

The use of simplified energy calculations in ethical decision making of biofuels by secondary school students: From a case study in a Thai international school

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Abstract

Many countries include a requirement in the curriculum for secondary school students to apply ethical reasoning when considering alternative actions within society. Ethical arguments can be founded in a number of different frameworks and this can make argument complex or difficult to weigh for secondary students. To make fully informed decisions regarding renewable energy (RE) resources a scientific understanding of the technologies and processes is needed. The majority of secondary school science curricula require students to master the ability to balance and subsequently use stoichiometric equations in calculations. This frequently becomes a stumbling block for a significant number of students. Having learned different approaches to balancing equations from various renewable energy (RE) processes including pyrolysis, gasification, partial oxidation, anaerobic fermentation, Fischer-Tropsch reactions, esterification for biodiesel and combustion of alcohols students were then required calculate and analyse trends in the enthalpy of combustion for two homologous series. This paper demonstrates the successful use of a novel approach for calculation, classifies the cause of common errors made by inexperienced students and statistically quantifies the errors. The test group used approximated bond energy values whereas the control group used published values. This is set within a small case study of eighteen secondary school students in an international school, who were applying scientific arguments whilst studying environmental ethics. The students applied their knowledge gained to justify a choice of a second generation fuel using scientifically informed ethical reasoning. Through the application of their stoichiometric skills in analysis and ethics in argumentation students demonstrate the use of higher order cognitive thinking skills. The acquisition and application of these skills is evidenced in interview extracts where students construct arguments in favour of particular fuels. This case study illustrates the potential for teachers to deliver simplified, yet challenging, chemical knowledge to enhance the teaching of applied ethics.

Keywords:

Ethical frameworks, biofuel reactions, simplified bond energy calculations, mixed methods research, secondary school, arithmetic error analysis

1. Introduction

Since the 2005 Universal Declaration on Bioethics and Human Rights (UDBHR) [1] the national curricula of many countries contains various requirements for students in secondary education to be able to make informed ethical choices especially with regard to sustainable development [2]. The UDBHR contains specific articles that are relevant to students making ethical decisions regarding energy choices: article 16 addresses the need to protect future generations; article 17 the protection of the environment, biodiversity and biosphere and article 23 that specifically states that the purpose of education and training should be to: "achieve a better understanding of the ethical implications of

scientific and technical developments, in particular for young people.” Many researchers [3,4,5,6] have observed that to be able to make fully informed ethical choices there is a need for scientific knowledge and understanding relevant to the issue. In the case of energy choices this includes the chemistry related to biofuels as opposed to conventional fossil fuel derivatives. [7]

There is good reason to promote the learning of science and ethics by school students. It has been reported in the UK [8] that the teaching of Philosophy, to upper primary school students, had a positive impact on 11 year-olds Standard Assessment Tests in Science, Mathematics and English. In Thailand secondary school students gain knowledge and understanding of the Sufficiency Economy Philosophy (SEP) developed by His Majesty King Bhumibol Adulyadej of Thailand¹ [9]. The SEP is founded on conditions of knowledge and morality, both requiring understanding of the principles and applications.

Traditional ethics based on virtues such as frugality, a framework based on deontological rules or utilitarian arguments for the common good all provide a basic foundation for students to explore these issues. The application of general principles as opposed to rigid rules is a pragmatic approach that enables students to address the key ethical arguments in different situations. This includes the precautionary principle when there is a degree of uncertainty and the principles of stewardship of the environment and vulnerable ecosystems, social inclusiveness and empowerment [4,5,10]. In this study the students had previously studied different ethical frameworks and principles, but had not yet applied the theory to fuel choice arguments.

The wide variety of technologies, feedstocks and chemical or biochemical reactions that are possible to generate biofuels amounts to a vast body of knowledge therefore understanding principles is of great value. Collectively the scientific, technological and ethical considerations demand that students hold a large amount of information in their minds when making evaluations. Thus simplifying, whilst retaining the essential elements, makes key points more accessible and clearer, thereby enabling students to construct their own arguments rigorously and with more confidence.

