# A Guideline for Designing Electric Bicycles

by

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## Abstract

Society is on the verge of a radical swing in the way that we commute and travel, at least in part due to the climate crisis. There is a rapid shift towards urban living and away from dependence on personal automobiles. The electric bicycle market has seen exponential growth due to these rapid shifts. With the growth of a new market, specific consumer groups begin to emerge. It is important for the designer in this space to identify these consumer groups and learn to design for each.

This study is aimed at identifying these consumer groups and understanding the needs and expectations of each to create successful products. A competitive landscape will be created to understand where the market stands and to try and identify any potential trends in the market. A case study will be done to try and learn from successful past products and gain insight that can be used to better serve the new market.

The objective of this thesis is to develop a guideline that will lead a designer through the process of designing an electric bicycle while keeping a specific consumer group in mind. The guideline will cover aspects of the design that affect not only the look of the bicycle, but the ride characteristics and capabilities of the bicycle as well.

**Keywords: Transportation Design, Sustainable Design, Consumer Group, Ergonomics, Semantics, Evaluation**

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| | |
|---|---|
| EV | Electric Vehicle |
| KW | Kilowatt |
| KWh | Kilowatt Hour |
| W | Watt |
| Wh | Watt Hour |

# Chapter One
# Introduction

## 1.1 Problem Statement

The ultimate success of two-wheeled electric vehicles depends on how product designers address the different consumer groups and their specific needs within a design. These needs can drastically change depending on the intended use of the vehicle. Current examples on the market do not do enough to address these specific needs.

Transportation is due for a redesign. Society has commuted in the same fashion for over 60 years even though our pattern of commuting has changed dramatically. There has been a huge shift in the past 10-15 years to more densely populated urban areas, which is a perfect scenario for smaller personal vehicles. With the rising popularity of electric cars, there has also been a rise in the popularity of alternative electric vehicles such as electric motorcycles, bicycles, and scooters. This rise in popularity can be attributed, in part, to the growing concern about societies role in global warming and climate change.

Local and state governments have been pushing to improve their electric vehicle infrastructure with the addition of new charging stations as well as updating pedestrian and cyclist infrastructure. As it continues to become safer and easier to commute or travel with alternate forms of transportation, such as bicycles or scooters, designers must focus on making these products more appealing and practical for the consumer.

The overall goal of the study is to create a tool to help further the success of the overall electric vehicle market through the thoughtful design of two-wheeled electric vehicles.

## 1.2 Need for Study

The success of the two-wheeled electric industry depends on how well designers address the actual needs of the consumer. These alternate electric vehicles have seen an increase in popularity over the past few years and have a chance to really develop a strong following if designed well. Two-wheeled electric vehicles have a few limitations in the current market such as skepticism from the consumer as well as the perceived cost to value ratio.

Electric motorcycles tend to be too expensive or designed and built for the wrong consumer. The electric bicycle and scooter market seem to be on the upswing as a broader market of consumers are emerging. Designers seem to be struggling to find the right user to target and create something that breaks the mold.

Designers also need to find ways of increasing the usability of two-wheeled electric vehicles. There needs to be a way for a designer to easily identify key user needs and then be able to solve for these needs. This can be done through research and thoughtful design.

A guideline will help compile valuable research and provide a design tool to help better design these products.

### 1.3 Objectives of Study

The objective of this study was to develop an approach to designing electric bicycles that are targeting broad consumer groups. This approach will include a guideline to designing electric bicycles that will cover each user group. The goal of the guideline is to be able to guide designers to create unique, creative, and well thought out designs of electric bicycles.

A case study was conducted to gain insight from successful products and apply these insights into the design guideline. This included design and marketing research to help understand the success of the product.

Another objective of this study was to gain an in-depth knowledge of frame geometry and its importance when designing electric bicycles. This study covers current technology and drivetrains available for use with electric bicycles, as well as styling and material trends.

The guideline was then be applied to a design project to show its effectiveness. The guideline covers multiple consumer groups with specific design considerations for each group.

## 1.4 Definition of Terms

**Amp –** short for ampere, a unit to measure the flow rate of electricity (Dictionary, 2021)

**Amp Hour –** a measurement for energy needed to let 1 ampere flow for 1 hour. (Dictionary, 2021)

**E-Bike –** Electric Bicycle

**EM –** Acronym for Electric Motorcycle

**Ergonomics -** an applied science concerned with designing and arranging things people use so that the people and things interact most efficiently and safely (Merriam-Webster, 2021)

**EV –** Acronym for Electric Vehicle

**Kilowatt –** (Kw) a measurable unit of power equal to 1,000 watts. (Dictionary, 2021)

**Kilowatt Hour –** a measurement used that is equivalent to 1,000 watts used over 1 hour. (Dictionary, 2021)

**Semantics -** the study of the symbolic qualities of man-made forms in the context of their use and the application of this knowledge to industrial design (Choi, 2017)

**Watt –** (W) a measurable unit of power equivalent to 1 joule per second. (Dictionary, 2021)

## 1.5 Assumptions

1. **There are specific consumer groups to be identified in the two-wheeled electric market**
    - The success of the study relies on the ability to outline specific consumer groups to aid in the design process.
    - Design considerations will be outlined for each of the consumer groups.
2. **Current electric bicycles' biggest limitation is their design**
    - Designers are not doing enough to appeal to broader audiences in the electric bicycle market.
    - Designers are not designing for the consumer groups that have the most to gain from electric bicycles.
3. **The electric bicycle market is a growing industry and consumers are becoming more accepting of electric bicycles.**
    - The success of the design tool hinges on the success of the overall market for E-Bikes.
    - The assumption is that the average person has become more accepting of an electric future. Without an accepting consumer, the product will fail.

## 1.6 Scope and Limits

**Who:** With the field of study being electric bicycles, the primary focus will be on experienced riders and users who are interested in purchasing any product that falls into the category of electric bicycles. Potential users in the Auburn, AL or Columbus, GA area will be the targeted group for current research.

**What:** This study includes exploring new ways of efficiently designing electric bicycles that meet outlined user needs. This study does not focus on designing vehicles with more or less than two wheels, or vehicles that are not powered by electricity.

**When:** This study took place from the Fall of 2019 until the completion in the Fall of 2021.

**Where:** This study took place at Auburn University.

**How:** The research was led by myself, Ian Lee, with the help of my major professor, Chris Arnold, and with the help of my committee.

### 1.7 Procedures and Methods

1. **Research the two-wheeled electric vehicle market**
    - Recognize successful products and patterns to begin to understand consumer behavior
    - Research consumer groups to identify specific needs
    - Study bicycle frame geometry to better understand its effect on the design and the rider
2. **Conduct case study**
    - Identify a successful product that created a market
    - Research the design decisions to better understand the intent
    - Research the marketing strategy involved with launching the product
    - Gather insights from the product that can be used to help form a guideline
3. **Develop a guideline to aid in the designing of electric bicycles**
    - Create a method to identify user's needs and offer a visual guide to help aid design decisions
    - Provide a resource of knowledge to help teach the designer about two-wheeled electric vehicles
4. **Apply the guideline on a design project**
    - Design an electric bicycle to test the guideline's effectiveness

## 1.8 Anticipated Outcomes

Through research, different consumer groups will be outlined to identify a variety of markets for electric vehicles. Focusing on specific consumer groups helps narrow the guideline for more concise design decisions.

Provide an understanding of frame geometry and how the design of the frame affects the look and feel of the vehicle will be incorporated into this research into the design guideline.

The goal of the study is to develop a universal tool for addressing user's needs when designing two-wheeled electric vehicles. This tool can be used to help guide a designer through the process of addressing user's needs and applying rational solutions to solve for these needs. Some of these needs may include ways of increasing the vehicle's overall range, speed, versatility, and styling. This tool will be generalized to fit a wide variety of users or even be used to fit one specific user.

## Chapter Two
## Literature Review

> *After nearly a century with the internal combustion engine dominating the personal transportation sector, it now appears that the electric vehicle is on the verge of experiencing rapid growth in both developed and developing vehicle markets. The broad-scale adoption of the electric vehicle could bring significant changes for society in terms of not only the technologies we use for personal transportation, but also moving our economies away from petroleum and lessoning the environmental footprint of transportation (Brown & Pyke, 2010).*

As the preceding quote shows, society is on the edge of a transportation revolution. Electric vehicles are a crucial next step in the continuing forward progress of transportation design. We have created an environmental crisis due to the burning of fossil fuels and will soon reach a tipping point. Electric vehicles will play a crucial part in the transformation of personal transportation.

