.

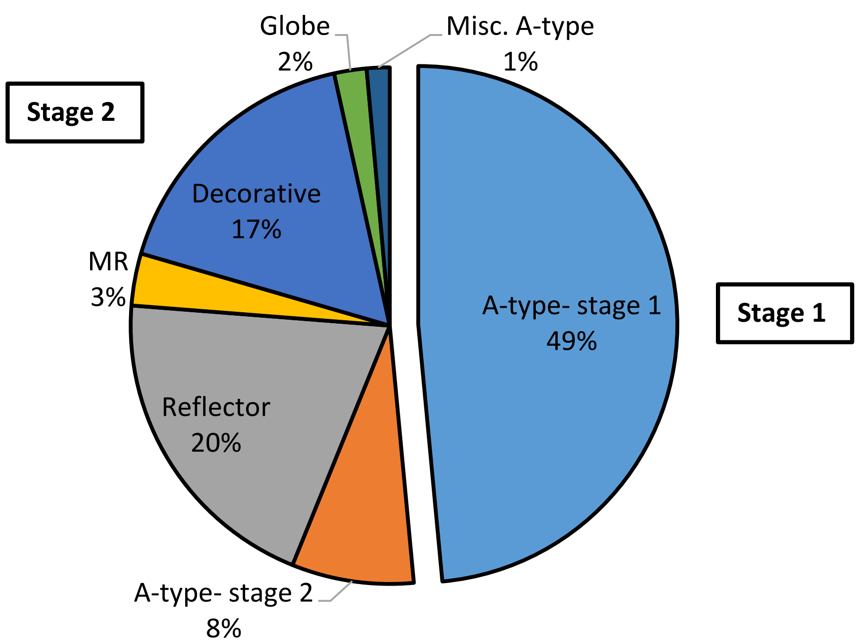

Figure B1. Breakdown of cumulative electricity bill savings through 2050

The savings from the stage 2 standards for A-type bulbs make up 8% of the total savings from the standards, whereas the savings from the expanded scope account for 44% of the total. Reflector bulbs account for the largest share of stage 2 savings, contributing 20% to the total cumulative savings. Decorative bulbs, primarily candelabra bulbs, are the second largest, making up 17%. Multifaceted reflectors or MR light bulbs, globe-shaped bulbs, and miscellaneous A-type bulbs represent 3%, 2%, and 1% respectively. (Miscellaneous A-type bulbs consist of rough service, vibration service, shatter resistant, 3-way, and very high light output bulbs.)

Notably, even the lamp types that contribute relatively small savings are still significant. As shown in table B1, each lamp type contributes cumulative electricity bill savings of at least $10 billion for consumers. For comparison purposes, the combined electricity savings from MR, globe, and miscellaneous A-type bulbs (which make up about 5% of the total light bulb savings) are greater than the savings from DOE's 2017 residential central air conditioner and heat pump standards.

Figure B2 shows annual electricity bill savings over time. Annual savings increase sharply after 2020 with the stage 2 standards. By 2025, most light bulbs in use will be compliant bulbs. The annual savings rate from stage 2 standards declines some after 2025 because a growing portion of consumers would select energy-efficient bulbs even if these standards did not exist. Annual savings from the stage 1 standards continue to increase over time, mainly due to projected increases in residential floor space, which results in more bulbs in use.

