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Potential deaths averted in USA by replacing cigarettes with e-cigarettes

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ABSTRACT

Introduction US tobacco control policies to reduce cigarette use have been effective, but their impact has been relatively slow. This study considers a strategy of switching cigarette smokers to e-cigarette use ('vaping') in the USA to accelerate tobacco control progress.

Methods A Status Quo Scenario, developed to project smoking rates and health outcomes in the absence of vaping, is compared with Substitution models, whereby cigarette use is largely replaced by vaping over a 10-year period. We test an Optimistic and a Pessimistic Scenario, differing in terms of the relative harms of e-cigarettes compared with cigarettes and the impact on overall initiation, cessation and switching. Projected mortality outcomes by age and sex under the Status Quo and E-Cigarette Substitution Scenarios are compared from 2016 to 2100 to determine public health impacts.

Findings Compared with the Status Quo, replacement of cigarette by e-cigarette use over a 10-year period yields 6.6 million fewer premature deaths with 86.7 million fewer life years lost in the Optimistic Scenario. Under the Pessimistic Scenario, 1.6 million premature deaths are averted with 20.8 million fewer life years lost. The largest gains are among younger cohorts, with a 0.5 gain in average life expectancy projected for the age 15 years cohort in 2016.

Conclusions The tobacco control community has been divided regarding the role of e-cigarettes in tobacco control. Our projections show that a strategy of replacing cigarette smoking with vaping would yield substantial life year gains, even under pessimistic assumptions regarding cessation, initiation and relative harm.

INTRODUCTION

Harms from cigarette smoking remain unacceptably high even though smoking prevalence in the USA has decreased markedly over the past 50 years.[1 2] Two of three long-term smokers will likely die prematurely of a smoking-attributable disease.[3–5] Although many tobacco control policies, such as higher cigarette taxes, smoke-free public places, media campaigns, cessation treatment programmes and advertising restrictions, have already been implemented with substantial effectiveness, their pace in averting preventable deaths has been relatively slow and their potential to secure quick and substantial new smoking declines is limited.[6 7] Accordingly, tobacco control experts and national governments have begun considering what might be done to accelerate declines in tobacco-caused health harms and eventually eliminate all tobacco consumption (often termed an 'endgame'). The 2014 US Surgeon General Report recommended an endgame strategy for the tobacco epidemic.[6] Finland, New Zealand, Hong Kong and Ireland have already set the goal of reaching an endgame.[8]

While some refer to an endgame for all tobacco, most appear to focus on cigarettes as a more realistic and most important target, since they cause the vast majority of harm.[7 9–16] However, a credible plan to minimise cigarette use has yet to be implemented. At the same time, emerging nicotine-delivery products, such as e-cigarettes, call for an updating of traditional tobacco control strategies to better address new opportunities and threats that they present.[17]

Rather than focusing on policies designed exclusively to reduce cigarette use, some public health experts suggest a complementary approach to encourage the use of less harmful nicotine delivery products, such as e-cigarettes, as a substitute for cigarettes.[6 9 18–21] Some public health experts and officials fear that e-cigarette use ('vaping') may increase overall tobacco-related harms by serving as a gateway to smoking or prompting smokers to vape or engage in dual use instead of quitting all use.[22–25] However, evidence is mounting that e-cigarettes deliver only a small percentage of the toxicants delivered by cigarettes.[26–32] In addition, newer e-cigarettes models have been shown to more efficiently deliver nicotine[29 30 33] than older models and provide sensorimotor experiences and 'throat-hit' similar to smoking,[34] thus increasing their potential to serve as effective substitutes for cigarettes.

The goal of this paper is to show the potential health impact from an endgame strategy directed at replacing all or most cigarette smoking by e-cigarette use over a 10-year period. The 10-year time frame is used for illustrative purposes to show the potential health gains that could be secured by a potent switching-based strategy. To address the major concerns about switching smokers to e-cigarettes, some of the projections assume a much smaller net reduction in health harms from switching to e-cigarette from cigarette use than existing research suggests, and that the switching strategy will increase initiation into regular vaping by youth and others who would not otherwise use any nicotine delivery products and will prompt some smokers who would otherwise have quit all tobacco and nicotine use to instead use e-cigarettes. To distinguish the effect of policies on younger and older cohorts, we present separate analyses for the cohorts age 15 years and age 35 years in 2016.