2. Methodology

This paper forms part of a wider case study based on a mixed ability class of eighteen 14 – 15 year-olds during the first year of the International General Certificate of Secondary Education (IGCSE) for a science course at St. Stephen’s International School, Khao Yai campus in Thailand. The students had been fully informed that participation in this aspect of the course was optional and they were allowed to not participate in the programme or to withdraw at any point. They were asked to give consent that data from their work may be used for research purposes, assured that no names would be disclosed and that the results were for educational research purposes only. This included the use of previously obtained standardized Cognitive Ability Test (CAT) scores. The CAT scores illustrate the range of ability within the group that contained no first language speakers. There were two students of mixed Thai – German heritage who used dual languages at home. The rest were full Thai citizens who spoke Thai dialects at home. There were seven boys and eleven girls.

¹ In 2006 His Majesty King Bhumibol Adulyadej was awarded the United Nations first Human Development Lifetime Achievement Award. Presenting this prestigious award Secretary-General Kofi Annan gave worldwide recognition to His Majesty’s visionary thinking and the timely relevance of the SEP.

Box 1 Examples of partially completed equations students balanced relevant to renewable energy

Pyrolysis of plant material like rice straw or a starch based feedstock is a type of thermal decomposition:

$$\text{C}_6\text{H}_{12}\text{O}_6 \rightarrow \text{CH}_4 + \text{H}_2\text{O} + _ \text{H}_2 + _ \text{CO}$$

Steam gasification is hydrolysis. Can use cellulose based materials such as switchgrass or municipal waste:

$$\text{C}_6\text{H}_{10}\text{O}_5 + \text{H}_2\text{O} \rightarrow _ \text{CO} + _ \text{H}_2$$

Partial oxidation uses limited oxygen. This example is representative of a section of cellulose:

$$\text{C}_6\text{H}_{10}\text{O}_5 + _ \text{O}_2 \rightarrow 6 \text{CO} + _ \text{H}_2\text{O}$$

Fischer Tropsch reactions use catalysts to convert carbon monoxide and hydrogen into alkane fuels:

$$_ \text{CO} + _ \text{H}_2 \rightarrow \text{C}_2\text{H}_6 + 2 \text{H}_2\text{O}$$

This can also be used to produce longer-chain liquid fuels like petrol that are in high demand:

$$_ \text{CO} + 17 \text{H}_2 \rightarrow \text{C}_8\text{H}_{18} + _ \text{H}_2\text{O}$$

Esterification to produce biodiesel from oils extracted from plants such as palms, sunflowers or rapeseed:

$$\text{C}_6\text{H}_5\text{O}_6\text{R}_3 + _ \text{CH}_3\text{OH} \rightarrow 3 \text{C}_2\text{H}_3\text{O}_2\text{R} + \text{C}_3\text{H}_8\text{O}_3$$

Anaerobic fermentation of domestic waste, sewage or manure to produce methane:

$$\text{C}_6\text{H}_{12}\text{O}_6 \rightarrow _ \text{CO}_2 + _ \text{CH}_4$$

Ethanol fermentation from sugarcane or corn using a yeast such as *Saccharomyces cerevisiae*:

$$\text{C}_6\text{H}_{12}\text{O}_6 \rightarrow _ \text{CO}_2 + _ \text{C}_2\text{H}_5\text{OH}$$

Lignocellulose from woody plant matter, some microbe strains can use sugars like xylose to make ethanol:

$$_ \text{C}_5\text{H}_{10}\text{O}_5 \rightarrow 10 \text{C}_2\text{H}_5\text{OH} + _ \text{CO}_2$$

Firstly, students were taught to balance chemical equations using a several different approaches. The benefit of learning various approaches to solve problems has been demonstrated by a number of researchers into [11,12,13]. The equations were all from a range of biochemical reactions associated with the production or use of fossil fuels; including pyrolysis, gasification, partial oxidation, anaerobic fermentation, Fischer-Tropsch reactions, esterification and combustion [14]². Having learned this skill, they were given a short assessment task to assist in allocating them to either a test or control for subsequent research topics. An example of partially completed equations to balance is given in box 1.

It was explained that through both theoretical and experimental research improvements can be made in cost reduction, efficiency and ultimately the sustainability of biofuel production. Working individually but within assigned groups students calculated the ratio of gaseous molecules produced compared to the gaseous reactants during the complete combustion of selected alkanes, alcohols and hydrogen. This enabled them to determine which would produce the biggest increase in volume required to push the cylinder in a piston and therefore be a measure of its predicted effectiveness as a fuel. Noting the decrease in mole ratio for hydrogen they were asked why the reaction caused an explosion. This introduced the idea of calculating and measuring the energy change associated with different reactions.