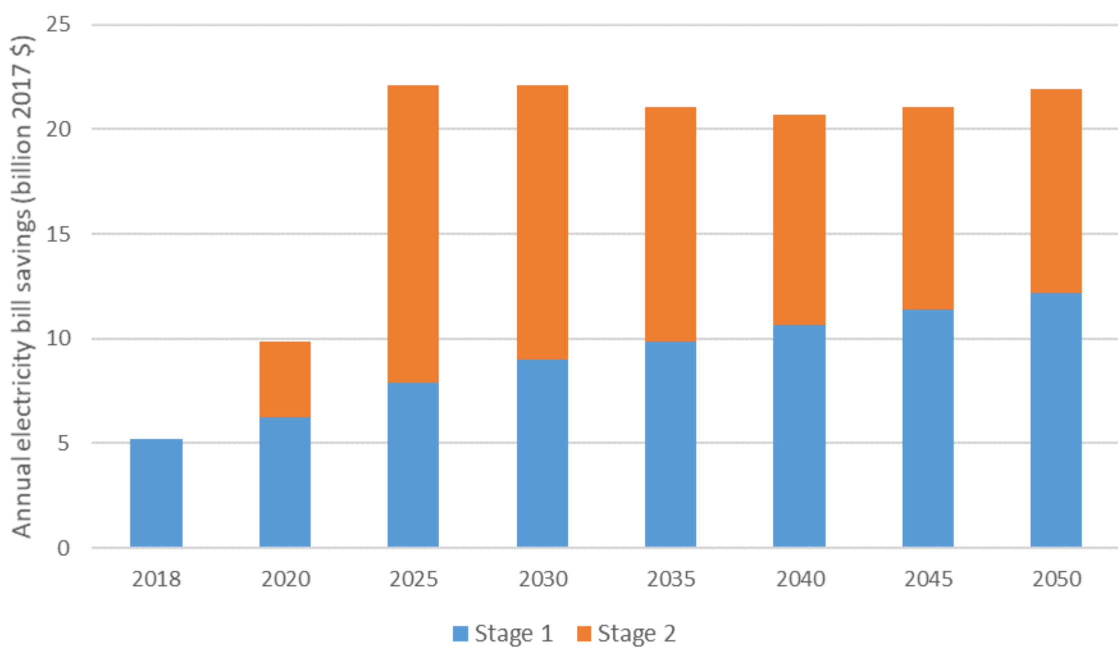

Figure B2. Annual electricity bill savings

Figure B3 shows how the light bulb standards affect consumer expenditures and savings. Electricity bill savings and total consumer savings (including the change in spending on light bulbs) largely reflect the electricity savings. Notably, total savings exceed bill savings starting in the early 2020s. Typically, products meeting an efficiency standard are modeled with an estimated incremental cost, resulting in net savings that are lower than electricity bill savings. That relationship holds during the first part of the analysis period for light bulbs. However, since efficient bulbs last much longer, consumers spend less on bulbs over time because they purchase fewer bulbs, even though they cost more on a per bulb basis (see text box table in the Issue Brief). Therefore, their total spending on bulbs is less with standards than without standards by the early 2020s. In 2025, consumers will save about $1.7 billion on bulb purchases in addition to their electricity bill savings. Cumulatively by 2050, consumers will spend $38 billion less on light bulbs due to efficiency standards. Calculated on a net present value basis using a 5% real discount rate, total savings for consumers over the analysis period are more than $360 billion.