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METHODS

The analysis begins with a Status Quo Scenario for smoking rates and health outcomes. E-cigarette Substitution models are then developed in which cigarette use is replaced by vaping. Projected mortality and life years lost (LYL) under the Status Quo and E-cigarette Substitution models are compared to determine the public health impact.

To reflect the population of smokers alive today in USA, we confine the analysis to the population age 15 years through age 99 years in 2016. Projections are applied through the year 2100 to incorporate the potential health effects of those at younger ages. The model was built in Excel for transparency and to facilitate use by interested parties. The model equations, an explicit statement of the assumptions, and further details, are provided in supplement 1 technical appendix.

Status Quo Scenario

The Status Quo Scenario focuses on cigarette use and is initialised in 2016 with the population classified as never, current and former cigarette smokers. Due to data limitations and to simplify the analysis, the Status Quo Scenario only considers cigarettes, and does not include smokeless tobacco, e-cigarettes or cigars.

Future cigarette use

Smoking rates are projected forward using age-specific and sex-specific initiation and cessation rates, and age-specific, sex-specific and smoking status-specific mortality rates. Holford *et al*[1 35] developed the initiation and cessation rates by applying an age-period-cohort statistical model to data from the 1965–2012 National Health Interview Surveys while correcting for bias due to higher mortality among current and former smokers. They were validated by comparing the smoking prevalence projections based on these initiation and cessation rates over the period 1965 through 2010 against observed rates.[34] Age-specific, sex-specific and cohort-specific initiation and cessation rates were used to project forward current, former and never smoker rates from their initial 2016 levels. To distinguish between successful cessation and short-term cessation followed by relapse, cessation is measured as having quit smoking for at least 2 years. All-cause cohort life tables subclassified by smoking status (never, former and current) were developed for the 1864–1980 birth cohorts,[36] and projected forward[35 37] using data on smoking prevalence and relative risks by age, sex and smoking status derived from the first two American Cancer Society Cancer Prevention Studies and the smoking prevalence data described above.

Mortality outcomes

Under the Status Quo, the number of smoking-attributable deaths for current smokers is calculated by age, sex and year as the product of their excess mortality risks (ie, current smoker mortality rate minus never smoker mortality rate) multiplied by the number of smokers. A parallel process is used to derive estimates for former smokers. The numbers of smoking-attributable deaths for current and former smokers are combined and then multiplied by the expected years of life remaining of a never smoker in their age group to estimate LYL from smoking.

E-cigarette Substitution Scenarios

Starting with the same proportions of smokers, former smokers and never smokers as in the Status Quo Scenario, the two E-cigarette Substitution Scenarios were constructed to show the impact of substituting e-cigarette use for cigarette smoking. The Optimistic Scenario is based primarily on current use patterns in e-cigarettes and published evaluations of harm reduction, while the Pessimistic Scenario is intended to reflect the 'worst case' of suggested harms (eg, with e-cigarettes more harmful than the science indicates), and the switching strategy substantially increasing vaping beyond those who would have smoked in the Status Quo Scenario.

Future cigarette and e-cigarette use

We assume that the prevalence of cigarette use will be reduced to a 5% residual prevalence of cigarette use in the Optimistic Scenario and to 10% in the Pessimistic Scenario. This residual of cigarette smokers would reflect those unwilling or unable to quit cigarettes as well as those who initiate e-cigarette use and progress to smoking. The substitution of e-cigarette for cigarette use under the Optimistic Scenario is modelled as a 10% reduction in the difference between the 2016 smoking prevalence and the 5% residual at each age to each cohort each year over 10 years starting in 2017, that is, replacing 10% of cigarette by e-cigarette users over 10 years, so that a residual of 5% cigarette smoking prevalence remains in 2026. In the Pessimistic Scenario, the corresponding annual reduction is calculated to instead yield a 10% prevalence of cigarette use after 10 years.