> *In California cities where pollution levels are high, emissions from each gallon of burned gasoline cause an average of $1.50 worth of damage. In less polluted cities like Boston, equivalent emissions cause about 75 cents worth of damage. In rural areas, pollution damage is near zero. But even these cost estimates underestimate the problem (Sperling et al., 2013).*

The previous quote highlights just what the cost of continued reliance on gasoline powered vehicles is. This also shows the need for cleaner alternative forms of transportation to help combat emissions pollution. Gasoline powered vehicles have dominated the transportation in part due to the cost effectiveness of gasoline engines. Within the past decade, huge improvements have been made to the manufacturing of electric drivetrains to reduce overall costs. "Without major fanfare, electric drive has become cheaper and far more efficient. For example, advances in power electronics have made possible alternating-current (ac) drives that are cheaper, easier to maintain, and more compact, reliable and efficient" (Sperling et al., 2013). Automobile manufacturers have begun to utilize this new technology and have started the biggest push for electric vehicles that the transportation industry has ever seen. The need for an emissions solution, partnered with the huge push from companies like Tesla Motors, has prompted some states and countries to pass legislation either limiting or effectively banning gasoline burning engines within the next ten years.

This literature review discusses the brief history of electric transportation as well as the current status of electric motorcycles. The climate crisis is discussed as well as sustainability issues relating to the production and disposal of lithium-ion battery cells. This review will also discuss the current limitations of electric vehicles which includes the range, accessibility to charging stations, speed, as well as the lack of audible feedback present in current models.

## 2.1 Climate Crisis

> *Nearly one half of all Americans—an estimated 150 million—live in areas that don't meet federal air quality standards. Passenger vehicles and heavy-duty trucks are a major source of this pollution, which includes ozone, particulate matter, and other smog-forming emissions (Memo, 2011).*

This is not just an American problem; this is a worldwide problem that has caused unmeasurable damage to not only the planet itself but to all the people and species living on our planet.

A 2011 study compared emissions of motorcycles and cars from the 1980s, 1990s, and 2000s. The study showed that while motorcycles consume less gasoline and produce less carbon dioxide pollution, they produce far more harmful hydrocarbons and carbon monoxide than the automobile. Hydrocarbons, which can cause cancer, breathing and heart ailments, and contribute to smog, were produced at rates of up to 300% more with a motorcycle while poisonous carbon monoxide was produced up to 8000% more (Carpenter, 2011).

The study concluded that since the mid-1970s the automobile industry has faced increased regulations regarding emissions while the motorcycle industry has not faced the same pressure. With over 200 million active motorcycles in the world, the need for a cleaner alternative is absolute.

There is a need to shift focus to either cleaning up the emissions of modern motorcycles and start imposing stricter regulations on the manufacturing of these motorcycles, or we need or start trying to develop a better, cheaper electric option that can still attract even the most dedicated enthusiast.

## 2.2 Brief History of Electric Vehicles

The very first electric automobiles were made in the mid to late 1800s. There were many inventors working on their own version of the electric car, and no one is quite sure who made the first electric vehicle. In 1891, William Morrison created the first electric car that had any kind of success in the United States (Wilson, 2021). By 1900 electric cars were common and made up nearly a quarter of all vehicles (AP, 2009). Around this time is when gasoline motors truly stole the show and dominated the market due to their ability to quickly refuel and continue driving.

The next big push for the electric vehicle did not come for another 70 years when battery technology improved to the point that electric cars did not seem so impractical. Lithium-ion batteries were invented, which drastically reduced the weight of the battery packs in these cars. In 1976, a company located in Florida called Sebring-Vangaurd introduced the CitiCar. The CitiCar was created in response to the fuel crisis of the time (Lieberman, 2009).

**Fig 1** 1976 Sebring CitiCar
(Magazin, 2019)

The CitiCar (see Fig 1) was roughly the size of a golf cart and could reach a top speed of 39 miles per hour (Lieberman, 2009). It is interesting to note that the main market for these vehicles were people who lived in the city and had a short daily commute. This was the only market where the CitiCar made sense at the time.

Sebring-Vangaurd was not the only company pursuing electric vehicles at the time. Bigger automobile companies like General Motors were also joining the push. Unfortunately, most of the electric vehicles produced during this time period were never introduced to a mass market and slowly died in their tracks. As soon as the fuel crisis was over, so was the interest that these companies had in producing electric cars.

## 2.3 Two-Wheeled Electric Vehicles

There has been a big wave of two-wheeled electric products hitting the market for consumer use. Electric skateboards and electric scooters have become popular modes of transportation for college students as well as people who live in a big city and commute to work. A lot of bigger cities also have rental options for people who just want to explore the city or who are in a hurry to get somewhere.

Electric rental scooters have increased in popularity within the past five years or so. Companies like Bird, Lime, and Skip have introduced a line of electric scooters that all participate in a rental program in bigger urban areas like San Francisco and New York (Hawkins, 2020). These rental programs are not without their problems and some people are more accepting of these programs than others.

| GOALS | CURRENT CHALLENGES | PERMITTED COMPANIES MUST … |
|---|---|---|
| ***Ensure Safety and Access*** | Illegal Sidewalk Riding<br>Lack of Helmet Use | • Provide user education |
| | Improper Parking | • Provide user education<br>• Remove inappropriate parking within 1 hour of notice<br>• Provide detailed guidance on appropriate parking<br>• Consider piloting stations or locking mechanism |
| | Scooter Proliferation | • Have no more than 2,500 scooters in total, across no more than five permitted companies. For the first six months, the cap is lower – 1,250 scooters in total.<br>• Share operations and maintenance plans with the city that address disposal of retired scooters |
| ***Promote Equity*** | Scooter Costs | • Provide a low-income membership option |
| | Scooter Availability | • Encourage deployment in Communities of Concern |
| | Multilingual Access | • Post multilingual information on website |
| ***Increase Accountability*** | Data Sharing | • Share anonymized trip and demographic data for the pilot evaluation |

**Fig 2** Electric Scooter Ride Sharing Challenges
(Hawkins, 2020)

Fig 2 illustrates several problems associated with electric scooter. One of the main issues is illegal sidewalk riding, which can be very dangerous for pedestrians. These electric scooters, capable of speeds up to twenty miles per hour, are made to be ridden on the side of the road but riders prefer to ride on the sidewalk because they worry about dealing with cars and being in a dangerous situation. Another common issue with these types of scooters is the lack of helmet use, which can cause serious injuries if a crash occurs.

Improper scooter parking is another major issue that cities are having to deal with. Disregarded scooters are supposed to be returned to a charging station but do not always find their way back to one. A lot of these scooters are left on the sidewalk or leaned up against a building and not properly returned. Currently there are around 2500 scooters used in San Francisco's rental program (Hawkins, 2020). How do we as designers create a solution for this problem?

Another major concern for the success of these scooter rental programs is the cost of renting and the availability of the scooters. At around one dollar a trip, these scooters will not terribly ruin a budget but the fact that these scooters are littering the sidewalks when not in use can cost the city more money in cleaning them up than they make from the actual rental. A solution for this problem is to start incentivizing people to return their scooter to a proper station in return for either a small monetary reward or refund. If people were better about returning the scooters, the availability problem will almost solve itself as more and more charged scooters can be found at the rental stations.

## 2.4 Electric Motorcycles

Currently the number of electric motorcycle companies is limited, but most people familiar with the subject would say that Zero motorcycles is leading the market. Zero

Motorcycles have been around since 2006 and currently offers four models of completely electric motorcycles to appeal to more motorcycle enthusiasts (Fogelson, 2018). Although electric motorcycles cost more than comparable gasoline motorcycles, the technology is still relatively new, and the price should eventually lower as it becomes easier to produce these motorcycles. Zero Motorcycles offers the most cost-effective street legal electric motorcycle available for purchase with the Zero FXS (see Fig 3).


**Fig 3** 2019 Zero FXS
(Toll, 2019)

The Zero FXS boasts a combined highway/city range of around 70 miles (40/100). The Zero FXS also has a top speed of about 90 miles per hour. The opening price point before tax incentives is right at $8,500 and with the addition of a second battery can bring the total to above $10,000 (Fogelson, 2018).

### 2.4.1 Limitations

Today's options for electric transportation can have limitations that turn off some potential consumers. These limitations can be anything from range, speed, sustainability, access to charging, and even the cost of the electric technology. The responsibility of designers is to tackle these limitations head on and create reasonable solutions. "Designers must be generalists who can innovate across all disciplines" (Norman, 2007, p.172). To design for the solution, we must first fully understand the problem.

This study will discuss the current limitations of electric vehicle technology and potential approaches to solutions. The discussion will start with the sustainability of a lot of modern products and the consumer culture that has been created. This consumerist society can be very bad for the planet if we as designers do not think about product life cycles and material sourcing throughout the design process. The paper addresses the elephant in the room when it comes to electric vehicles, which is the range and accessibility to charging stations. This section also discusses the infrastructure needed to sustain a community that is filled with electric vehicles.

Another limitation to the success of electric vehicles in today's market is the cost of the technology. Electric vehicles are still relatively new technology and come with a relatively high price tag when compared to similar gasoline powered vehicles. This leads to many potential buyers being turned away from electric vehicles without ever giving them a legitimate chance.