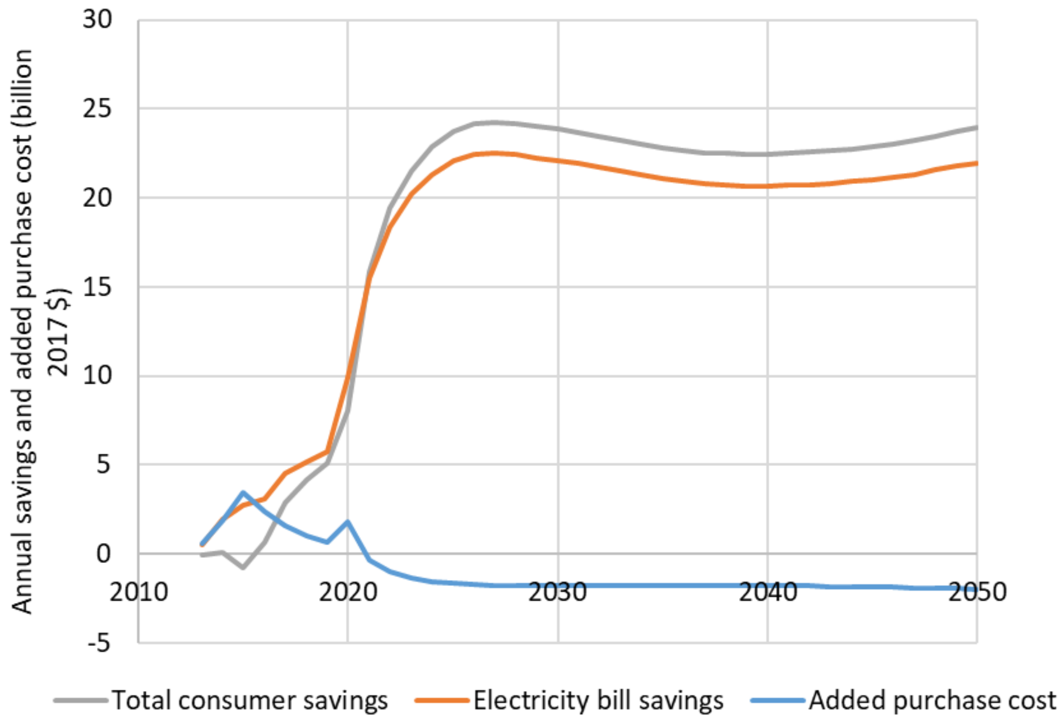

Figure B3. Consumer economic impacts

Appendix C: State-by-state results

This appendix consists of two tables that show electricity and bill savings (aggregate and average household) and emissions reductions in each of the 50 states and the District of Columbia in 2025. Emissions reductions are the result of electricity savings at fossil fuel power plants, but because power is produced regionally, the emissions reductions may occur at a plant outside of a state's borders. In addition, because total NO_x and SO_2 emissions are capped in some areas, the reductions due to the standard may help meet the caps rather than reduce total emissions. Appendix D explains the methodology used for calculating state-level impacts.

Table C1. Annual electricity, electricity bill, and per-household electricity bill savings in 2025

	Annual savings in 2025								
	Electricity (GWh)			Electricity bills (million 2017$)			Per-household electricity bills (2017$)		
	Stage 1	Stage 2	Total	Stage 1	Stage 2	Total	Stage 1	Stage 2	Total
Alabama	791	1,440	2,231	101	184	285	55	95	149
Alaska	107	197	303	24	44	67	96	165	261
Arizona	1,046	1,890	2,936	130	233	363	53	92	145
Arkansas	488	888	1,376	60	108	168	53	91	143
California	5,470	9,961	15,432	1,207	2,180	3,387	94	163	257
Colorado	876	1,572	2,448	101	180	281	49	85	134
Connecticut	579	1,053	1,632	121	219	341	90	155	245
Delaware	149	272	420	25	45	70	72	124	196
District of Columbia	118	233	351	18	35	53	66	113	179
Florida	3,158	5,793	8,950	386	699	1,085	52	90	142
Georgia	1,543	2,831	4,374	190	345	534	52	91	143
Hawaii	193	347	540	58	105	163	129	224	353
Idaho	255	458	712	24	43	68	41	71	111
Illinois	2,051	3,758	5,809	314	565	880	65	113	179
Indiana	1,074	1,957	3,031	155	279	434	62	106	168
Iowa	531	958	1,488	62	111	173	50	86	136
Kansas	477	875	1,352	64	116	180	57	99	156
Kentucky	734	1,330	2,064	73	131	204	42	73	115
Louisiana	739	1,372	2,111	86	158	244	49	86	135
Maine	235	423	659	39	70	109	71	123	193
Maryland	930	1,712	2,642	165	299	464	76	131	207
Massachusetts	1,093	1,996	3,089	218	396	613	85	147	232
Michigan	1,649	3,012	4,661	272	488	759	70	122	192
Minnesota	912	1,654	2,566	113	203	316	53	91	144
Mississippi	469	856	1,326	61	111	172	55	96	151
Missouri	1,013	1,853	2,866	125	227	352	53	91	144
Montana	176	318	495	19	33	52	45	78	123
Nebraska	317	578	895	34	61	94	45	78	123
Nevada	440	788	1,228	48	85	134	47	81	128
New Hampshire	223	403	626	43	77	120	82	142	225
New Jersey	1,365	2,541	3,905	268	489	757	84	145	229
New Mexico	326	588	914	40	72	112	52	91	143
New York	3,103	5,726	8,830	961	1,700	2,661	132	229	361
North Carolina	1,630	2,985	4,615	209	377	587	55	95	150
North Dakota	130	246	377	13	24	37	42	73	116
Ohio	1,965	3,596	5,561	300	541	840	65	113	178
Oklahoma	624	1,156	1,781	74	135	209	51	88	138
Oregon	660	1,210	1,870	68	122	190	44	76	119
Pennsylvania	2,119	3,869	5,988	367	656	1,023	74	128	202
Rhode Island	175	318	493	34	62	96	83	144	228
South Carolina	785	1,434	2,220	116	208	324	63	109	171
South Dakota	142	262	404	16	29	45	48	83	131

Tennessee	1,077	1,972	3,049	106	194	299	42	72	114
Texas	3,968	7,368	11,335	405	749	1,154	44	75	119
Utah	392	711	1,103	42	74	116	45	78	123
Vermont	110	198	308	20	36	56	78	134	212
Virginia	1,320	2,450	3,770	174	316	491	56	98	154
Washington	1,152	2,116	3,268	105	190	295	39	67	106
West Virginia	316	573	889	44	79	123	60	103	163
Wisconsin	987	1,805	2,791	171	309	480	74	128	202
Wyoming	97	179	276	10	19	29	45	79	124
U.S.	**50,277**	**92,080**	**142,357**	**7,879**	**14,209**	**22,088**	**67**	**116**	**183**