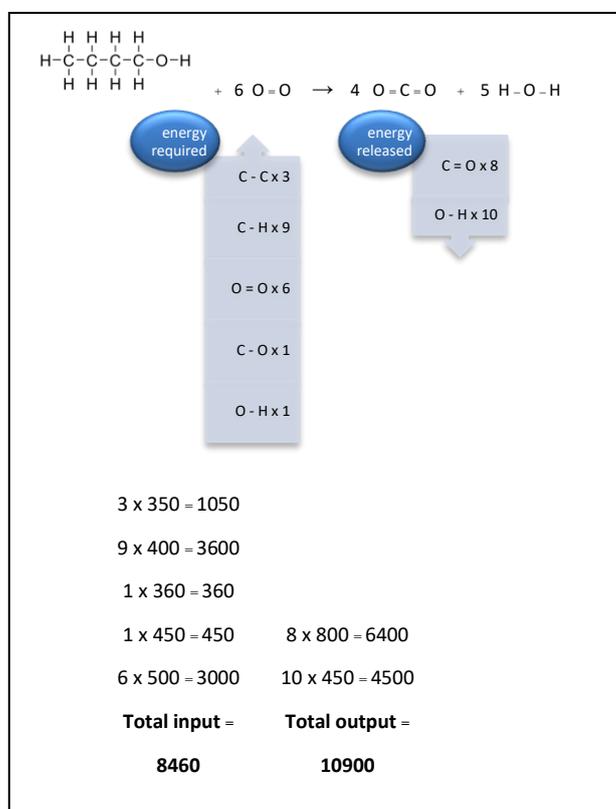
Within the series of lessons the students performed several experiments. These included some well established procedures such as simple calorimetric comparisons of the heat of combustion of alcohols. Additional experiments included some that have not previously been used for the purpose of specific teaching the potential value of biofuels. For example, one experiment developed a model to investigate the relationship of bond strength and length. The students recorded the relationship of

² Simplified reactions were adapted from Lee, S and Shah, Y.T. 2013

distance between magnets and the magnetic field force using a 0 – 1 N newtonmeter. They plotted the distance between magnets against the magnetic force then separately plotted the bond length against average bond energy for O–H, C–C, C–H and H–H bonds found in biofuels. They also used cylindrical cardboard models with magnets hidden inside as a kinesthetic aid to learning to emulate the energy required to break various bonds within biofuels during combustion. The students made models and sketched structural formulae of organic compounds that they thought could be possible options for biofuels. The key learning point during this part of the scheme of study was to gain an understanding of a fundamental principle involved in bonding, to spark an interest and assist visualization of bond energy principles. The students were engaged in a problem-oriented approach to their learning as advocated in many contemporary syllabi [15].

2.1 Calculations using bond approximated energies.

Box 2 Using approximated bond energies to estimate the enthalpy of combustion of butanol.



Following the initial assessment the students were assigned equally (nine per group) into two stratified randomized groups [16] a test group M and control group N based on the stoichiometric skills test and their CAT test scores.

The students required to make theoretical predictions of the energy released in combustion reactions. Group M (test group) used approximated values for average bond energies, whereas group N (control group) used standard published values. For group M, to aid the simplicity of calculations thereby reducing the numeracy challenge, which could potentially become a barrier to learning the key chemical concept, average bond energy values from published tables were rounded to the nearest 50 kJ/mol. An exception to this rule was the C – O bond which was assigned a value of 360 kJ/mol instead of the published value of 358 kJ/mol as the C – C bond was assigned 350 kJ/mol being rounded up from the published 348 kJ/mol. The values used are in table 1.

Table 1 The bond energy values used by each group.