### 2.4.2 Sustainability

On top of the looming climate crisis, we have become a consumerist society that struggles with sustainable solutions. We are always buying the newest product and disposing of our old products without thinking of the environmental impact that we have. The sustainability problem does not start and end with the consumer; that burden lays with the manufacturer.

“Unfortunately, most of today’s mass-produced products are not representations of ‘good work’” (Walker, 2006, p.59).

Companies are designing more and more products with limited life and are always upgrading current products to entice the consumer to continuously buy new things and dispose of old ones. “If the product is functional, aesthetically pleasing and affordable, there would seem little point in constantly creating marginally different versions” (Walker, 2006, p.155). This short product life cycle has led to the floating trash epidemic in our oceans as well as the massive, over capacity landfills that we have created.

Some may argue that the production and disposal of lithium-ion batteries are still bad for the environment. While the production of lithium-ion batteries can have an adverse environmental impact from the mining of the lithium as well as the disposal of used lithium cells, the impact from lithium batteries does not even compare to the sustained impact from burning fossil fuels. Data shows that the biggest threat to our environment is the production of greenhouse gases. The largest contributor of greenhouse gases from human activity is the burning of fossil fuels for transportation (EPA, 2020). The need for oil has also led to countless ocean oil spills and unmeasurable damage to the ecosystems surrounding those areas. As more and more people become aware of their personal carbon footprint and the impact that they have on the environment, we will see companies focusing on sustainable design. “If the strategy includes economic and social as well as environmental considerations, for instance, fair trade in its raw materials or good working conditions in the factories making it, the product may be considered to be sustainable design” (Roy, 2016, p.16).

The appearance of sustainability will become more important as our society shifts towards an eco-friendlier way of living. Consumers will care more about how their products are produced as well as the life span of the products. Products that do not meet the environmental threshold of the customer will fail and this will ultimately lead to a more competitive market where sustainability is on the minds of all designers. “If, in its design and manufacture, the associated environmental, ethical and socio-economic issues are ignored, then the object can become symbolic not of beauty but of ugliness and harm” (Walker, 2006, p.59).

If a company focuses their energy and resources trying to make good examples of sustainable design, the rewards from consumers can be great. People tend to gravitate towards companies that they feel are doing the right thing or the company that they feel has the highest quality product.

### 2.4.3 Range and Accessibility

“Today the actual power is almost invariably an internal combustion engine. The only alternative attempted, that of driving by means of electric accumulators, has never been developed because of the excess weight” (Samuely, 1947, p.175). In the early days of the electric vehicle, engineers struggled with the battle of weight. Electric motors were very cumbersome, heavy, and energy inefficient. In order to power these motors, twelve-volt lead-acid batteries were connected in sequence to achieve the desired voltage to turn the motor. This led to short battery life and led to the initial abandonment of the electric vehicle solution. “Change can still occur over time, but it will be purposeful, based on technological development” (Walker, 2006, p.159). As overall acceptance of electric vehicles increased, manufacturers have shifted more focus onto improving the technology. Over the past twenty years, lithium battery and electric motor technology have increased to the point where weight is no longer a major limiting factor to the success of the vehicle. Electric drives and motors have become lighter, more powerful, and more efficient than their technological ancestors. Lithium-ion battery technology was first introduced to the mass market in the 1970s and has since been improved upon. Lithium is the lightest of all metals, and due to its high electrochemical potential has the largest energy to weight ratio of any other metal. This innovation significantly reduced the weight of batteries needed to support a practical electric vehicle. Current electric cars and motorcycles rely on series of lithium-ion cells or variations of lithium-ion cells known as LiFePo4 cells. These new battery cells have a higher battery capacity than previous cells and have a longer cycle life (Smythe, 2019).

Lithium cells come in a few different shapes and sizes and are used to power many things in our everyday lives. Lithium cells are offered as flat cells that are found in a lot of personal electronic devices, cylindrical cells that are used for a lot of small to medium electric applications, and prismatic cells that offer the most capacity for size but are also the most expensive option (Power Sonic, 2021). Utilizing this new battery technology, modern electric cars have seen ranges of over 300 miles on a single charge (Wallace, 2021).

Electric motors differ from gasoline motors in the fact that they have a wider power range and can spin at higher RPMs without damage. With the ability to spin at higher RPMs and the ability to access all the motor’s torque with a single rotation, electric vehicles do not necessarily need a transmission. Most electric automobiles and motorcycles operate on a single speed system to reduce the total weight of the vehicle. With the motor now needing to maintain higher RPMs when traveling at faster speeds, the power consumed at highway speeds far exceeds the power needed at city speeds. Companies like Tesla are already trying to develop efficient transmissions to increase range and make the idea of an all-electric semi-truck a possibility (Lambert & Berman, 2021).

Electric motorcycles could benefit from the idea of a transmission or even just access to an overdrive gear to reduce motor rotations at highway speeds. Current electric motorcycle options available to the public have city mileage ratings that far outnumber the highway range. This is due to the increased power output at higher speeds as well as the increased air resistance.

Another major limitation to the acceptance of electric vehicles is the access to charging stations away from our homes. Humans are creatures of convenience and will almost always choose the option that seems the most convenient to them. Gasoline powered vehicles, although bad for the environment, offer a sense of convenience that today's electric vehicles cannot match regarding refueling/recharging. Gasoline vehicles can find a refueling station at almost every exit on the highway or interstate and at almost every intersection in urban areas. While the electric vehicle may only cost a few dollars to recharge, the quickest chargers available can still take fifteen to thirty minutes to completely recharge a battery pack. Not to mention that these quick chargers are not nearly as accessible as your neighborhood gas station. Such problems with charging may mean that, "if the innovation depends on technology, materials, components or infrastructures that are insufficiently developed, or its looks are too novel or unusual, it may fail to catch on and die" (Roy, 2016, p.17).

Big cities and eco-conscious states were the first to begin implementing the changes necessary to create the proper infrastructure needed to make electric vehicles practical. Smaller and more rural areas have yet to see the same changes being made, which in turn makes people in these areas less likely to adopt electric vehicle technology. This fact leads to a need for a reasonable systems design solution to help further the acceptance of electric vehicles, because, "With mechanical systems, the evolution is entirely up to the designer who analyzes existing systems and makes modifications" (Norman, 2007, p.41).

### 2.4.4 Aerodynamics

When trying to overcome the range limitation with electric vehicles, aerodynamics plays a huge role in the efficiency of the battery packs. The faster the vehicle is moving, the more air has to be pushed through and more energy is then expended.

> *This air resistance is proportional to the square of the speed, and a vehicle traveling at 100 mph has to overcome twenty-five times the air resistance of a vehicle moving at twenty mph. It is an indisputable fact that this resistance is of minor importance for speeds of less than fifty mph. Thus, for the vast majority of road vehicles there is no sound reason for introducing streamlining (Samuely, 1947, p.175).*

Streamlining is a very popular way of introducing aerodynamics to the design of a product. The basic idea of streamlining is to design an object in a way that offers the least amount of resistance when moving through air or water. Streamlined objects are generally smooth with easy transitions and minimal silhouettes. These design features serve at least two purposes: "Glossy surfaces, simple lines, with little if any projection, always gives an impression of speed and urgency, and at the same time really help to increase the speed by lessening the friction" (Samuely, 1947, p.156).

Automobiles are naturally more aerodynamic than motorcycles and often have a lot easier time cruising at higher speeds. Enclosed passengers, closed wheel designs, and lack of exposed drivetrain give the automobile a steep advantage when pushing through wind. Most motorcycles are aerodynamic nightmares with motors that are air-cooled and need to be exposed to the wind as well as a rider who is constantly battling with headwinds and crosswinds. Modern electric motorcycle companies have not really pushed the design envelope for their motorcycles and often end up with motorcycles that look like their gasoline counterpart and offer the same aerodynamic limitations. Designers need to break out of the cyclical nature of motorcycle design and really get more creative to help alleviate some of these limitations. Technological and design changes could mean significant redesign of the vehicle, because "Such technological development usually invokes a change in the form of the functioning parts, which in turn will affect the appearance of the product" (Walker, 2006, p.159).

Fast moving vehicles generally have a shape or form that gives the impression of speed. With automobiles, a longer hood and shorter trunk can give the impression of brute force speed, while a vehicle with more balanced proportions and a lower center of gravity can give the impression of being very nimble and quick.

> *It is for fast moving objects that the appearance of speed becomes all important, not only from a psychological point of view, but also because of the fact that, as the air resistance is proportional to the square of the speed, it becomes essential to have a shape that is technically suitable (Samuely, 1947, p.156).*

### 2.4.5 Speed

Many motorcycle enthusiasts are looking for a rush of adrenaline while riding. A lot of these same riders turn to speed to accomplish this. "The emphasis on speed is really a characteristic of our time, and one that seems to overshadow everything else" (Samuely, 1947, p.179).