Table C2. Annual emissions reductions in 2025

	Annual emissions reductions in 2025								
	NOx (tons)			SO_2 (tons)			CO_2 (thous. MT)		
	Stage 1	Stage 2	Total	Stage 1	Stage 2	Total	Stage 1	Stage 2	Total
Alabama	52	94	146	81	147	228	351	640	991
Alaska	198	364	562	24	44	68	33	61	93
Arizona	437	790	1,227	123	222	344	444	802	1,246
Arkansas	132	241	373	66	120	185	218	397	615
California	492	897	1,389	115	210	326	741	1,350	2,092
Colorado	595	1,068	1,663	95	171	266	492	882	1,374
Connecticut	100	183	283	48	88	136	125	227	352
Delaware	27	50	77	41	74	115	58	106	164
District of Columbia	22	43	65	32	64	96	46	91	137
Florida	1,356	2,487	3,843	303	556	859	1,391	2,552	3,943
Georgia	101	185	286	158	290	447	685	1,258	1,943
Hawaii	312	561	873	342	614	956	93	168	261
Idaho	67	120	187	22	39	61	59	107	166
Illinois	509	933	1,442	1,804	3,304	5,108	1,332	2,441	3,774
Indiana	255	465	720	826	1,505	2,330	661	1,205	1,866
Iowa	296	534	830	144	259	403	270	488	758
Kansas	128	235	364	52	95	146	267	491	758
Kentucky	127	230	357	200	362	562	385	698	1,083
Louisiana	201	372	573	100	185	284	331	614	944
Maine	41	74	114	20	35	55	51	91	142
Maryland	171	315	487	254	467	721	363	669	1,032
Massachusetts	190	347	536	91	166	257	236	431	667
Michigan	311	568	879	949	1,733	2,682	898	1,640	2,537
Minnesota	509	923	1,432	247	447	694	465	843	1,308
Mississippi	83	152	236	74	134	208	218	398	616
Missouri	276	505	780	819	1,497	2,316	684	1,252	1,936
Montana	46	83	130	15	27	42	41	74	115
Nebraska	177	323	500	86	156	242	161	295	456
Nevada	159	285	444	47	83	130	157	280	437
New Hampshire	39	70	109	19	34	52	48	87	135
New Jersey	251	468	719	372	693	1,066	533	993	1,526
New Mexico	136	246	382	38	69	107	138	249	388
New York	472	870	1,342	275	507	782	1,063	1,961	3,024
North Carolina	144	264	408	171	313	484	544	996	1,540
North Dakota	73	137	210	35	67	102	66	125	192
Ohio	467	854	1,320	1,511	2,765	4,276	1,210	2,213	3,423
Oklahoma	243	450	692	132	245	377	293	543	836
Oregon	173	317	490	56	104	160	154	282	436
Pennsylvania	422	770	1,192	873	1,593	2,466	961	1,755	2,716
Rhode Island	30	55	86	15	26	41	38	69	106
South Carolina	69	127	196	82	150	233	262	479	741
South Dakota	79	146	226	39	71	109	73	134	206

Tennessee	187	342	528	293	537	831	565	1,035	1,600
Texas	658	1,222	1,880	453	841	1,294	1,855	3,444	5,299
Utah	103	186	289	34	61	94	91	166	257
Vermont	19	34	53	9	16	26	24	43	66
Virginia	117	217	333	138	257	396	440	818	1,258
Washington	302	554	856	99	181	280	269	493	762
West Virginia	75	136	211	243	441	683	194	353	547
Wisconsin	369	676	1,045	2,228	4,076	6,304	837	1,531	2,367
Wyoming	38	71	109	9	17	26	33	60	93
U.S.	**11,837**	**21,639**	**33,476**	**14,296**	**26,159**	**40,455**	**20,950**	**38,378**	**59,328**

Appendix D: Methodology

We estimated savings from the lamps[4] initially covered by the original Energy Independence and Security Act (EISA) 2007 standards, which are A-type medium screw base lamps ("A-type"), as well as five lamp types covered by the expanded definition (reflector, MR, decorative, globe, and miscellaneous A-type lamps). For the A-type lamps, we estimated savings for the stage 1 and stage 2 standards. For each of the lamp types, we calculated state-by-state annual energy savings and incremental purchase costs, emissions reductions, and electricity bill savings.