Those who replace cigarettes with e-cigarette use before age 40 years are treated as never smokers using e-cigarettes, since their risks as former smokers will be close to that of never smokers.[38] Those who replace cigarette with e-cigarette use after age 40 years are treated as former smokers using e-cigarettes.

In the Status Quo Scenario, most never smokers initiate cigarette smoking by age 24 years. Under the Optimistic Scenario, never smokers who would have smoked cigarettes instead become e-cigarette users at the same rates as initiation of cigarette use in the Status Quo Scenario after the 5% smoking prevalence is reached, reflecting the small percentage of never smokers who have been found to use e-cigarettes.[39–41] Under the Pessimistic Scenario, e-cigarette initiation is assumed to occur at 150% of the Status Quo smoking initiation rate to reflect some renormalisation of nicotine use.[22–25]

The Optimistic and Pessimistic Scenarios are also distinguished by the rate of cessation from e-cigarettes. Like cigarette smokers, e-cigarette users may quit e-cigarette use for health or other reasons. Indeed, some studies have found e-cigarettes vary substantially in nicotine delivery and can have lower nicotine addiction liability than when the nicotine is delivered via inhaled smoke from the combustion of tobacco smoking.[33 42–45] Under the Optimistic Scenario, e-cigarette users each year quit at the same age-specific and sex-specific cessation rate as smokers in the Status Quo Scenario. Under the Pessimistic Scenario, e-cigarette users each year quit at half the rate of cigarette smokers in the Status Quo Scenario.

The final distinction between the Optimistic and Pessimistic Scenarios is the expected risk of e-cigarette use, which is measured here relative to the excess risk of cigarettes. Although the health risks have yet to be thoroughly characterised, e-cigarettes appear to have much lower levels of toxicants than cigarettes[26–29 32] Under the Optimistic Scenario, an excess risk of e-cigarette use at 5% of cigarette excess risk is applied to current e-cigarette users, reflecting estimates from published reports.[27 46] We assume that the risk to former smokers from using e-cigarettes is proportional to the difference in risks between current and former smokers. Applying the 5% excess risk of exclusive e-cigarette use to former smokers using e-cigarettes, their excess risk is estimated as

that of former smokers plus (5% x (current smoker mortality rate − former smoker mortality rate)). Although worst case estimates of excess risks have not been published, we apply an excess risk of 40% for e-cigarette use under the Pessimistic Scenario, as suggested by some critics of vaping.[47 48] Parallel to the Optimistic Scenario, the 40% risk is then also scaled by the difference in risks between current and former smokers.

Health outcomes

For the Optimistic and Pessimistic E-Cigarette Substitution Scenarios, total premature deaths and LYL are calculated for e-cigarette users that never smoked, e-cigarette users among former smokers, former e-cigarette users, and current and former smokers who have not yet switched to e-cigarette use. At each age, excess risks are multiplied by the number of individuals in each of these categories and summed to obtain premature deaths and multiplied by expected life years remaining of a never smoker to obtain LYL.

Public health impact of replacing cigarette use by e-cigarettes

For the Optimistic and Pessimistic Scenarios, the public health impact is estimated by subtracting total premature deaths in each of these Scenarios from those in the Status Quo Scenario, and similarly for LYL. The public health impact is first determined for each cohort by summing overall remaining ages, and then summed over cohorts to determine the overall impact. By dividing the change in LYL by the 2016 population, we obtain a measure of the impact of the E-cigarette Substitution Scenario on life expectancy.

RESULTS

Table 1 contains the premature deaths and LYL by age predicted under the Status Quo and the two E-cigarette Substitution Scenarios. Supplement 2 contains additional results by sex and for different levels of e-cigarette risk.

Status Quo Scenario

Under the Status Quo Scenario, smoking prevalence (age 15–99 years) in 2016 is 19.3% for men and 14.1% for women, and declines over time for cohorts above age 24 years in 2016. A cumulative total of 26.1 million (18.8 million male; 7.3 million female) premature deaths and 248.6 million (177.9 million male; 70.8 million female) LYL are projected.

