Efficiency of an Engine

**Cynthia Dayton (Southwestern CC)**

| **Major Section** | **Content** |
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| Lesson Overview | Overall Purpose* To apply lessons in thermodynamics (thermochemical equations, stoichiometry, work, and internal energy) to engineering design and assess impacts on pollution, fuel economy, cost, and safety

Estimated Timeframe:* 1 Lecture (2 hr 40 min)Review writing a proposal, assign groups, have students assign responsibilities within the group and create an action plan for how they will work on this project. Review design elements of an internal combustion engine.
* 1 lab period (2 hr 40 min)Take Home Assignment (3 hours to complete; allow students one week to complete assignment)

Courses for Implementation* General Chemistry I
* Physics I
* Engineering

Key Terms* Thermodynamics
* Thermochemistry
* Heat
* Work
* Conservation of energy
* Fuel efficiency

Standards/Skills AddressedAcademic Concepts* Math: Equations, graphing, analysis, calculations involving units of measurement
* Engineering: Design factors affecting heat and work in a combustion engine
* Chemistry: Using balanced thermochemical equations to perform stoichiometric calculations including limiting reactant, energy, heat, and work
* English: Composition, analysis, comprehension
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|  | Employability Concepts:* Applied academic skills: Reading, writing, math-strategy/procedures, science-strategy/procedures
* Critical thinking: Creativity, problem solving, reasoning
* Personal qualities: Works independently, adapts and shows flexibility, demonstrates responsibility
* Resource management: Manages time, manages money, manages resources
* Information use: Locates, organizes, uses, and communicates information
* Communication: Comprehends written material, conveys information in writing
* Technology use: Graphing and data analysis