Motorcycle designers often design fast looking machines whether intentionally done or not. There are many design elements that can make a motorcycle appear fast. This can include an aggressive design or stance, aerodynamic body panels, and even the color of the motorcycle. The most common approach to designing a fast motorcycle is to incorporate aerodynamic features to make the motorcycle appear to cut through the air. “The speed of a vehicle can be expressed in various ways: the most obvious is to streamline it; that is to shape it so that it offers the least resistance to the medium through which it moves” (Samuely, 1947, p.156).

Motorcycle designers are always designing for different degrees of speed. Some modern motorcycles are designed and engineered to achieve speeds of up to 200 miles per hour while other motorcycles only need to cruise around town. “Speed is a relative quality, and different vehicles have to be designed for various speeds. Speed certainly does not dictate the shape of everything that moves” (Samuely, 1947, p.156). Even though there is a stark difference in top speeds, each motorcycle offers different experiences and feelings of speed. A modern sports bike will feel a lot slower while riding at sixty miles per hour than, for example, an older café racer style motorcycle would feel at the same speed. “Sometimes it is possible to express speed indirectly through the power that produces it” (Samuely, 1947, p.156). Using the same comparison as before, a modern sports motorcycle may look fast through the aerodynamic fairings and aggressive styling while an older café racer might look fast when looking at the stance and exposed engine.

> *With all vehicles that need a smooth surface on which to run, stability is a prerequisite for speed. The lower the center of gravity the less dangerous are high speed and jerks due to an uneven surface. It is interesting to note that a low center of gravity and a high degree of stability suggests speed (Samuely, 1947, p.157).*

Electric vehicles are known for their fantastic weight distribution. The Tesla Model S sedan, thanks to the rows of lithium-ion cells stored in the floorboard of the car, has a lower center of gravity than a new Corvette (Schwartz, 2012). Electric motorcycles also benefit from having a lower center of gravity and often impress riders with how well they handle and how stable they feel.

### 2.4.6 Feedback

When humans are interacting with machines, there is nothing more important than feedback. Feedback in this context is essentially a dialogue between the human and the machine for the human to understand the machine. “Feedback is essential to the successful understanding of any system, essential for our ability to work in harmony with machines” (Norman, 2007, p.146).

“Actually, feedback is probably even more essential when we interact with our machines than with other people. We need to know what is happening, what the machine has detected, what its state is, and what actions it is about to do” (Norman, 2007, p.139). For the motorcycle rider, there is no more important feedback than the sound of the exhaust. The sound of the exhaust can tell an experienced rider how well their motorcycle is running or when they need to shift. The constant hum of the motor can be heard and irregularities in the sound can foreshadow a problem. This feedback is necessary to keep the motorcycle running at peak performance and to keep the rider on the same page as the machine.

Electric motorcycles do not provide most of the sound from a gasoline powered motor. All the rider hears at speeds under forty miles per hour is the tires meeting the ground and a slight buzz as the motor accelerates. At speeds above forty miles per hour the rider is subject to mostly wind noise. This near silence can deter motorcycle enthusiasts from riding an electric motorcycle due to the pivotal role that noise plays for the riding experience. Aside from the feedback the exhaust note gives, there are other points of information that the rider must know to ride their motorcycle without any issues. A rider must also be able to tell how much fuel they have, the running temperature of their engine to ensure that it does not overheat, as well as being able to tell their speed and RPMs by looking at a gauge. The electric motorcycle rider needs some of the same important information and must be able to communicate with their machine just as easily.

With less moving parts than a standard internal combustion motor, the electric motor is a lot easier to service as well as maintain. Electric motor noise is not as critical to the health of the system as is the noise of a gasoline motor. As mentioned before, the exhaust and various sounds that come from an internal combustion motor give indications of when the motor needs to be serviced. “Machines, though, are artificially created by people who often assume perfect performance on its part and, moreover, fail to understand the critical importance of a continuing dialogue between cooperating entities” (Norman, 2007, p.136). For example, a rough or uneven idle might tell the rider to look over their fuel delivery system while noticeable ticking noises might let the rider know that a valve adjustment is needed. With an electric motorcycle, the servicing is pretty much replacing tires and drivebelts every 50,000 miles. The electric motor has far fewer things that can go wrong within the system which allows for a certain peace of mind while riding. Even with this in mind, the electric motorcycle must still be able to easily communicate any issues to the rider without overloading their senses. “Although sound is important for providing informative feedback, there is a downside. Sounds are often annoying. We have eyelids that permit us to shut out things we do not wish to watch: there are no earlids” (Norman, 2007, p.63).

It is important when designing these machines that we as designers do not use too many sounds or notifications. Too many sounds and other means of feedback can give a sense of panic or a feeling of being overwhelmed.

## 2.5 Insights

With the inevitable rise of the electric vehicle, it is our job as designers to help guide the transition with honest and intelligent solutions to the common problems that this technology faces when hitting a new market. We must be able to innovate and push the boundary of what can be done and what should be done. We know how important it is to reduce our fossil fuel dependency for the future of our planet. Our job is to make the technology look more appealing to a broader audience in hopes of swaying people to accept and adopt the new technology.

It is an exciting time to be in the field of design and to be able to witness and participate in such a disruptive idea to radically change the way people travel and commute. It is not often in our lives that we get to witness such a change within century old technology. The gasoline motor has always been the most practical solution for transportation, even at the detriment of our planet. We are on the cusp of changing the way people have thought about transportation and the way we travel. With change this extreme, engineers and designers must be able to get it right as soon as possible to help ease the transition and adoption.

## 2.6 Electric Motorcycles

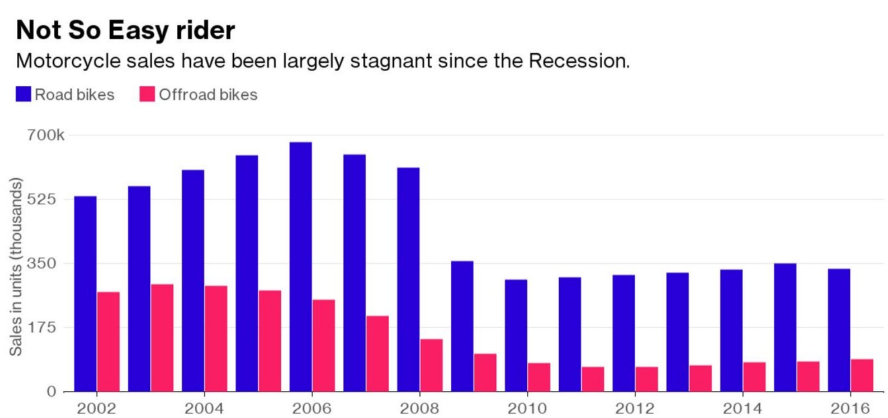


**Fig 4** Decline in Motorcycle Sales
(Stock, 2017)

Over the past decade, there has been a decline in overall motorcycle sales in the United States (see Fig 4). This decline started during the Great Recession and never seemed to gain back the ground that it lost. There has also been a reluctance from younger consumers to purchase motorcycles which leaves the motorcycle companies relying on an aging customer base (Stock, 2017).

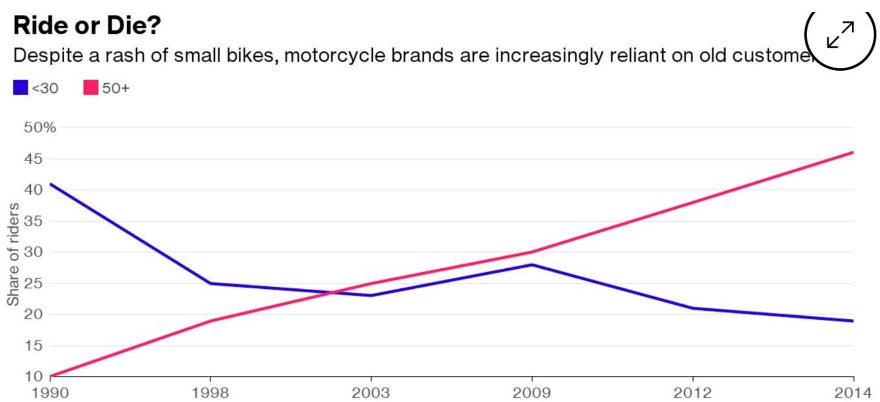


**Fig 5** Motorcycle Consumer Age
(Stock, 2017)

Motorcycle companies have begun to push to attract the younger generation to keep the industry alive. In terms of numbers, the youngest generations are the most appealing to companies. "In 2003, only about one-quarter of U.S. motorcycle riders were 50 or older. By 2014, it was close to half. The market has been cruising on a demographic that may only be able to buy one more bike." (Stock, 2017). See Figure 5.