E-Cigarette Substitution Scenarios

Under the Optimistic Scenario, a cumulative total of 19.5 million (14.0 million male; 5.5 million female) premature deaths and 161.9 million (115.0 million male; 46.9 million female) LYL are projected. Compared with the Status Quo Scenario, a net gain of 6.6 million (4.8 million male; 1.7 million female) fewer premature deaths and 86.7 million (62.9 million male; 23.9 million female) fewer LYL are projected, representing 25% fewer premature deaths and 35% fewer LYL. The reduction in LYL translates to an increased average life expectancy of 0.33 (0.49 male; 0.18 female) years for the 2012 age 15 years and above population.

Under the Pessimistic Scenario, the e-cigarette prevalence is slightly larger in the early years (due to the 10% rather than 5% residual smoking prevalence), but does not decline as rapidly over time as in the Optimistic Scenario. With a 10% residual prevalence, the models allows no switching to e-cigarette use after age 61 years for men and after age 54 years for women, since smoking rates are 10% at those ages in 2016. Health outcomes are worse than the Optimistic Scenario with a cumulative total of 24.4 million (17.4 million male; 7.0 million female) premature deaths and 227.8 million (160.0 million male; 67.8 million female) LYL. Compared with the Status Quo Scenario, a net gain of 1.6 million (1.4 million male; 0.3 million female) representing 6% fewer premature deaths and 20.8 million (17.8 million male; 3.0 million female) representing 8% fewer LYL are projected. Average life expectancy increases 0.08 years (0.14 male; 0.02 female).

The 2001 birth cohort

As shown in table 2, male smoking prevalence under the Status Quo Scenario for the 2001 birth cohort (age 15 years in 2016) is 4.5% at age 15 years, increasing to 21.7% at age 25 years, and decreasing to 10.6% at age 55 years. Female smoking prevalence is substantially lower beginning at 2.4%, increasing to 15.2% at age 25 years and falling to 8.3% at age 55 years. A cumulative total

Table 1 Status quo and e-cigarette substitution, premature deaths and life years lost for all cohorts, men and women combined

Outcome	Year 2016	2026	2060	2080	2100	Cumulative (2016–2100)	Deaths prevented/ life years gained*	% Change relative to status quo
Status Quo Scenario†								
Premature deaths	461 588	470 743	316 556	167 037	2905	26 065 448		
Life years lost	5 689 458	5 625 286	2 626 503	685 593	1852	248 639 532		
Optimistic Scenario‡								
Premature deaths	461 588	380 832	233 243	56 399	459	19 484 289	6 581 159	25.2%
Life years lost	5 689 458	3 839 765	1 345 385	183 297	294	161 905 579	86 733 953	34.9%
Pessimistic Scenario§								
Premature deaths	461 588	456 297	298 689	127 706	2188	24 432 065	1 633 383	6.3%
Life years lost	5 689 458	5 261 398	2 319 388	528 926	1396	227 835 203	20 804 329	8.4%

*Life years gained=life years lost in Status Quo Scenario – Life years lost in E-cigarette Substitution Scenario.
†Status Quo Scenario: smoking rates evolve from initial 2016 levels based on age, gender and cohort-specific smoking initiation and cessation rates in the absence of e-cigarette use.
‡Optimistic Scenario: e-cigarettes excess risk 5% of smoking, 5% of the population continues to initiate cigarette smoking or remain as smokers, the remainder of never smokers then initiate e-cigarette use at the rate of cigarette smoking initiation in the Status Quo Scenario, and both smokers and e-cigarette users quit at the rate of smokers in the Status Quo Scenario.
§Pessimistic Scenario: e-cigarettes excess risk 40% of smoking, 10% of the population continues to initiate cigarette smoking or remain as smokers, the remainder of never smokers then initiate e-cigarette use at the 150% rate of cigarette smoking initiation in the Status Quo Scenario, and e-cigarette users quit at 50% of the rate of smokers in the Status Quo Scenario and smokers quit at the Status Quo cessation rate.