Bond	Approximated bond energy (kJ/mol) Test group M	Published bond energy (kJ/mol) Control group N
C – C	350	348
C – H	400	413
C – O	360	358
O – H	450	467
C = O	800	799
O = O	500	498

The students were shown how to perform calculations using the approximated bond energy values, as illustrated for butanol in Box 2. The difference of input and output in this example is 2440 kJ/mol, which is comparable to the standard value of 2470 kJ/mol. They were required to calculate the enthalpy of complete combustion for selected alkanes and alcohols. They were given the molecular formulae of the organic compounds and were told that the products would always be just carbon dioxide and water. The time they took to complete the calculations was recorded and their errors analysed, building on a coding system proposed by Gulacar [16]. The effect of the errors made it difficult for students to identify clear trends. To counter this, corrected stoichiometric equations were provided when required so as not to leave any students unfairly disadvantaged. To promote a growth mindset students were encouraged to view mistakes as opportunities for future learning rather than as failures [17] through the identification of the exact source of errors. Students were given specific questions to answer for the analysis relating to their theoretical values of the enthalpy of combustion for the different homologous series. In this study stoichiometric errors refer to incorrectly balanced equations, computational errors include both input and arithmetic errors. Structural errors are defined as those limited to misappropriation of bonds within reactant molecules.

The students were requested to identify trends and comment on patterns in the data from their calculations. This included:

1. The difference in enthalpy of combustion between members in one homologous series
2. Comparing the enthalpy of combustion of compounds with identical carbon chain length between two different homologous series
3. Compare the volume of oxygen required for the complete combustion of different fuels
4. Compare the ratio of the moles of gaseous reactants to products

2.2 Ethical choices of biofuels

During follow-up interviews students were asked to give scientific, technological, socioeconomic and ethical reasons for their choices. These interviews were semi-structured small group interviews where specific questions were directed towards individual students based on data analysis tasks and the degree of participation the teacher had observed during the course. In this regard the case study demonstrates an action research approach where data obtained within the research programme has influenced and further defined the QUAL→quan research design [18]. Qualitative data was actively used to inform and define the subsequent qualitative data collection from interviews. The benefit of this approach was that interviewees were encouraged to express with confidence what they had achieved and how their knowledge had increased.

3. Results and Analysis

During the initial use of stoichiometric equations all but one of students noted that alcohols required less oxygen for complete combustion compared to alkanes. Thirteen further calculated that the ratio of gaseous moles of reactants to products in the complete combustion of ethanol is 1:1.25, in butane is 1:1.2 and butanol is 1.29. The majority of the students were clearly able to make a simple observation in the different general combustion equations and compare amounts of the reactants and

products involved. The more challenging step was the use of the bond energy data to identify other trends.

The expected calculation results for the enthalpy of combustion of small alkanes and alcohols using average and approximated bond energy values are shown in Table 2.

Table 2 Enthalpy of combustion from approximated average bond energy values i.e. test group, M.

Alkanes	-ΔH (kJ/mol)		Alcohols	-ΔH (kJ/mol)	
Methane	800	(808)	Methanol	640	(647)
Ethane	1400	(1415)	Ethanol	1240	(1255)
Propane	2000	(2023)	Propanol	1840	(1862)
Butane	2600	(2630)	Butanol	2440	(2470)

Table 3 Comparison of completion times and errors ($n = 9$ in both control and test groups).

	Average completion time (s)	Stoichiometric		Number of errors			Computational		Total
		½ mol O ₂	Other	Structural	Computational				
				C-H	CO ₂	COH	Input	arithmetic	
Test group M [n=9]	865	13	5	3	2	2	6	0	31
Control group N [n=9]	952	11	4	3	3	3	9	16	51

Values in brackets are calculated from standard average bond energy tables (Control group, N). The time for students to complete calculations and percentage of errors for groups test and control groups is given in table 3. The 9% reduction in completion time and 39% reduction total errors allowed more time and reliability during the data analysis by the test group. The stoichiometric and structural errors occurred at similar rates in both groups. Both of these sources of error would not be expected to be significantly different as the approximation of bond energy values is not involved in these stages of the overall calculation. The χ^2 value of 0.60 of these two errors between both groups shows that this is not a significant difference. However, the χ^2 value of 6.01 for computational and non-computational errors across the groups does show a significant statistical difference at the 2.5% level³. The computational errors are significantly less in the test group due to there being less input and no arithmetic errors. χ^2 analysis of the input and arithmetic errors across the two groups shows that the difference is significant at the 0.1% level⁴. Common to both groups were stoichiometric errors arising from either the requirement to include a ½ mole of oxygen in the equations for methanol, propanol, ethane and butane. Alternatively, some students omitted the step to reduce their calculated value by a factor of 2 if their equation was for 2 moles of the aforementioned compounds. Structural errors consisted of omission of one or more C – H bonds, carbon dioxide being ascribed single bonds or alcohols with trivalent oxygen atoms that had both C=O double bonds and O-H bonds.