> *Suddenly, bike-makers desperately need new riders and millennials, apparently, are the best hope. Not only are there more of them than GenXers, but they have a longer expected lifetime value, which is corporate way of saying they're a further away from needing a hip replacement (Stock, 2017).*

With most of the motorcycle industry focused on attracting new and younger riders, there has been a big push towards smaller, more manageable motorcycles. “Everybody is trying to do the same thing,” said Lee Edmunds, manager of Honda’s motorcycle marketing. “They’re all realizing they need to have more people come in at an entry-level stage” (Stock, 2017).

These smaller displacement motorcycles have really gained popularity, especially among the targeted audience. “Between 2011 and 2016, sales of motorcycles with engines smaller than 600cc increased by 11.8 percent, while bigger, more powerful bikes managed only a 7.4 percent gain” (Stock, 2017). This has caused a shift in the motorcycle industry away from the larger cruising motorcycles and powerful street motorcycles and towards smaller and slower motorcycles. “Motorcycling in America is getting a makeover. Industry stalwarts and upstart competitors are trying to attract new riders who want something different from Harley-Davidson's big burbling cruisers or screaming Japanese and European performance bikes” (Valdes-Dapena, 2019).

Even with this shift towards smaller motorcycles, the truth is that consumers just are not buying as many motorcycles as they use to. The motorcycle industry overall is losing popularity and will need a much larger transformation to make it a viable commuting option for everyone. “These younger riders are looking for motorcycles suited to a more casual relationship rather than a serious commitment” (Valdes-Dapena, 2019). With this realization, companies and designers should focus their efforts away from this industry and towards a more widely accepted form of transportation, the electric bicycle.

## 2.7 Electric Bicycles

The electric bicycle market is currently one of the fastest growing industries with annual sales nearly doubling every year. "Electric bicycle sales accounted for nearly 15 percent of our sales in 2019, and we predict that they will account for nearly 60 percent of our sales within the next 5 years" (Specialized Bicycles sales representative, personal communication 2020).

This exponential growth is attributed to multiple factors. The first factor is a large-scale shift in where people are living. There has been a trend within the past 15 years or so where more people, especially younger people, are moving to more densely populated urban areas. Millennials show a pattern of moving to these urban areas and living in a closer proximity to their place of work. "Millennials' transportation behaviors continue to change in ways that would suggest continued reductions in their reliance on cars and driving" (Dutzik & Ingles, 2014).

Along with this geographical shift, Millennials also tend to rely less and less on cars and more on other means of public and private transportation (see Fig 6). When it comes to commuting to work or school, 77 percent of Millennials travel via car, compared with 92 percent of Generation Xers and 90 percent of Baby Boomers, according to a 2013 survey by the Urban Land Institute (Dutzik & Ingles, 2014).

There has also been a noticeable shift towards public transportation, especially amongst younger demographics (see Fig 7). The ULI survey found that 20 percent of Millennials take public transit once a week or more, compared with 7 percent of Generation Xers and 10 percent of Baby Boomers (Dutzik & Ingles, 2014).

> *"At 16 years (1981 to 1996), our working definition of Millennials is equivalent in age span to their preceding generation, Generation X (born between 1965 and 1980). By this definition, both are shorter than the span of the Baby Boomers (19 years) – the only*

*generation officially designated by the U.S. Census Bureau, based on the famous surge in post-WWII births in 1946 and a significant decline in birthrates after 1964" (Dimock, 2019).*

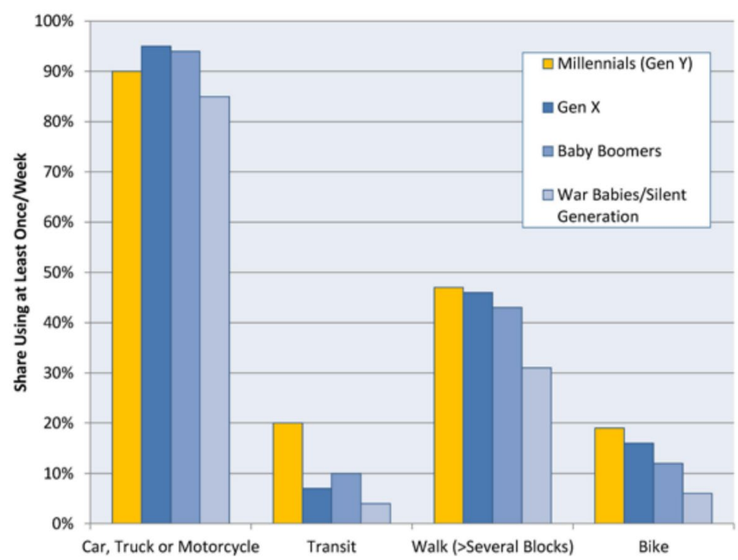


**Fig 6** Generational Transportation Pattern
(Dutzik & Ingles, 2014)

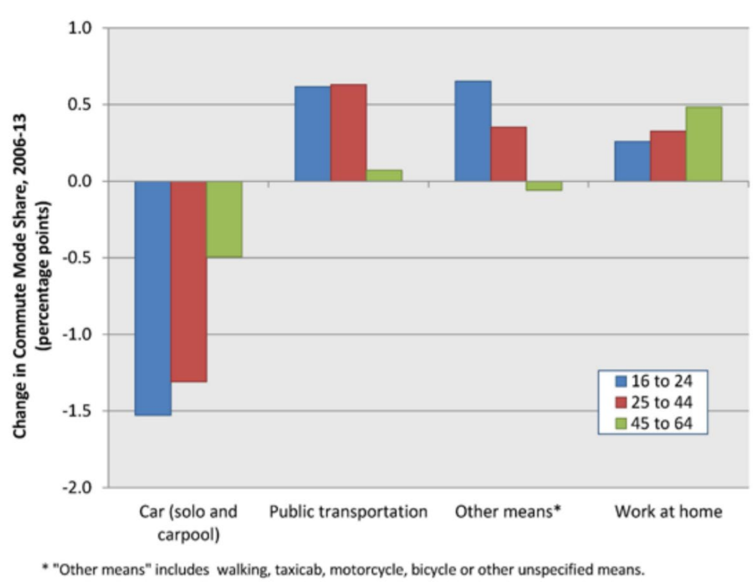


**Fig 7** Changes in Transportation
(Dutzik & Ingles, 2014)

Another factor in the success of the electric bicycle market is the familiarity of bicycles themselves. Electric bicycles, unlike electric motorcycles, can target such a large group of consumers since nearly every person in the world has either owned or ridden a bicycle before. This gives the electric bicycle a comfortable familiarity that is hard to find in another form of alternate transportation. Nearly one out of five Millennials (19 percent), according to the ULI survey, bikes at least once a week (Dutzik & Ingles, 2014).

Areas with large youth populations have tended to experience greater changes over the last several years. College towns have consistently led the list of cities that have experienced the greatest surge in bicycle commuting since the mid-2000s (Dutzik & Ingles, 2014). This quote shows the need for companies to focus on the needs of consumers in cities and college towns due to the increased bicycle traffic. Cities and college towns would benefit the most from the new technology.

## 2.8 Findings

This literature review discussed a major shift away from complete reliance on gasoline powered vehicles as well as the importance of the continued success of the electric vehicle market. Limitations of the electric vehicle market such as range and charging infrastructure were covered as well as current potential solutions to address these limitations. Transportation trends over the last decade were discussed and show the geographic and commuting shift of the younger generations.

The decline of the motorcycle market is covered in order to explain the shift in focus to electric bicycles. This decline is due to and aging consumer demographic as well as a lack of acceptance from younger consumers. The bicycle market, on the other hand, is experiencing a popularity surge due in part to a change in commuting trends. Due to this shift away from motorcycles and towards bicycles, the case study will focus on the Honda Super Cub due to its ability to serve as a transitionary product from the two markets. The design guideline produced in this paper will only cover electric bicycles due to the shift in focus.

# Chapter Three
# The Honda Super Cub: A Case Study

This case study aims at diving deeper into the decisions made and the steps taken, both in development and post-production, that led to the overwhelming success of such a modest form of transportation as the Honda Super Cub. The Super Cub serves as an example of a transitionary product away from typical motorcycles and to a more manageable form of transportation. This study will discuss the timeless marketing strategies used as well as the challenges brought by different markets. Both successes and failures will be covered to try and find a pattern that can be replicated for future design projects.

## 3.1 Soichiro Honda and Takeo Fujisawa

To better understand the decisions made during the early trials of the Super Cub, you must first better understand the people who made those decisions. Soichiro Honda, the founder of Honda Motors, along with Takeo Fujisawa, the Chief Marketing Officer of Honda Motors, can be credited with most of the decisions made regarding the Super Cub development (see Fig 8).