Table 2 Status quo and e-cigarette substitution, premature deaths and life years lost, men and women born in 2001 (age 15 years in 2016)

	Year	2016	2026	2056	Cumulative (2016–2100)	Deaths prevented/ life years gained*	% Change relative to status quo
Outcomes	Age, years	15	25	55			
Male							
Status Quo Scenario†							
Prevalence	Never smoker	95.5%	75.5%	72.8%			
	Cigarette smoker	4.5%	21.7%	10.6%			
	Former smoker	0.0%	2.8%	16.7%			
Premature deaths		0	0	1381	176 915		
Life years lost		0	0	43 507	2101 908		
Optimistic Scenario‡							
Prevalence	Never smoker	95.5%	75.5%	72.5%			
	Cigarette smoker	4.5%	5.0%	2.1%			
	Former smoker>age 40 years	0.0%	0.0%	1.2%			
	E-cigarettes exclusive	0.0%	16.7%	8.7%			
	Former smoker<age 40 years	0.0%	2.8%	10.5%			
	E-cigarette/former smoker	0.0%	0.0%	0.0%			
	Former E-cigarette user	0.0%	0.0%	4.9%			
Premature deaths		0	0	301	29 556	147 359	83.3%
Life years lost		0	0	9496	402 823	1699 085	80.8%
Pessimistic Scenario§							
Premature deaths		0	0	1247	141 287	35 629	20.1%
Life years lost		0	0	39 308	1793 892	308 016	14.7%
Female							
Status Quo Scenario†							
Prevalence	Never smoker	97.6%	82.8%	79.4%			
	Cigarette smoker	2.4%	15.2%	8.3%			
	Former smoker	0.0%	2.1%	12.3%			
Premature deaths		0	0	369	63 244		
Life years lost		0	0	12 513	711 172		
Optimistic Scenario‡							
Prevalence	Never smoker	97.6%	82.8%	79.4%			
	Cigarette smoker	2.4%	5.0%	2.1%			
	Former smoker>age 40 years	0.0%	0.0%	1.3%			
	E-cigarettes exclusive	0.0%	10.2%	6.2%			
	Former smoker<age 40 years	0.0%	2.1%	7.5%			
	E-cigarette/former smoker	0.0%	0.0%	0.0%			
	Former e-cigarette user	0.0%	0.0%	3.5%			
Premature deaths		0	0	109	14 297	48 947	77.4%
Life years lost		0	0	3687	181 846	529 326	74.7%
Pessimistic Scenario§							
Premature deaths		0	0	387	61 469	1775	2.8%
Life years lost		0	0	13 106	737 757	−26 585	−3.7%

*Life years gained=life years lost in Status Quo − Life years lost in E-cigarette Substitution Scenario.
†Status Quo Scenario: Smoking Rates evolve from initial 2016 levels based on age, gender and cohort-specific smoking initiation and cessation rates in the absence of e-cigarette use.
‡Optimistic Scenario: e-cigarettes excess risk 5% of smoking, 5% of the population continues to initiate cigarette smoking or remain as smokers, the remainder of never smokers then initiate e-cigarette use at the rate of cigarette smoking initiation in the Status Quo Scenario, and both smokers and e-cigarette users quit at the rate of smokers in the Status Quo Scenario.
§Pessimistic Scenario: e-cigarettes excess risk 40% of smoking, 10% of the population continues to initiate cigarette smoking or remain as smokers, the remainder of never smokers then initiate e-cigarette use at the 150% rate of cigarette smoking initiation in the Status Quo Scenario, and e-cigarette users quit at 50% of the rate of smokers in the Status Quo Scenario and smokers quit at the Status Quo cessation rate.

of 240 thousand (176.9 thousand male; 63.2 thousand female) premature deaths and 2.8 million (2.1 million male; 0.7 million female) LYL are attributed to smoking for the 2001 birth cohort. For the same cohort under the Optimistic Scenario, 29.6 thousand premature deaths and 402.8 thousand LYL are projected for men and 14.3 thousand premature deaths and 181.8 thousand LYL for women, yielding a net public health gain of 196.3 thousand fewer premature deaths and 2.2 million fewer LYL, representing 82% fewer premature deaths and 79% fewer LYL. Life expectancy increases by 0.5 years (0.8 male; 0.3 female), largely reflecting the 2.9 years (3.7 male; 1.7 female) increase in life expectancy of otherwise smokers. Compared with the Status Quo Scenario, 16% fewer premature deaths and 10% fewer LYL are projected under the Pessimistic Scenario.