Learner Outcomes/Student Learning ObjectivesLearners will be able to:* Use thermochemical equations to calculate quantities of heat, moles of fuel, and grams of fuel.
* Use work equations to determine the amount of work being performed.
* Use internal energy equations to determine the amount of heat lost by a system.
* Calculate fuel efficiency.
* Consider design elements such as surface area of a cylinder, volume of expansion, and compression ratio to determine heat loss and work performed.
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| Equipment / Materials | Materials/Equipment/Texts* Student handout
* Charts of fuel values and alternative fuel values from U.S. Department of Energy (<https://cta.ornl.gov/data/appendix_b.shtml>)
* Laptop cart with printer
* Calculators
* Animation of different engine designs (<http://www.animatedengines.com/>)
* Toyota combination of Otto/Atkinson cycle (<https://www.youtube.com/watch?v=WKKILW3Zj_Y>)
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| Discussion | Industry BackgroundThe Corporate Average Fuel Economy (CAFE) standards were first enacted by the United States Congress in 1975 in response to the 1973–1974 Arab oil embargo. The embargo caused oil costs per barrel to quadruple in just one year. Concerns over America’s dependency on foreign oil caused Congress to introduce restrictions on how much gas vehicles consume. While energy independence has remained an important national security issue in the United States, increases in CAFE standards have recently been the result of environmental concerns. Fossil fuels contribute to air pollution and increase carbon dioxide in the air. Companies have taken several approaches to increasing the number of miles of per gallon achieved by the vehicles they manufacture. One approach is to reduce the size of the engine, which requires making lighter-weight vehicles. Another approach is to produce electric cars, either as hybrids or as full electric models. Both of these approaches have had drawbacks. Lighter-weight vehicles have been blamed for increases in traffic fatalities. Hybrid and electric vehicles have long charging times and lower horsepower than internal combustion engines. Another approach is to combine engine types such as the Atkinson combustion cycle and Otto 4-stroke. Computers in the engine can switch from the more powerful 4-stroke operation to the more fuel-efficient Atkinson operation to save fuel when less power is needed. Many hybrid models use electric motors to replace the 4-stroke engine and the Atkinson cycle as the combustion portion of the engine. The key component to any engine is the amount of work it can perform. The energy released by the fuel must be harnessed to do work or it will escape the system and be lost as heat. In a combustion engine, the work is performed when a piston under pressure is moved by expansion of gas caused by combustion of fuel. The total energy available is determined by the thermochemical equation of the particular fuel being used. Some fuels will produce more energy than others. Most combustion engines have a fuel efficiency of only 30%, meaning only about 30% of the energy released is used for work. That means 70% of the energy is lost as heat. Designing a more fuel-efficient engine means reducing heat loss and increasing the work being performed.Fuel type is also a factor in fuel efficiency. Different molecules produce different amounts of energy when burned. They also produce different products that contribute more or less to air pollution. Fossil fuels have traditionally been used in internal combustion engines in different blends. Blends of fuel are given octane values. An octane value is not actually based on the percentage of the molecule octane in the blend. It is a rating of the performance of the fuel (energy output) compared to octane. It is also a rating of potential autoignition of the fuel at improper times (knocking), which can lead to loss of power. This is why it is possible to produce a 130-octane fuel. You cannot have a fuel that is 130% octane, but you can produce a fuel that produces 130% of the energy of octane. Higher-octane fuels are produced either with higher proportions of larger aromatic compounds or higher quantities of oxidant additives such as ethanol. Looking at the thermochemical equation for the combustion of octane,we see that the reaction is also dependent on the amount of oxygen available. Oxidants such as ethanol provide the oxygen needed for combustion of the fuel, reducing the amount of air that must enter the cylinder for complete combustion to occur. This is also why car racers add a nitrous boost to their engines to increase power. Turbochargers can be added to smaller engines to boost power output and fuel efficiency by compressing the air being pushed into the engine cylinder. This gives more oxygen per volume of air.Biofuels are also being developed to replace fossil fuels in internal combustion engines. There are many types of biofuels. Natural gas, ethanol, and biodiesel are examples. Each fuel has its own enthalpy (energy) when burned. Some of these fuels require engine modifications as well.Real-world ScenarioYou work for an automobile manufacturer whose goal is to improve fuel efficiency in its new sport utility vehicle. You will work on designing an engine that meets that goal. You will measure the fuel efficiency of your proposed vehicle and then work on choosing a fuel that will help improve fuel efficiency and reduce pollution.Things to think about:* Pollutants (leaded gasoline, sulfur-containing compounds, carbon monoxide, and carbon dioxide emissions) leave the engine through exhaust. What environmental problems does this create? (greenhouse gases, smog)
* Alternative fuels (biodiesel, ethanol, hydrogen). What are their fuel values? Are these fuels hard to produce? What design elements are required? Are these feasible alternatives? What kind of reduction in pollution can we expect?
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| Instructional Strategies | Proposed Teaching Strategies * Teamwork
* Experiential learning
* Data gathering and manipulation
* Measurement
* Calculation
* Analysis
* Research
* Design

Bloom’s:* Create: Students will create a proposal recommending the type of engine, fuel, and other features they have chosen.
* Evaluate: Students will justify their selection with data derived from their own calculations and information they have found through research.
* Analyze: Students will compare their calculated values with values offered by a car company for a similar engine. They will use research to determine whether or not the company’s information is reliable.
* Apply: Students will use concepts such as enthalpy, work, and heat to explain their results.
* Understand: Students will recognize equations from the lecture and use them to perform calculations.

REACT:* **Relate**—Students will assess fuel efficiency and horsepower in vehicles. Students can relate their own experience with a low-power or low-fuel-efficiency vehicle.
* **Experience**—Students will calculate energy used in combustion based on the size of the engine and compare these calculations to the projected work to see how low the fuel efficiency of the average vehicle actually is. Students will learn to make Excel spreadsheets and use math functions and graphing in Excel.
* **Apply**—Students will use what they have learned about thermodynamics, energy of reactions, and work performed by burning fuel in an engine.
* **Cooperate**—Students must work together to complete the Excel spreadsheet and make decisions about which engine and fuels are the best choices.
* **Transfer**—Students should be able to use the proposal written for this lab to perform research and use data to support arguments in other projects.
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| Activities / Lesson Procedure | Activity PreparationInstructor* This lab is meant to be performed after a lecture on thermochemistry, internal energy, work, and enthalpy of reactions.
* Review design elements of engines and their relation to thermodynamics.
* Heat loss as determined by the surface area of the cylinder: The cylinder size affects the expansion done by the piston (the amount of work per detonation) but also increases heat loss and can increase the weight of an engine.
* Type of engine: Diesel, Atkinson, and 4-stroke (gasoline) all have different compression ratios. (Increased compression leads toincreased work.)
* Energy of fuel used: Thermochemical equation gives value of energy per mole of fuel burned.
* Volume and type of oxidant: Oxygen from the air is often used, but the air is only 21% oxygen, so a large volume of air is required to get oxygen to the fuel unless another oxidant is used or the engine is turbocharged (compressed air is supplied to the cylinder instead of air at normal pressure).