Annual energy savings and incremental purchase costs

<u>A-type lamps</u>

For the A-type lamps, because more than 95% are used in the residential sector (DOE 2017a), we calculated savings only for the residential sector. For the stage 1 base case (i.e., absent EISA), we assumed a 70% market share for conventional incandescent lamps and 30% for compact fluorescent lamps (CFLs) based on DOE's analysis of the EISA standards (DOE 2009).[5] CFLs and LEDs are close to interchangeable for savings analysis purposes. Because the average lifetime of CFLs is about five times longer than that of conventional incandescent bulbs, a 30% market share for CFLs results in a base case stock penetration of CFLs of almost 70% by 2020.

For the stage 1 standards case, we used data from the National Electrical Manufacturers Association (NEMA) on the market share of conventional incandescents, halogens, CFLs, and LEDs for 2012-2017 (NEMA 2017). Given the declining market share of CFLs, whose sales are largely being replaced by LEDs, we assumed that beginning in 2020, A-type lamp sales would be evenly split between halogens and LEDs. (Because the average lifetime of LEDs is more than 15 times longer than that of halogens, an even split in market share results in a stock penetration of halogens of less than 10% beginning in 2025.) We assumed linear increases/decreases between 2017 and 2020 for the market shares for halogens, CFLs, and LEDs. For stage 2, the base case is equivalent to the stage 1 standards case. For the stage 2 standards case, we assumed a 100% market share for LEDs beginning in 2020.

To calculate the residential stock of each lamp type in each year, we started with estimates of the stock in 2012, 2014, and 2015 as shown in Table D1.[6]

[4] Lamp is commonly used in the lighting industry to mean light bulb, rather than a lighting fixture. In this methodology, lamp means light bulb.

[5] We note that while it is possible that LEDs may have gained significant market share even absent the stage 1 standards, recent market data show that LEDs are largely replacing CFLs. Because the wattages of CFLs and LEDs are similar (and are both significantly lower than those of conventional incandescent and halogen lamps), incorporating LEDs in the stage 1 base case market share would likely have minimal impact on the results of our analysis.

[6] We estimated the total stock in 2012 and 2014 based on the 2015 stock and the average annual growth in floor space (EIA 2017b).

Table D1. Residential stock of A-type lamps in 2012, 2014, and 2015 by lamp type

Lamp type	2012 stock		2014 stock		2015 stock	
	Lamps (million)	% of total	Lamps (million)	% of total	Lamps (million)	% of total
Conventional incandescent	2,073	61%	905	26%	777	22%
Halogen	136	4%	905	26%	693	20%
CFL	1,156	34%	1,601	46%	1,814	51%
LED	34	1%	70	2%	240	7%
Total	3,399	100%	3,482	100%	3,524	100%

Sources: DOE 2015; DOE 2017a.

We used these stock estimates as estimates of the stock in the standards case. For the base case for 2012 and 2014, we assumed that absent the stage 1 standards, the stock of conventional incandescent lamps would have been equal to the combined stock of conventional incandescent and halogen lamps, and the stock of CFLs would have been equal to the combined stock of CFLs and LEDs. Our base case assumption is likely conservative because sales of CFLs likely increased due to the standards. Therefore, in the absence of the stage 1 standards, the share of conventional incandescents would likely have been higher than what we assume. (We calculated the base case stock in 2015 using the methodology described below for calculating the stock in future years.)

We calculated the number of lamps of each lamp type being replaced each year based on the stock in the previous year and the average lamp lifetime. We also accounted for shipments of lamps going to new construction based on EIA's projections of the average annual growth in residential floor space (EIA 2017a). We calculated the stock of each lamp type in each future year as the sum of replacement shipments, shipments to new construction, and lamps not being replaced (i.e., installed lamps that did not burn out in the previous year).

We calculated total annual energy use in each year based on the stock of each lamp type in each year and the per-unit energy use, and we calculated total purchase costs based on the number of shipments in each year and the purchase price for each lamp type. We calculated per-unit average annual energy use assuming average residential operating hours of 2.3 hours per day (DOE 2016). Table D2 shows our assumptions for each lamp type including average wattage, lifetime, annual energy use, and 2016 purchase price.

Table D2. Assumed average wattage, lifetime, annual energy use, and 2016 purchase price by lamp type

Lamp type	Average wattage (W)[7]	Average lifetime (years)[8]	Average annual energy use (kWh)	Average 2016 purchase price (2017 $)[9]
Conventional incandescent	63.0	1.2	52.9	0.51
Halogen	45.2	1.2	37.9	1.63
CFL	13.7	6.4	11.5	2.04
LED	10.5	19.3	8.8	4.38

Sources: DOE 2017a; DOE 2016; LUMEN Coalition 2011; DOE 2017b; APEX Analytics 2017.