The 1981 birth cohort

As shown in table 3, male (female) smoking prevalence under the Status Quo Scenario for the 1981 birth cohort (age 35 years in 2016) begins at 28.4% (21.0%), decreasing to 21.4% (16.3%) at age 45 years and 5.5% (3.7%) at age 75 years. Compared with the Status Quo Scenario, the projected net public health gain with the Optimistic Scenario is 160.5 thousand (119.9 thousand male; 40.5 thousand female) or 43% fewer premature deaths and 2.2 million (1.7 million male; 559.8 thousand female) or 52% fewer LYL. For the Pessimistic Scenario, 13% fewer premature deaths and 17% fewer LYL are projected.

DISCUSSION

Our analysis shows that a hypothetical substitution of e-cigarette for cigarette use provides tremendous potential to avert premature deaths due to smoking, with only a relatively small amount of premature deaths due to e-cigarettes. Among those aged 15 years and above in 2016, almost 6.6 million fewer premature deaths and 86.7 million fewer LYL due to cigarette use occur in the Optimistic Scenario. The average 15-year-old would increase their life expectancy by 0.5 years, reflecting the increased life span of those who have, or would otherwise have smoked cigarettes, switching to e-cigarettes. Our results also show that although there would still be considerable premature deaths and LYL in all scenarios (table 1), these are primarily due to the impact of smoking among those aged 35 years and older in 2016 (tables 2 and 3). This estimate corresponds, in our view, to reasonable estimates of initiation, cessation and e-cigarette risk known to date.[19 49]

Even in the Pessimistic Scenario, where we allow for long-term ongoing renormalisation of tobacco use in terms of e-cigarette initiation, reduced cessation, far smaller reductions in harm from e-cigarettes than existing science indicates, and a residual prevalence of 10%, there are still overall net gains in averted premature deaths and LYL. Accordingly, this study suggests that, even under a worst case scenario, an endgame strategy that successfully prompted most cigarette smokers to switch to vaping would secure substantial public health gains.

In addition to the reductions in mortality, further health benefits would accrue from reduced disability, tobacco-related disease incidence and exposure to secondhand smoke. The reduced disability and disease burden would also translate directly into lower medical costs associated with cancer, chronic obstructive pulmonary disease and heart disease, reduced productivity losses due to death and disease primarily among those of ages 40 years through 64 years , and improved quality of life.[6] These gains can be expected to reduce health disparities, since smoking rates are highest among those with lower income and education.[6] In addition, secondhand exposure to e-cigarette aerosol has been found to be less extensive and less harmful than exposure to cigarette smoke,[50 51] thus reducing mortality and morbidity in non-smokers.

Unlike previous models of e-cigarette use,[49 52–54] our model was not developed to predict future e-cigarette and cigarette use based on past trends. Rather the aim was to examine a hypothetical endgame strategy of reducing cigarette use through switching to e-cigarettes. As with any hypothetical modelling exercise, a number of limitations are worth noting.

The Status Quo Scenario is developed based on past smoking uptake and cessation rates through the years 2012, prior to the major growth in e-cigarette use.[55 56] The projections do not incorporate tobacco control policy changes and the effect of increases in e-cigarette use that have occurred after 2012. To the extent that e-cigarette use and tobacco control policies implemented since 2012 would have already reduced cigarette use, our estimates of the gains under the Optimistic and Pessimistic Scenarios would be reduced.