Student* Work within a group to create an action plan for the lab. Who will take on what responsibility? How will progress be measured?

Activity Steps* Students will watch animations of the three main types of engines being studied (diesel, 4-stroke, and Atkinson).
* Students will work in groups of 3–4 to analyze design elements and perform calculations of work performed by the engine in an Excel spreadsheet. For each type of engine, students will calculate the work that can be performed using a different number of pistons and a different cylinder volume and choose which engine performs the most work (based on using octane alone as the fuel) as well as the fuel efficiency of the engine.
* Students will watch the short video on the Toyota combination engines and discuss how combining engine types or adding a turbo charger will increase fuel efficiency (<https://www.youtube.com/watch?v=WKKILW3Zj_Y>).
* Students will use the charts of fuel values from the U.S. Department of Energy to calculate the maximum energy each fuel type can produce by converting the J/kg given in the chart to enthalpy (KJ/mol) in the chemical equation. Students will select two fuels, one biofuel and one fossil fuel, for use in their engine. Students will then calculate the fuel efficiency of an engine using alternative fuels.
* Students will use air-to-fuel ratios to calculate the efficiency of using additives like nitrous oxide, racing fuel, and ethanol.
* Students will select which design elements they want to incorporate into their engine and check that the fuel they have selected will work with this engine.

Take Home Assignment* Students will research engine modifications required to accommodate the biofuel they selected for their engine. Students will also research known disadvantages of their selected biofuel (such as residue buildup and temperature impacts). Students will compose a proposal for a company using their findings to justify their recommendations on engine design and fuel choices. Students will use this research to put together a design proposal. Class time can be given to students in the next lecture to work together on finishing their proposals. After the project is completed, students will complete an assessment of how well their group worked together, what problems they encountered, and how they could avoid these problems in the future.

Expected Results* Students will use results calculated in Excel to determine how design elements affect work output. Students will be expected to use their research skills to find sources that can help them decide on whether or not their selected biofuel is a practical option. Students will then use composition skills to write a formal recommendation. Students can recommend any combination of design and fuel elements so long as their recommendation is well supported by research.

Extension Options* Have students give a presentation of their recommendations using graphs and tables of data.
* Have students research which car companies are using the design combinations they have selected. Have students find performance data and safety testing on the car model that most closely resembles their selection.
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| Faculty Resources | Background Material* Nasa Glenn Research Center 4 Stroke engine<https://www.grc.nasa.gov/www/k-12/airplane/engopt.html>
* Approach to High Efficiency Diesel and Gas Engines<https://www.mhi.co.jp/technology/review/pdf/e451/e451021.pdf>
* Laser Sparks Revolution in Internal Combustion Enginesby Optical Society of America <https://www.sciencedaily.com/releases/2011/04/110420125502.htm>
* US: NASA Glenn Research Center. 2014-06-12<https://www.grc.nasa.gov/www/k-12/UEET/StudentSite/engines.html>
* The Five-Stroke Concept<http://www.ilmor.co.uk/capabilities/5-stroke-engine>