**Fig 8** Soichiro Honda *(left)* and Takeo Fujisawa *(right)*
(Honda Global, 2017)

### 3.2 Why the Super Cub?

There have been many iconic vehicles over the past century. One that comes to mind is the Volkswagen Beetle, a quirky car with a questionable upbringing. Fueled by a counterculture in the late 60's and a revival in the early 2000's, the Volkswagen Beetle sold more than 23 million units during its lifetime. It is so infused into everyday life that most people probably know someone who has owned a Beetle, or even has owned one themselves. The Ford F-150 truck, an American staple that made its reputation as being "Built Ford Tough," is another example of an identity created a multi-generational following with a strong loyalty to the Ford brand and this has led to the F-150 out selling any competitor in the American market for over four decades (Bell, 2021).

There is another iconic vehicle that comes to mind. A vehicle that sent a 10-year-old company born in a post-war depression, into the manufacturing stratosphere. A vehicle which, at its peak, was manufactured at a rate of roughly 450,000 units per month, or 15,000 units per day– The Honda Super Cub (Sakiya, 1982, p.78).

With over 100 million units sold worldwide, the Super Cub is the best-selling vehicle of all time (Marker, 2019). Why was the Super Cub so popular? Some will say that it was introduced in the right place at the right time, while others might say that the marketing strategy that Honda used was unlike any at the time for similar products. Both statements can be true. The ability of the initial development team to spot a need, solve the need, and then repeat in different markets, led to the Super Cub quickly becoming a lifestyle product that was able to stand alone in a crowded market of motorcycles and scooters (see Fig 9).

**Fig 9** 2019 Honda Super Cub
(Honda Global, 2017)

### 3.3 Initial Development

#### Spotting the Need

In 1955, Honda already had a motorcycle, the Honda Dream, in production (see Fig 10). Rumor has it, the name 'Dream' came about because it was Soichiro Honda's dream to build a complete motorcycle (Saurel, 2020). The Dream did well among Japanese motorcycle riders but struggled to compete in the crowded foreign market.

**Fig 10** 1955 Honda Dream
(Honda Global, 2017)

Honda wanted to develop a new mode of transportation that would not only do well in Japan but also had the ability to do well in other markets.

> *At the time, everybody in the company was talking about how important it was to create a larger engine, but we also agreed that we really needed to focus our efforts on producing a popular small bike for the masses that could mark a new beginning for Honda - Akira Akima, engineer (Honda Global, 2017).*

In the mid-1950s, Italy had the highest concentration of small motorcycles and scooters in the world. Fujisawa and Honda were shocked to see the shear amount of these scooters being used. They took note of who all were riding scooters. One of the biggest things they noticed was how vastly different the riding environment was in Italy than it was in Japan. While Italian roads were smooth, Japanese roads were more rural and rarely paved (Fitzgerald, 2019).

The 1955 Vespa GS 150 in Fig 11 was a popular model of scooter at the time in Italy. It featured a classic platform frame with a small two stroke motor mounted adjacent to the rear wheel. This gave the scooter a wide rear end designed to conceal the motor. Another feature of the GS 150 was the small 11-inch wheels that allowed for quick, sharp turns (Fitzgerald, 2019).

**Fig 11** 1955 Vespa GS 150
(D'Ascanio, 2018)

## Design Considerations

Development on the new motorcycle began as soon as Honda and Fujisawa returned from Italy. Mr. Honda gathered his small development team and set some design guidelines for the initial phase of the project. He wanted them to 'design things that fit it the hand' and to 'design things that are easy to use' (Honda Global, 2017).

> *The Old Man always said, 'Create things you can hold with your hands.' At first, I could not quite grasp the correct meaning of these words, thinking this was probably some local saying from around Shizuoka, which was where he grew up. I asked Mr. Kawashima (Kiyoshi Kawashima, later to become Honda's second president) in the Engine Design department to tell me what it meant, since I knew he was from the same area of Hamamatsu as the Old Man. He told me, 'It means that we should make small things that can be held in one's hands or body.' In other words, we should make a*

*compact bike that anybody can operate with ease." -Jozaburo Kimura, Industrial Designer (Honda Global, 2017).*

This quote from Jozaburo Kimura, a designer for the Super Cub project, really helps explain what Soichiro Honda meant when he wanted them to 'design things that fit in the hands'. Honda meant this as an overall theme that can be used for reasoning and be applied throughout the development of the Super Cub. This means to design things to be compact to reduce size and weight to give inexperienced riders confidence so that they can control the vehicle and maneuver with ease.

This line of thinking can also be applied to the servicing of the motorcycle. Designers should think of how their product will be maintained and how easy they make it for the consumer, or mechanic, to fix and maintain their motorcycle. They need to design things that are easy to access and remove and keep things small enough to be easily removed and installed. Proper maintenance will prolong the lifespan of the motorcycle and help ensure proper performance. Keeping things small was carried throughout the design of the motorcycle, including the brand-new motor that Soichiro Honda requested from his team. He wanted a new four stroke motor, no larger than 50cc. The scooters in Italy were mostly powered by two stroke motors, which Mr. Honda found obnoxious. Two stroke motors can revolve quicker than 4 strokes but produced more smoke and were quite loud. He also requested that this new motor produce at least 4 horsepower to tackle the rough roads of Japan (Brown, 2010, p.17).

Soichiro Honda saw a great need for this newly developed 4 stroke motor and was very much involved in its creation. Along with the engine development team, they began to work on the layout of this new motor. They quickly concluded that they needed a horizontally mounted motor. This would lower the entry point of the motorcycle allowing riders of any size and age to be able to get on and off the motorcycle with ease. This horizontal orientation also allowed for better cooling of the combustion chamber as it allowed more airflow to encounter the cylinder head. After many changes to the motor design, the team was able to achieve of 4.5 horsepower at 9,500 RPMs. The engine power and rotational speed of this new 50cc motor were both unheard of for motors of comparable sizes at the time (Brown, 2010, p.18).

After the motor was completed, the next task for the development team was to design a new shifting technology that Soichiro Honda requested to be 'able to be operated using one hand'. In order to achieve this goal, the team would have to get rid of the clutch lever for the left hand and rely on a new automatic centrifugal clutch system. This new centrifugal clutch would allow the rider to shift gears with just the use of their left foot.

> *Since the automatic centrifugal clutch was a totally new mechanism, it could not be developed overnight, so it goes without saying that its development proved to be difficult and required a lot of time. Mr. Akima never gave up, and single-mindedly came up with eight separate designs. That clutch turned out to be an especially important feature of the Super Cub and made the bike so convenient and easy-to-handle that women wanted to ride it as well - Jozaburo Kimura, industrial designer (Honda Global, 2017).*

This insight from Jazaburo Kimura shows that the focus of the design team was to create a product that could be used and enjoyed by anyone and that they made intentional design choices to reinforce the ease of use. The design team also showed that collaborative meetings can be an essential aspect of product development as it allows for more ideas to develop. "This process allowed for many great ideas and collaborations to come forward during the development. The idea of waigaya, or 'boisterous meetings' began to define the corporate culture of Honda at the time" (Honda Global, 2017). Meetings like this encourage collaborative problem solving, which can often lead to ideas with a lot of potential as it allows a team of people to sift through many ideas and build off one another's ideas.

With the engine and transmission finalized, the design team turned its attention to the ergonomics of the motorcycle. This new design needed to be cost effective, user friendly, and stylish. Any rider should be able to get on the motorcycle and ride with ease (Brown, 2010, p.18).

The horizontal motor allowed the design team to lower the entry point of the motorcycle as well as the overall center of gravity, resulting in an easier ride. This motor orientation also allowed the team to develop a slender, lightweight, monocoque frame.  The gasoline tank was incorporated seamlessly into the design, allowing access by lifting the hinged seat. Stamped sheet metal pieces were used to cover the motor and chain to keep any dirty, moving parts from soiling the rider's clothes. A simple cantilever front fork and a dual rear shock absorber gave the Super Cub a comfortable ride. The overall weight of the motorcycle was kept to under 200 pounds for easy maneuvering. A rear rack was included to make the Cub more utilitarian by allowing a 200-pound payload including the rider (Brown, 2010, p.18).

The wheels of the Super Cub were unlike any other wheels of the time (see Fig 12). While the scooters that Honda and Fujisawa witnessed while in Italy had small 10-12" wheels, they felt that small wheels could not handle the terrain in Japan. A smaller wheel allows for sensitive, nimble steering but does not handle obstacles or rough roads very well. The team came up with a final wheel dimension of 17" x 2.25". This size came from research on both the mechanical requirements for the terrain and the size of the average Japanese consumer, which allowed for a good ergonomic overall height to the motorcycle and a strong, stable wheel (Brown, 2010, p.18).