Our models were limited to cigarette and e-cigarette use, and do not incorporate the use of other nicotine delivery products, including smokeless tobacco, water pipes and cigars. While use of these other products are relatively minor contributors to overall tobacco-related harms, policies should be directed at all combustible tobacco to reduce the likelihood of substituting other harmful smoked products, such as little cigars.[57] Taking into account the substitution of e-cigarettes for these other products would further increase the estimated public health gains from an e-cigarette substitution strategy.

The choice of a 10% residual rate of smokers in the Pessimistic Scenario and a 5% residual in the Optimistic Scenario were included to allow for the possibility that some current cigarette smokers would be unlikely to quit. The residual prevalence of cigarette smokers will depend on the potency of policies directed at cigarette use. Traditional cigarette-oriented policies, including significant cigarette tax increases,[10 58–60] large and graphic pictorial warnings on cigarette packages,[61] and retail point-of-sale restrictions on advertising displays,[62] have each been projected to reduce smoking prevalence by at least 10% in relative terms. A previous study estimated that strong policies (including a $2.00 tax increase) would reduce cigarette use by 40%. A nicotine reduction policy may substantially reduce cigarette use if properly enforced,[16 63 64] especially when accompanied by a more permissive approach to e-cigarettes.[65] In addition, a menthol cigarette ban may encourage cessation and discourage youth and young adults from cigarette use.[66] Synergies may enhance the effect of these policies.

Substitution from cigarettes to e-cigarettes will also depend on the policies directed at e-cigarette use. Information dissemination policies that provide the best available information on the relative risks of e-cigarettes are likely to encourage switching to e-cigarette use. In addition, just as innovations have improved both the appeal and delivery of nicotine in a satisfying manner,[29 30 33] innovations are likely to improve the substitutability of e-cigarettes for cigarettes, unless there are major regulatory hurdles for introducing new products. Once smokers were switched to vaping and any significant new re-emergence of smoking were discouraged, the same tools that have successfully been employed in reducing cigarette use, such as increasing e-cigarette taxes,[67] raising and enforcing the minimum purchase age,[37] and restricting marketing directed at youth, could be applied to e-cigarette use if vaping were found to be more harmful than current evidence suggests or if e-cigarette use was at unacceptably high levels through normalisation of vaping.

Table 3 Status quo and e-cigarette substitution, premature deaths and life years lost, men and women, cohort born in 1981 (age 35 years in 2016)

	Year	2016	2026	2056	Cumulative (2016–2080)	Deaths prevented/ life years gained*	% Change relative to status quo
Outcomes	Age, years	35	45	75			
Male							
Status Quo Scenario†							
Prevalence	Never smoker	56.1%	55.9%	58.4%			
	Cigarette smoker	28.4%	21.4%	5.5%			
	Former smoker	15.5%	22.7%	36.1%			
Premature deaths		0	1110	5927	278 703		
Life years lost		0	42 538	70 549	3217 819		
Optimistic Scenario‡							
Prevalence	Never smoker	56.1%	55.8%	56.8%			
	Cigarette smoker	28.4%	5.0%	1.2%			
	Former smoker>age 40 years	15.5%	17.6%	25.4%			
	E-cigarettes exclusive	0.0%	8.4%	3.0%			
	Former smoker<age 40 years	0.0%	3.8%	3.9%			
	E-cigarette/former smoker	0.0%	8.1%	2.5%			
	Former e-cigarette user	0.0%	1.3%	7.3%			
Premature deaths		0	300	3412	158 760	119 943	43.0%
Life years lost		0	11 497	40 613	1559 546	1658 273	51.5%
Pessimistic Scenario§							
Premature deaths		0	777	5123	236 850	41 853	15.0%
Life years lost		0	29 783	60 982	2621 426	956 393	18.5%
Female							
Status Quo Scenario†							
Prevalence	Never smoker	67.1%	66.8%	67.6%			
	Cigarette smoker	21.0%	16.3%	3.7%			
	Former smoker	11.9%	16.9%	28.7%			
Premature deaths		0	137	1924	98 714		
Life years lost		0	5673	26 525	1078 282		
Optimistic Scenario‡							
Prevalence	Never smoker	67.1%	66.8%	67.0%			
	Cigarette smoker	21.0%	5.0%	1.1%			
	Former smoker >age 40 years	11.9%	13.4%	20.9%			
	E-cigarettes exclusive	0.0%	5.8%	1.6%			
	Former smoker <age 40 years	0.0%	2.6%	2.6%			
	E-cigarette/former smoker	0.0%	5.5%	1.4%			
	Former e-cigarette user	0.0%	0.9%	5.3%			
Premature deaths		0	47	1020	58 186	40 528	41.1%
Life years lost		0	1936	14 066	518 499	559 782	51.9%
Pessimistic Scenario§							
Premature deaths		0	108	1777	89 933	8781	8.9%
Life years lost		0	4451	24 492	950 737	127 544	11.8%