Handouts and Supplemental Materials* Handout: Efficiency of an Engine – Combustion Engine Lab
* Worked examples of calculations (see accompanying Excel file)
* Other items as needed to cover the following:
* Calculation of compression ratio
* Conversion of Watt to Horsepower
* What is meant by rpm (revolutions per minute) and how this relates to power output
* Work equations for each engine
* Fuel energy data
* Specifications for each engine design (pressure inside cylinder, calculation of work performed by octane to expand inside cylinder, calculation of power using rpm at top speed)

Suggested Links* Jerald A. Caton, “The Thermodynamics of Internal Combustion Engines: Examples of Insights,” *Inventions,* 22 May 2018 (<https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&ved=2ahUKEwjxgfqelrrhAhUOVt8KHfUuDEAQFjABegQIARAC&url=https%3A%2F%2Fwww.mdpi.com%2F2411-5134%2F3%2F2%2F33%2Fpdf&usg=AOvVaw2vjq9xz9qRoA1IFYV_i14t>)
* *Transportation Energy Data Book,* Edition 37 (<https://cta.ornl.gov/data/appendix_b.shtml>)
* “Animated Engines” (<http://www.animatedengines.com/>)
* Toyota combination of Otto/Atkinson cycle (<https://www.youtube.com/watch?v=WKKILW3Zj_Y> )
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| Assessment | How will students demonstrate what they have learned?* Students will hand in a written report on the engine they have chosen. The report will include calculations and an explanation of design elements chosen. Students must justify their choices. (There is no correct choice, but choices must be supported by facts and calculations.) Students will include data in their discussion and will reference outside research in their conclusions.

Assessment Tools or Processes* Rubric: Efficiency of an Engine – Combustion Engine Lab
* Create writing/discussion prompts as appropriate:
* What is the projected horsepower of your engine? Show calculations and compare your horsepower to the reported horsepower of an engine currently in use.
* What is the calculated fuel efficiency of your engine? Show your calculations and compare to the reported fuel efficiency of an engine currently in use. (This is not the mpg.)
* What kind of fuel does your vehicle use?
* Could you improve the fuel economy of your vehicle by using additives or a higher ethanol blend? Why?
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**Handout: Efficiency of an Engine – Combustion Engine Lab**

**Created by: Cynthia Dayton (Southwestern CC)**

# Seven Elements of the Proposal

## Introduction

Your proposal should include a clear statement of purpose that describes your position with the company, concisely summarizes your recommendations for engine type, describes at least one additional design element (turbocharger, laser spark plugs, Atkinson-Otto cycle model, or other feature), and identifies two types of fuel to be used in the vehicle (one fossil fuel and one biofuel).

## Defining the Issue

Use research (at least three sources) to help define the need for the engine you are recommending. Answer questions such as the following:

* Does this engine help the environment? (Does it create less pollution than engines already in use?)
* Does this engine have a market? (How does it compare to other vehicles in horsepower and fuel economy?)
* Will the recommended fuel be readily available to the consumer? (No one wants to buy a car that requires fuel they cannot find.)
* Think of your audience here. You are trying to sell a company on making production changes. What are the payoffs for the company?

## Defining Your Solution

Make clear recommendations for an engine type (diesel or 4-stroke) and size using data from the lab to support your decision. Data should include fuel efficiency and use thermochemistry concepts to explain how the data was calculated and how the size of the cylinder affects horsepower and fuel efficiency.

Make clear recommendations for an additional design element (turbocharger, laser spark plugs, Atkinson/Otto cycle, or other feature) using research to explain how this feature operates, how this feature makes the engine more efficient, and what kind of boost this feature will give to horsepower or fuel economy or both.

## Formatting

Your proposal should be written in plain, direct language. If you include a term that the average person would not recognize, the term should be defined. (Terms such as *volume, enthalpy,* and *work* should be defined with equations so that the reader understands how they were calculated. Terms such as *bore,* *ethanol85,* and *air to fuel ratio* [ARF] should be defined.) If the term is not used in everyday language or has a different meaning in this context, it should be defined in plain language. Check for spelling and grammar errors.

Use formatting from sample proposals. (See <https://www.wikihow.com/Write-a-Proposal> and <https://www.hloom.com/more/sample-proposal-templates/>.)