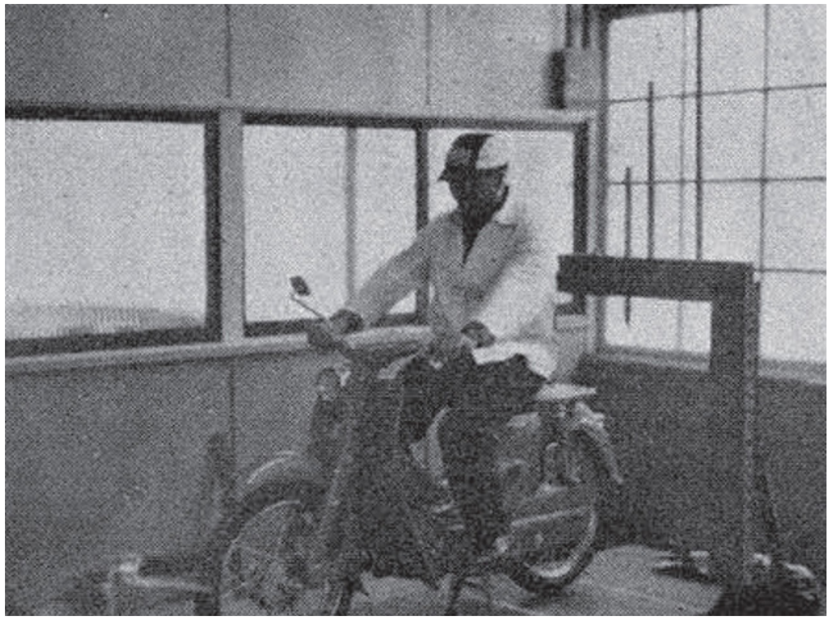

**Fig 12** Honda Super Cub Prototype
(Honda Global, 2017)

## 3.4 Japanese Market

### Early Years

With the Super Cub now in production, Honda believed that the product would do very well and boldly claimed that he could eventually sell 30,000 Super Cubs a month. Soichiro Honda did not want to rely solely on advertisement to sell the product. He believed that if the product truly made people's lives easier, then word of mouth campaigns would fuel the sales of the Super Cub (Honda Global, 2017).

When the Super Cub was introduced, it was an instant hit and sold unlike anything Honda had produced before (see Fig 13). Within the first five months of production, the Super Cub had sold over 24,000 units. The following year, sales continued to rise with over 167,000 units being sold to customers. This is quite remarkable considering the total motorcycle market in Japan was around 300,000 units per year (Fitzgerald, 2019).

**Fig 13** 1958 Honda Super Cub
(Honda Global, 2017)

This required Honda to begin rebuilding and upgrading the Suzuka plant to keep up with consumer demand. The Suzuka plant would become the main factory for all Super Cub production and could truly be the topic of a case study into manufacturing and efficiency (see Fig 14). At peak production, running a day and a night shift, the Suzuka plant was outputting 50,000 Super Cubs per month (Sakiya, 1982, p.78). This is a good reflection on how important manufacturing should be considered during the design process of any product (refer to Chapter 4 section 4.5).

**Fig 14** Suzuka Plant in Operation, 1960
(Honda Global, 2017)

**Marketing Strategies**

The first advertisement campaign for the Super Cub was a round of newspaper ads that were specifically aimed at Soba noodle shops and other local restaurants. The goal was to convince shop owners that the Super Cub was a smart choice for their business. The choice slogan for this ad was ‘The Soba is Good, Too, Ma!’ (see Fig 15). This advertisement told the story of a young soba noodle delivery boy writing home to his mother explaining how much business has boomed since the owner bought a Super Cub. The young delivery boy states that his job is more meaningful because his deliveries are more efficient, and his noodles never get soggy. He claims he can operate the Super Cub with one hand while holding more noodle trays with his left arm. Soon after these targeted ads were used, Honda got orders for around 4,000 Super Cubs from restaurant and noodle shops all over Japan (Honda Global, 2017).

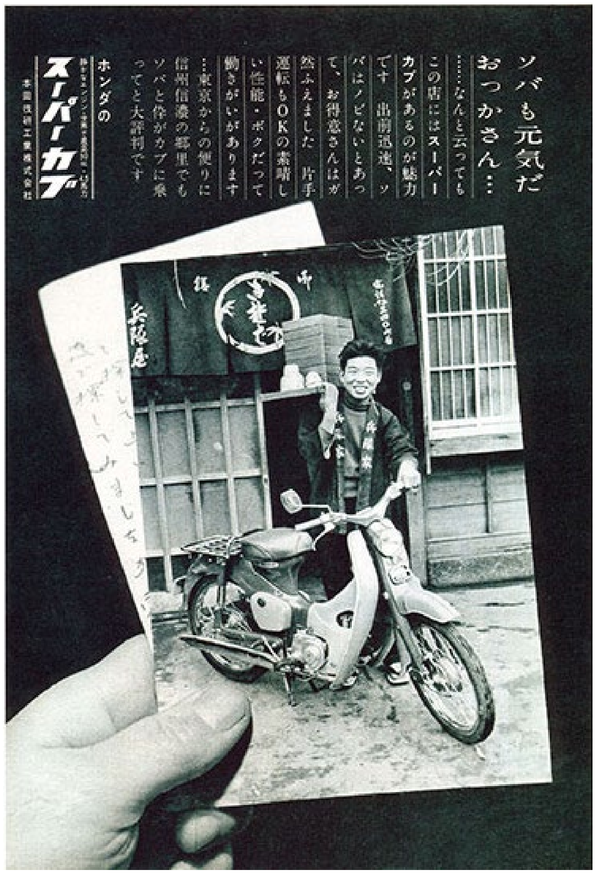


**Fig 15** ‘The Soba is Good, Too, Ma!’
(Tokyo Graphic Designers, 2017)

In 1961, very few of Japan’s roads were paved, and bridges were very scarce. This led to most Japanese workers having to take a ferry across water and then having to deal with rough roads. The advertisement shown in Fig 16 was centered around the idea of commuting in Japan (Honda Global, 2017).

**Fig 16** The Cub Grabs Headlines Again!
(Tokyo Graphic Designers, 2017)

Women have always been under served in the male-dominated motorcycle industry. Takeo Fujisawa, with help from Tokyo Graphic Designers, led a marketing campaign specifically targeting the female rider. Unheard of at the time, Honda placed motorcycle ads in some of the most popular women's magazines in Japan (Honda Global, 2017). These weekly ads depicted the Super Cub as a fun, easy to use, lifestyle product. They were often full spread color ads showing women taking spontaneous trips on their Super Cub or just having fun with the motorcycle on display (see Fig 17).

Fujisawa believed that "This has got to be a bike that anyone can ride, and especially one that makes women feel confident they can ride" (Honda Global, 2017).

Tsugio Ogata, director of Tokyo Graphic Designers, noted that “Motorcycle ads were simply not seen in women’s magazines in those days. People in other advertising and publication companies were astounded when we ran them. However, those advertisements are now kept in the collection of a print museum as testament to how revolutionary they were for the time” (Honda Global, 2017). Honda’s aim was to show the Cub as a versatile product that gave its owner the experience and the freedom that was once unattainable. The advertisements (see Figs 18-21) that Honda ran in general interest magazines of the early 1960’s sought to show the Cub as a lifestyle product (Fitzgerald, 2019).


**Fig 17** A Fashionable Stroll
(Tokyo Graphic Designers, 2017)


**Fig 18** High Noon
(Tokyo Graphic Designers, 2017)


**Fig 19** Cool Riding
(Tokyo Graphic Designers, 2017)


**Fig 20** A Short Trip to the Highlands
(Tokyo Graphic Designers, 2017)


**Fig 21** June Bride
(Tokyo Graphic Designers, 2017)

### 3.5 Tackling a New Market

### The Cub Takes on America

Honda Motors was a growing company with international ambitions. Fujisawa began marketing research during the development of the Super Cub to try and better understand the foreign motorcycle market. The results showed that for 1958, the largest motorcycle market was in Europe with over 2 million units sold annually. The American market, however, only bought around 60,000 units (Honda Global, 2017). America boasted the largest consumer market in the world at the time, and a successful entry into the American market with the Super Cub would mean they could acquire a share of the market and introduce Honda to America. At the time, motorcycle sales in the US were dominated by a few brands; Harley Davidson, Indian, Triumph, and BMW owned most of the American motorcycle market. The motorcycles sold were bigger bikes with larger motors and often came with the stigma of the owner being a 'biker' (Andrezak, 2013).


**Fig 22** American Honda Motor
(Honda Global, 2017)

## Design for Versatility

Honda opened their first American shop in Los Angeles, California in June of 1959 (see Fig 22). They offered three models at the time: The Dream 250, the Benly 125, and the Honda 50 (aka the Super Cub). Sales were extremely slow during the first month with only 8 motorcycles being sold (Honda Global, 2017).

Kihachiro Kawashima, the man appointed by Takeo Fujisawa to head the American Honda shop, noted in their first sales report that although the sales were low, customers seemed open to the idea of such small motorcycles. Fujisawa took this insight and then instructed Kawashima to begin to investigate different aspects of the American lifestyle that the Honda 50 could benefit. After observing the American consumer, Kawashima noticed distinct differences between American consumers and Japanese consumers. Americans considered the Honda 50 a 'toy-like' product that was made for recreation (see Fig 23). Kawashima did not see this as a failure of the product, but instead another market that the Super Cub could serve. He began to market the product to outdoor supply stores to sell from their showroom. He believed that he could convince the hunters and fishers of America that the Super Cub would not only benefit their chosen recreational activity, but also add many more benefits to their daily lives (Honda Global, 2017).