The results of their subsequent trend analyses, presented as the percentage of students who reached different depths of the analysis, are given in table 4.

³ Using the Yates correction the χ^2 value $6.01 > 5.02$ [5.02 is the 2.5% level of significance (P) for one degree of freedom]

⁴ The χ^2 value $14.6 > 10.83$ [10.83 is the 0.1% level of significance (P) for one degree of freedom]

Table 4 Student observations and analysis of the patterns in their results.

	% of students making correct analyses in test group M [n=9]	% of students making correct analyses in control group [n=9]
Qualitatively identified an increase of ΔH_c in alkanes	100	100
Quantitatively identified an increase of ΔH_c in alkanes	67	22
Qualitatively identified an increase of ΔH_c in alcohols	100	78
Quantitatively identified an increase of ΔH_c in alcohols	67	0
Effect on ΔH_c of doubling the chain length in alcohols	44	0
Noted that the increase of ΔH_c in alkanes and alcohols is very similar	67	56
Qualitatively noted that similar members of the two homologous series alcohols have lower ΔH_c	67	11
Identified additional CH_2 and extra $1\frac{1}{2}$ molecules of O_2	44	0
Calculated that ΔH_c of ethanol was 11% lower than ethane but butanol only 6% less than butane	33	0

The combined effects of limited time and errors in calculations hindered the identification of trends in the data. There was a noticeably higher percentage of test group students who were able to make qualitative observations to compare alcohols with alkanes. Furthermore, there was a complete inability in the control group to make quantitative trend analyses.

3.1 Analysis of final interviews

During post course interviews when asked for ethical reasons of the choice of biofuel some students referred to Socratic ideas of wisdom being the greatest virtue and therefore scientific study would provide information that enabled the wisest choice. The students who made this first claim did not expand on it beyond saying that there was a need to protect the planet for the future. Several voiced their opinion that not caring about nature amounted to “poor” behaviour or a “bad” character. Some had made connections to different ethical frameworks:

“We must leave the planet the same for people in the future. If we don’t know what damage growing just oil palms will do we should not grow so many. Just enough for what we need.”

This student applied the principles of frugality and precaution, in addition to the consideration of future generations. Several students referred to the practical limitations of ethics, often suggesting that other factors would outweigh any ethically based choice.

“The price is what is important. People buy the cheapest.” When asked how learning chemistry had helped in making their choice, most answers made reference to their advancement in scientific knowledge of the processes and fuels, yet some students from the test group M connected scientific evidence or theory to an ethical point.

“The butanol gives more energy than ethanol so it is better. We don’t need as much.”

“Plants need carbon dioxide to grow. Burning alcohol makes carbon dioxide like fossil fuels but the plants use it. It is better for the environment.”

“Alcohols don’t give off carbon monoxide so that doesn’t hurt or poison people in cities. It is better than petrol. Biofuels are part of the carbon cycle so it is nature.”

The latter arguments show a partial understanding although may indicate some misconceptions. Firstly, that carbon dioxide from alcohols is somehow more useable for photosynthesis yet that sourced from fossil fuel combustion is less unusable. Secondly, the student has stated that incomplete combustion is impossible, rather than less likely, with alcohols compared to hydrocarbons.

However, when asked if studying this chemistry had helped them make ethical choices the students’ answers often showed their own connections between the science and the ethical problem.

“To work out the best choice or what will make the less damage the calculation show which is best. Need to try by experiment because some don’t burn that well. I compared them and worked out butanol most energy and does not make carbon monoxide. This means it’s better for health and won’t pollute the future.”

“In ethics have to work out what is best for most people. So this way helped. I found out that butanol is better, more energy and makes more explosion more product made in reaction. So won’t need as much. Grow less plants or use plants to feed people. Better for environment.”

“Ethics is being good, kind and wisdom. It is wise to be kind to nature. Chemistry is about knowing what chemicals do and how much pollution they make. The butanol made less pollution so it is the right one. Chemistry help make clever and safe choice not to hurt nature.”