LED prices are declining rapidly, and therefore we incorporated LED price trends developed by Lawrence Berkeley National Laboratory (LBNL) to project future LED prices relative to 2016 prices as shown in Figure A1.

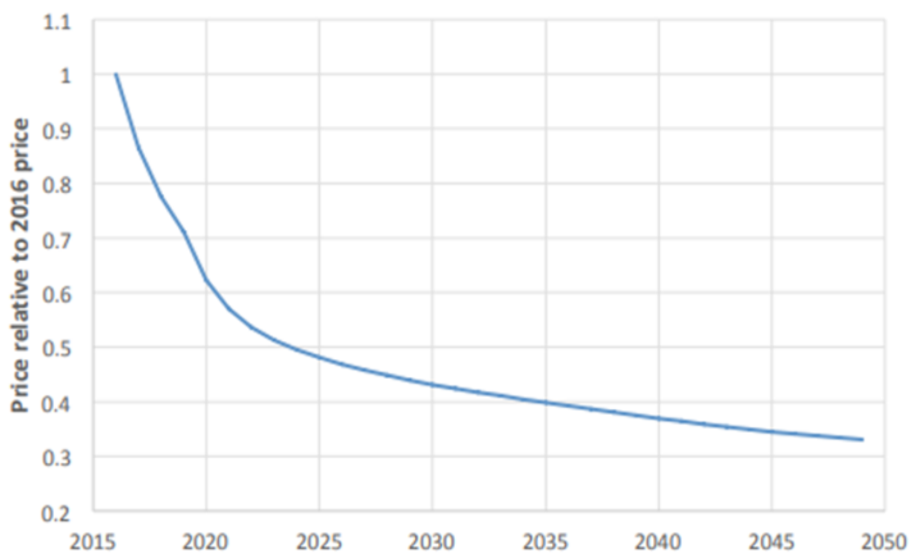

Figure D1. Projected future LED prices relative to 2016 prices. *Source*: Kantner et al. 2017.

We calculated annual energy savings and incremental purchase costs in each year based on the difference in total annual energy use and purchase costs in the base case and the standards case. We allocated national savings and costs to each of the 50 states and the District of Columbia based on the number of households in each state.

[7] We calculated average wattages for halogens, CFLs, and LEDs assuming wattages for 60 W conventional incandescent replacements of 43 W, 13 W, and 10 W, respectively.
[8] For conventional incandescent and halogen lamps, we assumed an average lifetime of 1,000 hours, or 1.2 years based on average annual operating hours of 2.3 hours/day.
[9] For LEDs, the average purchase price is the average of the prices of ENERGY STAR and non-ENERGY STAR LEDs.

Expanded definition lamps

For the five lamp types covered by the expanded definition, we developed the base case distributions of incandescent and LED shipments by lamp category starting with DOE's 2014 LED forecast (DOE 2014).[10] We followed LBNL's methodology of fitting a Bass adoption curve to the LED forecast for each lamp type to describe the LED market penetration in each year of the analysis period (Kantner et al. 2017). We then incorporated LBNL's central estimate of 25% "holdouts" (i.e., that 25% of the stock would remain incandescent (including halogen) in the absence of standards) by adjusting the parameter for maximum market penetration for each Bass adoption curve such that 25% of the stock would be incandescent at the end of the analysis period. (We also calculated savings assuming no holdouts; results are presented in Appendix E.) For the standards case, we assumed 100% market share for LEDs beginning in 2020.

Table D3 shows estimates of the 2015 stock of incandescents (including halogens) and LEDs by lamp category.

Table D3. Stock of expanded definition lamps in 2015 by lamp category and lamp type

Lamp category	2015 stock (million)		
	Incandescent	LED	Total
Reflector	787	10	797
MR	168	2	170
Decorative	1,344	0	1,344
Globe	330	0	330
Misc. A-type	83	0	83
Total	2,712	12	2,724

Sources: Kantner et al. 2017; DOE 2017c.

We assumed that all decorative, globe, and miscellaneous A-type lamps are used in the residential sector. We assumed that 96% of reflector lamps and 77% of MR lamps are used in the residential sector (and that the remaining lamps are used in the commercial sector) based on DOE's 2015 U.S. Lighting Market Characterization (DOE 2017a).