Each section of the proposal should have a clear heading. Use the heading feature in MS Word.

## Cost Benefit Analysis

This does not have to include numbers for things like the cost of a change in the production line. It can simply list the pros and cons of using your choices in the next model. Be sure to include any modifications required by your selected biofuel as well as any drawbacks in your design or choice of fuel.

## Summary

This paragraph should be a persuasive argument for why the company should adopt your design. Try to sell your design here, but be sure to back up your sales pitch with facts. Include one or two sentences summarizing data that supports your recommendations. You do not have to go into detail. Just give the headlines.

## References

Your proposal letter should include a bibliography of sources for your data. Choose APA or Chicago Style, but in either case use correct formatting. Inline citation should be included wherever you reference a source. You should have at least three sources, one provided by the teacher and two of your choosing.

**Rubric: Efficiency of an Engine – Combustion Engine Lab**

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| **ELEMENT** | **Beginning** | **Novice** | **Proficient** | **Distinguished** | **Comments** |
| --- | --- | --- | --- | --- | --- |
| **Introduction** | Student does not state purpose of proposal nor does student make required recommendations. | Student states purpose of proposal, but recommendations are not clear or some required recommendations are missing. | Student states purpose of proposal but does not summarize recommendations in opening paragraph. Recommendations are scattered throughout. | Student clearly states the purpose of the proposal and recommendations in opening paragraph. |  |
| **Defining the Issue** | Student does not give description of the need for the recommendation. Student makes no reference to research. | Student briefly mentions the need for the recommendations but does not make clear why they are needed. Student makes no reference to research. | Student clearly states the issue but is not persuasive as to why the recommendations are really needed. Student refers to research but does not show how research supports need.  | Student makes issue clear and follows with a persuasive argument as to why the recommendations are needed—backed by research. |  |
| **Defining Your Solution** | Student does not make the solution clear and is missing two or more of the key elements described above. | Student makes solution clear but does not support the proposed solution with facts. | Student makes solution clear and supports choices with facts, but one or more facts either contradict the argument or are extraneous to the topic. | Student makes solution clear and uses facts to support the recommendation. |  |
| **Formatting** | Missing one or more headings. Information is not presented in logical sections. Some information is in the wrong section. Terms are not defined. There are multiple spelling and grammar errors. | Proposal is clearly arranged in logical sections. Some terms are not defined or information is in the wrong section. There are more than 5 spelling and/or grammar errors. | Proposal is clearly arranged in logical sections. One or more terms are not defined. There are 2–5 spelling and/or grammar errors. | Proposal is clearly arranged in logical sections. All terms are clearly defined. There is only 1 spelling and/or grammar error (or none). |  |
| **Cost Benefit Analysis** | Student is missing 2 or more advantages or disadvantages. Student does not have data to support the argument being made and/or the data selected is not relevant to the argument. | Student is missing one or more advantages or disadvantages of the proposal. Data used does not support the argument being made. | Student clearly lays out the advantages of adopting their engine design with one or more pieces of data to support each bullet point. Student cites drawbacks in the design or fuel choices and uses data to support the argument. One or more bullet points has data that is extraneous or does not support the argument. | Student clearly lays out the advantages of adopting the engine design and provides one or more pieces of data to support each bullet point. Student cites drawbacks in the design or fuel choices and uses data to support the argument. |  |
| **Summary** | Student is missing 1 or more recommendations. Student is missing supporting data. How data is used to support recommendations is unclear. | Student includes all recommendations but is missing supporting data and does not make clear how data supports recommendations. | Student includes all recommendations, but summary of supporting data is too long or one or more pieces of data is missing. | Student includes all recommendations. Data supporting recommendations is summed up in one to two sentences. |  |
| **References** | Student is missing 1 or more references. References are not cited in the text. Reference formatting is incorrect. | Student has all three references but is missing inline citations. Formatting of bibliography contains 1-2 errors. | Student has all three references and correct inline citations. Formatting of bibliography contains 1-2 errors. | Student has all three references and correct inline citations. All items in bibliography are formatted correctly. |  |