“Ethics is important for companies to make sure fuel burns well and is safe for people and the environment. They are responsible. People buy petrol to make their car work. They aren’t thinking of principles. They’ll stop if it is dangerous.”

The first two quotes here illustrate reasoning, based on the application chemistry skills, in utilitarian terms. There is also reference to principles of sustainable development including future generations, environmental protection and meeting needs. The third quote indicates that this student has found that the use of chemical knowledge has helped make a virtuous option clear to them. This is the virtue of having concern and respect for other living organisms. The final quote suggests this student has adopted a pragmatic outlook yet this student does refer a principle of rights and responsibilities.

Some students who had demonstrated high ability at performing calculations and drawing conclusions were questioned a little deeper during interviews. They were asked specifically if analyzing the trends in the data was helpful when it came to making a choice of fuel.

“Alcohol gave less energy than alkane. Not much less. There wasn’t much difference in percentage when I compared butane and butanol.”

“They don’t need as much oxygen to burn completely as there is oxygen in the molecules. This makes them safer and more efficient.”

Generally, though interview dialogue it was clear that many students were engaged in higher order thinking skills of evaluation. They referred to patterns found in experiments and calculations. Some used this towards making suggestions for possible fuels that were novel to them. This illustrates use of information from different sources in the higher order synthesis thinking skill. There is clear evidence that simplifying bond energy values for calculations enable students in the test group to analyse trends in greater depth and subsequently apply their observations to making informed choices regarding fuels. The interviews revealed that many had gained an insight into a range of possibilities for producing biofuels and expressed their ideas with clarity and confidence.

3.2 Discussion of possible bias

This case study was part of a wider environmental ethics and science course and the scheme of study incorporated supplemental experimental investigations. So there were several opportunities for students to be influenced over their choices of fuels. Arguably the aforementioned quotes illustrate how students partially recalled statements made by the teacher during the course. This would imply

that there is no clear evidence of use of the higher thinking skills of analysis, evaluation or synthesis. Yet the interview extracts are illustrative of students making connections between different parts of the course; this is a synthesis skill. The fact that no students recommended fossil or nuclear fuels may also suggest a bias or desire not to advocate something that is perceived as being unacceptable. The stratified random selection of students into test and control groups was a reasonable precaution to eliminate bias when determining the impact of simplifying calculations.

4. Conclusion and recommendations

Understanding of the importance and application of stoichiometry in simplified enthalpy calculations provided students with more time and simplified the identification of trends in data. This enabled less numerically skilled students to overcome a stumbling block and progress to a more analytical stage. Additionally, the simplification allowed the more able students to draw deeper conclusions and make wider inferences. The analysis of errors shows that a number of errors are common to both the test and control groups, yet the simplification of bond energy values led to less arithmetic errors. Further research should determine if this was due to a common factor such as working memory span [19]. This could also be an important consideration in what limited the trends analysis by students. Increasing the working memory span may also assist their analysis of patterns in data [20].

A number of interview extracts illustrate clarity and strength in ethical argumentation by the end of the course. Concluding that to some degree, there is value in the use of chemical knowledge in making an ethical judgment. Some students made specific reference to skills acquired in chemistry that had enabled them to make a reasoned ethical choice. There is evidence of the application of various ethical frameworks from simplistic rules or values to more sophisticated use of principles. There was also a pragmatic view stated widely within the group as a whole that ethics has limitations. Several students said that other socio-economic considerations may be of greater importance to consumers. Further content analysis of interview transcripts through text density analysis and or coding for grounded theory development may reveal greater insights into connections students have made between ethical, scientific and technological reasons in their argumentation.

The development and use of higher order synthesis thinking skills during the modeling and presentation work afforded the opportunity for more able students to express their thoughts with justified reasons and critique their own argument. This was a challenge for many students, yet it illustrates the value of an approach that gives them the opportunity to develop advanced and rigorous decision making skills.

This study provides teachers with a useful framework that provides the students with the opportunity to develop and hone higher order thinking skills through the application of scientific in ethics. The research indicates that there is value for curriculum developers to ensure that, and for teachers to employ, a structured yet simplified approach to teaching ethics, scientific principles and RE technologies in secondary educational programmes. The regular use of examples drawn from various RE processes and technologies makes them more fully understood, more familiar and less of an “alternative” but more of a well thought out and justified selection by the upcoming generation of consumers.

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