As with the A-type lamps, we calculated the number of expanded definition lamps of each lamp category and type being replaced each year based on the stock in the previous year and the average lamp lifetime. We accounted for shipments of lamps going to new construction based on EIA's projections of the average annual growth in residential and commercial floor space (EIA 2017a). We calculated the stock of each lamp type in each future year as the sum of replacement shipments, shipments to new construction, and lamps not being replaced.

We used assumptions for average annual operating hours, wattage, lifetime, and purchase price from Kantner et al. 2017. We used the LED price forecast shown in Figure A1 to calculate future LED prices relative to 2016 prices. As with the A-type lamps, we calculated annual energy savings and incremental

[10] We followed LBNL's methodology of excluding CFLs from the analysis since CFLs are unaffected by the backstop. CFLs also represent a low percentage of the total stock of expanded definition lamps.

purchase costs for the expanded definition lamps based on the difference in total annual energy use and purchase costs in the base case and the standards case for each lamp category. Finally, we allocated national savings and costs to each of the 50 states and the District of Columbia for lamps used in the residential and commercial sectors based on the number of households and commercial lighting electricity use, respectively.

Emissions reductions and electricity bill savings

We calculated state-by-state CO_2, NOx, and SO_2 emissions reductions from electricity savings by multiplying annual electricity savings by respective state-by-state average emissions factors. We calculated emissions factors for each year of the analysis period for each of the North American Electric Reliability Corporation (NERC) regions by dividing projected electric power sector emissions by projected electric power sector generation using EIA's 2018 *Annual Energy Outlook* and assuming transmission and distribution losses of 5% (EIA 2018a; EIA 2018b). For states that span more than one NERC region, we calculated weighted-average emissions factors based on electricity sales (Kubes, Hayes, and Kelley 2016). Because Alaska and Hawaii are not included in the NERC region data, for these states we used emissions factors from eGRID for 2014 (EPA 2017). For future years we assumed the rate of change of emissions factors for Alaska and Hawaii would be equivalent to the US average.

We calculated electricity bill savings using state-by-state electricity prices for the residential and commercial sectors. We used price projections from EIA's 2018 *Annual Energy Outlook* to calculate electricity prices for each of the NERC regions for each year of the analysis period relative to 2016 prices (EIA 2018a). We then applied these projections for the NERC regions to 2016 state-by-state electricity prices (EIA 2017). For states that span more than one NERC region, we calculated weighted-average projected changes in electricity prices based on electricity sales (Kubes, Hayes, and Kelley 2016). For Alaska and Hawaii we assumed the rate of change of electricity prices would be equivalent to the US average.

Appendix E: Alternate scenario for stage 2: What if the market transitions to LEDs on its own at a faster pace than expected?

An important assumption for estimating the impact of the stage 2 light bulb standards is what would happen in the absence of the standards. As explained in the methodology in Appendix D, for the bulbs covered by the expanded definition we assumed that at the end of the analysis period, 25% of sockets would remain filled with incandescent (including halogen) bulbs if there were no standards. For A-type lamps, we assumed a 50%/50% sales split between halogen and LED bulbs in the base case beginning in 2020, which, due to the much longer lifetime of LEDs, results in less than 10% of sockets being filled with halogens beginning in 2025.

We ran an alternate scenario to understand the impact of the stage 2 standards if consumers switched to compliant light bulbs at a greater rate in the base case. In the alternate scenario, we assumed no holdouts, which results in virtually all sockets being filled with LEDs by 2050 even absent the stage 2 standards. (For A-type bulbs, in the alternate scenario virtually all sockets are filled with LEDs by 2025.) The results for this scenario are shown in tables E1 and E2 below, which are similar to tables B1 and B2 in appendix B for the primary scenario.

Table E1. Annual electricity and electricity bill savings in 2020 and 2025 and cumulative savings through 2050 for stage 2 in the alternate scenario

		Annual savings in 2020		Annual savings in 2025		Cumulative savings through 2050	
		Electricity (billion kWh)	Electricity bills (billion 2017 $)	Electricity (billion kWh)	Electricity bills (billion 2017 $)	Electricity (billion kWh)	Electricity bills (billion 2017 $)
Stage 2	A-type	5.9	0.9	1.6	0.3	38	6
	Reflector	9.3	1.3	28.6	4.4	338	53
	MR	0.7	0.1	2.8	0.4	34	5
	Decorative	4.0	0.6	15.1	2.4	156	24
	Globe	0.4	0.1	1.8	0.3	22	3
	Misc. A-type	0.8	0.1	0.4	0.1	7	1
Stage 2 total		**21.1**	**3.0**	**50.4**	**7.9**	**595**	**93**