*Life years gained=life years lost in Status Quo Scenario – life years lost in E-cigarette Substitution Scenario.
†Smoking rates evolve from initial 2016 levels based on age, gender and cohort-specific smoking initiation and cessation rates in the absence of e-cigarette use.
‡Optimistic Scenario: e-cigarettes excess risk 5% of smoking, 5% of the population continues to initiate cigarette smoking or remain as smokers, the remainder of never smokers then initiate e-cigarette use at the rate of cigarette smoking initiation in the Status Quo Scenario, and both smokers and e-cigarette users quit at the rate of smokers in the Status Quo Scenario.
§Pessimistic Scenario: e-cigarettes excess risk 40% of smoking, 10% of the population continues to initiate cigarette smoking or remain as smokers, the remainder of never smokers then initiate e-cigarette use at the 150% rate of cigarette smoking initiation in the Status Quo Scenario, and e-cigarette users quit at 50% of the rate of smokers in the Status Quo Scenario and smokers quit at the Status Quo cessation rate.

Another limitation is that we treated e-cigarettes as a homogeneous category in terms of risks. In fact, products vary in terms of their toxicant content,[28] price[68] and desirability.[69] We do not yet have evidence of the actual long-term health effects of e-cigarette use. However, applying sensitivity analysis to the Pessimistic Scenario, we found that substitution from cigarettes to e-cigarettes yielded public health gains with excess risks of e-cigarettes relative to cigarettes as high as 71% for men and 55% for women. Regardless, prudent product standards to limit known toxicants as much as practical would reduce the range of harm for different types and brands of e-cigarettes, and is likely to increase perceptions by smokers of reduced harm of e-cigarettes relative to cigarettes. If the relative risk of e-cigarettes were to be reduced to 3% and the residual prevalence to 2.5%, the relative reduction in LYL would increase from 35% to 44%. Furthermore, heat-not-burn tobacco products have been introduced in some countries, and these may be a better substitute for cigarettes than e-cigarettes, but have higher toxicant levels. While they may impose greater health risks, they are still likely well within the estimates used in our Pessimistic Scenario.

In conclusion, tobacco industry documents[70] reveal an industry strategy of 'divide and conquer' focused primarily on fostering divisions within the tobacco control community regarding modified risk products. Indeed, the tobacco control community has had divided approaches to e-cigarettes, and in the process may have lost focus on cigarettes, the most deadly form of nicotine delivery. Our analysis shows that a strategy of replacing cigarette by e-cigarette use can yield substantial gains, even with conservative assumptions about related risks. Most important, an e-cigarette substitution strategy provides the justification to redouble efforts to target cigarette use, as called for by the WHO Framework Convention for Tobacco Control.[71] An endgame scenario for cigarettes might well be within reach, if new technologies for delivering nicotine with substantially less harm, but sufficient satisfaction, are harnessed with sufficient passion and political will to aggressively phase out tobacco cigarettes.

What this paper adds

- The 2014 US Surgeon General's Report suggested the need for a new strategy to more quickly end tobacco use, but a credible strategy has not been provided. This paper considers a strategy of switching cigarettes smokers to e-cigarette use in USA to accelerate tobacco control progress.
- Using a previously validated simulation model, our projections show that a strategy of replacing cigarette smoking with e-cigarette use would yield substantial life year gains, even under pessimistic assumptions regarding cessation, initiation and relative harm.

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