Table E2. Annual emissions reductions in 2020 and 2025 and cumulative reductions through 2050 for stage 2 in the alternate scenario

		Annual emissions reductions in 2020			Annual emissions reductions in 2025			Cumulative emissions reductions through 2050		
		NOx (thous. tons)	SO_2 (thous. tons)	CO_2 (MMT)	NOx (thous. tons)	SO_2 (thous. tons)	CO_2 (MMT)	NOx (thous. tons)	SO_2 (thous. tons)	CO_2 (MMT)
Stage 2	A-type	1.5	1.7	2.5	0.4	0.5	0.7	9	11	16
	Reflector	2.4	2.6	4.0	6.7	8.1	11.9	80	101	139
	MR	0.2	0.2	0.3	0.7	0.8	1.2	8	10	14
	Decorative	1.0	1.1	1.7	3.6	4.3	6.3	37	46	64
	Globe	0.1	0.1	0.2	0.4	0.5	0.7	5	6	9
	Misc. A-type	0.2	0.2	0.3	0.1	0.1	0.2	2	2	3
Stage 2 total		**5.4**	**6.0**	**9.1**	**11.9**	**14.3**	**21.0**	**142**	**176**	**245**

Figure E1 shows a comparison of annual electricity bill savings for stage 2 in the primary scenario and the alternate scenario. Annual electricity bill savings in the alternate scenario peak in 2025 at about $8 billion (compared to about $14 billion in the primary scenario). After 2025, annual savings decline at a faster rate in the alternate scenario than the primary scenario because of the faster transition to LEDs in the base case.

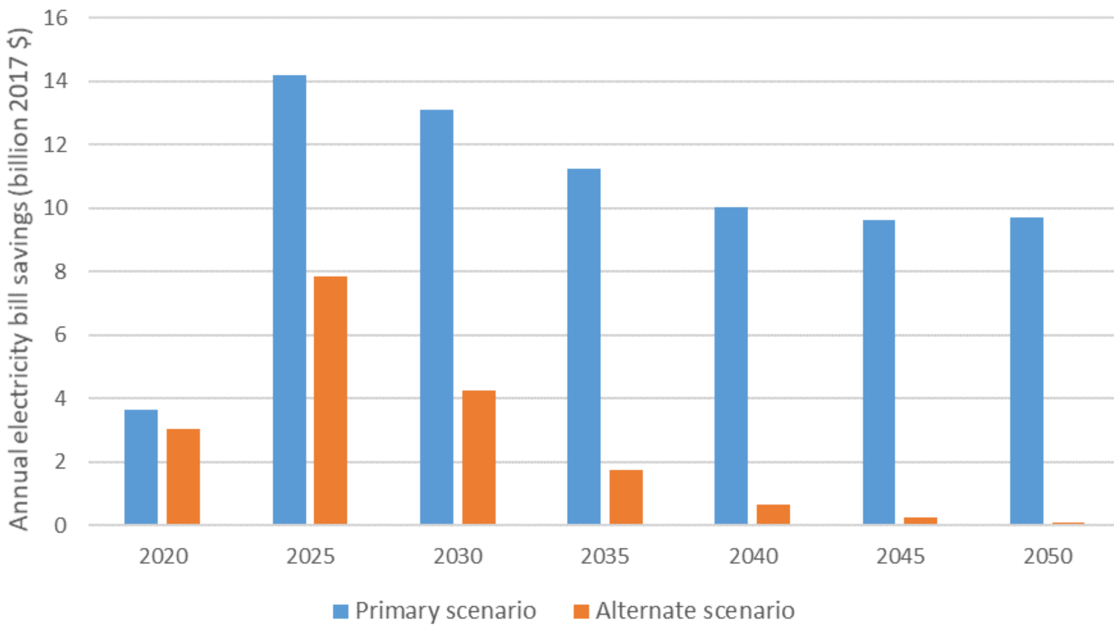

Figure E1. Annual electricity bill savings for stage 2 in the primary and alternate scenarios

The savings for stage 2 in the alternate scenario are less than in the primary scenario but still very large. For example, cumulative consumer bill savings are about $90 billion rather than $340 billion, and cumulative CO_2 savings are 245 MMT rather than 865 MMT. The sheer number of light bulbs in use and affected by the stage 2 standards and the big efficiency difference between incandescent (including halogen) and LED technology mean that even if standards accelerate the transition to LED technology by just a few years, the savings for consumers and the emissions reductions are still extremely large.

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