This proved to be a great idea, as sales of the Super Cub began to take off. Hunters began loading their Super Cubs into the backs of their trucks and relying on them once they get to the woods. Fishermen would load all their gear onto the Super Cub and quietly ride off to their favorite pond. The same marketing points from the Japanese market shone through to the American market in slightly different ways. "Thanks to these efforts, US sales rose to around 1,000 units per month in 1961 before slowing back down that summer" (Honda Global, 2017).

Takeo Fujisawa knew a different approach was needed to continue gaining market share in America. Fujisawa believed that Honda not only needed to develop a new product, or products, based on the same design considerations from the initial development of the Super Cub, but would also need a brand-new marketing campaign (Honda Global, 2017).

**Fig 23** The Honda 50 (aka Super Cub)
(Honda Global, 2017)

**A New Model…Sort of**

Honda needed something different to fulfill the needs of the American market. Fujisawa instructed the development team to work out a new model, one that both satisfied the needs of the consumer and the timeline of the company. Fujisawa requested that this new model be developed by the end of 1961 and ready to sell the following year (Honda Global, 2017).

This marked a critical moment in the early life of the Super Cub. The versatility of the design would be tested, as the new model would need to use as many parts from the Super Cub as possible to cause minimal disruption to the manufacturing process. A well-designed product should be versatile and be easily modified to address different consumer needs. By the end of 1961, the Honda Trail 50 was introduced (see Fig 24).

The Trail 50 is a great example of how the Super Cub was so well designed from the beginning, that it could be easily re-worked for another market while essentially being the same product. The designers removed the splashguard and engine cover while installing new off-road tires and an upswept exhaust system that avoided damage from rocks or roots (Uhl, 2020). The Trail 50 was the American outdoorsman's dream come true.

**Fig 24** The Honda Trail 50
(Honda Global, 2017)

**A New Strategy…Sort of**

To compliment the new Trail 50, Fujisawa planned to implement a new marketing strategy. This new strategy would introduce the Trail 50 to hunters, fishermen, farmers, recreationalists, and anyone else who loved to be outdoors. A rollout of new advertisements from Fujisawa and Ogata began to show the Super Cub as the ideal product for the avid outdoorsman. These ads highlighted the many potential uses of the Trail 50 as well as the ability to 'lighten the load' of any outdoor task (Uhl, 2020).

These new ads (see Figs 26-27) equated to sales success, as sales jumped to over 40,000 units in the following year. Honda began to build a reputation as a reliable, cheap form of recreational transportation. The price of the Trail 50 was so affordable that parents began buying them for their kids as gifts (Uhl, 2020).


**Fig 25** Honda Trail 50 Advertisement Brochure
(Uhl, 2020)


**Fig 26** Honda Trail 50 Christmas Advertisement
(Uhl, 2020)

Now that Honda had gained traction in the American market, they were set to expand their marketing strategy again. Honda had captured the off-road market but had yet to see a rise in Americans commuting on these vehicles. One of the issues was that Americans had a distinct view on motorcycle riders. Motorcycle riders at the time were seen as loud, leather-wearing rebels who rode by their own rules. This led to Fujisawa's next marketing mission, which was to change the stigma around riding motorcycle.

## The Nicest People

To help change people's perceptions of motorcycle riders, Takeo Fujisawa launched one of Honda's most successful marketing campaigns of all time. 'You meet the nicest people on a Honda' was a slogan created by an American college student during the mid-1960's that eventually became synonymous with the Honda brand itself (AP, 2009). This new campaign and slogan showed many diverse people riding Hondas and aimed at proving that motorcycles were for anyone who wanted one (see Figs 27-28). These ads, both print and television, showed anyone from students riding to school to grandmothers going shopping. This strategy was like the initial strategy in Japan, as it showed many different people riding the Super Cub to show how easy it was to ride. The difference between the two strategies, which is really a difference between the two countries, is that in Japan there is not a culture around large motorcycles and there was not as much of a stigma around riding one. The American strategy used similar advertisements in order to get a different result.

The ease of riding and owning were also a huge marketing point during this marketing campaign. Ads often spoke to how the Honda 50 was so easy to ride that "even your brother-in-law could master it" and was so easy to own that "A Honda 50 costs less to own than a good set of golf clubs" (AP, 2009).

The versatility of the Super Cub design was proven again and again as Honda continued to slightly modify it to appeal to different submarkets. Built around the same chassis, these new models pushed the limits of what the Cub could be. Some of these models were successes while others were deemed failures, but they allowed Honda to quickly develop new models without having to reinvent the Super Cub itself.


**Fig 27** You Meet the Nicest People on a Honda
(Honda Global, 2017)

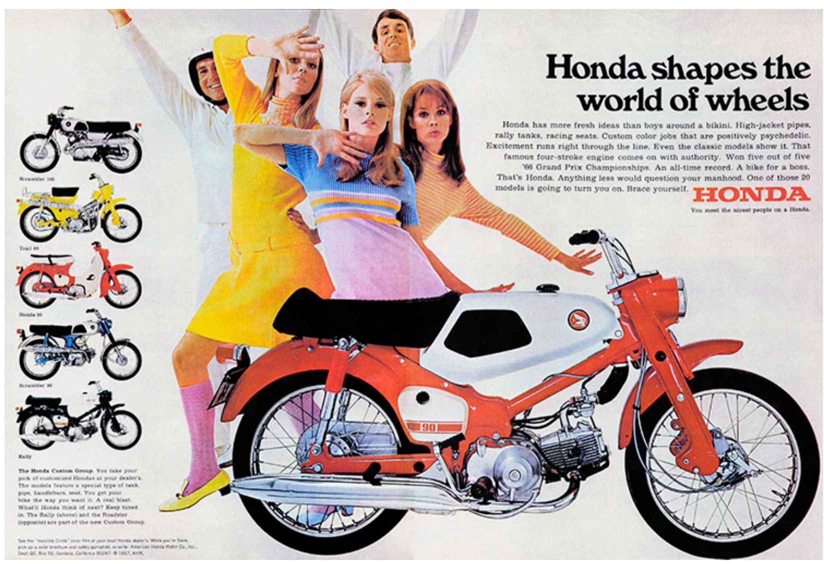


**Fig 28** Honda Shapes the World of Wheels
(Honda Global, 2017)

## 3.6 Lessons from the Cub

### Insights

After looking into more of the decisions and strategies made during the development of the Super Cub, a few things stand out as being a critical factor in the overall success. The goal is to extract these key factors to be able to take them and utilize them for potential future design projects. These factors can be for both design and marketing.

The main factor in the overall success was the versatility of the design of the Super Cub. This versatility led to the Super Cub benefiting many people's daily life. The versatility of the Super Cub's design is also what allowed Honda to successfully enter the American market. As designers, we should always think about the next step for our product and how our design allows for change.

Another factor for success was the ability of the development team to come together and find great solutions for the problems facing the Super Cub. Anytime the Super Cub ran into a problem, both pre- and postproduction, the development team was able to step back and collaboratively reassess to find a solution. "'Everybody's got to think carefully.' The Super Cub was truly a machine developed as a result of 'everybody' joining hands," Remembers Jozaburo Kimura, industrial designer (Honda Global, 2017).

The final factor for the overwhelming success of the Super Cub was the incredible and deliberate marketing campaign, led by Takeo Fujisawa, which took the Super Cub from a great product to a legendary product. Without the patience and insight from Fujisawa, the Honda Cub might have struggled to ever leave Japan. Fujisawa had a knack for effectively communicating a product's purpose and ability to benefit any consumer. Fujisawa, most importantly, was able to identify underserved markets and felt that these were more important because these were the customers that no one else was marketing to.

Designers should always focus on how our products enhance people's lives. A great design will impact a consumer's daily life in both intended and unintended ways. A great product should be versatile, inclusive, and useful.

# Chapter Four
# Electric Bicycle Design Guideline

## 4.1 Introduction

This guideline is intended to aid with the design process of electric bicycles by outlining areas of the bicycle design with considerations for specific consumer markets. The guideline will assist the designer with choosing a drivetrain and related components as well as the geometry of the frame itself

This guideline will only cover single rider stand-over style bicycle frames and will not cover untraditional frame designs such as tandems or recumbent bicycles. This guideline will also not cover aspects of the design that are consumable or easily changed by the consumer due to preference, such as grips and seats.

The goal of this guideline is to help further the success of the electric bicycle market by helping designers create better electric bicycles that best serve their intended consumer. The designs that come out of this guideline will be thoughtful and consider the needs and desires of the rider.

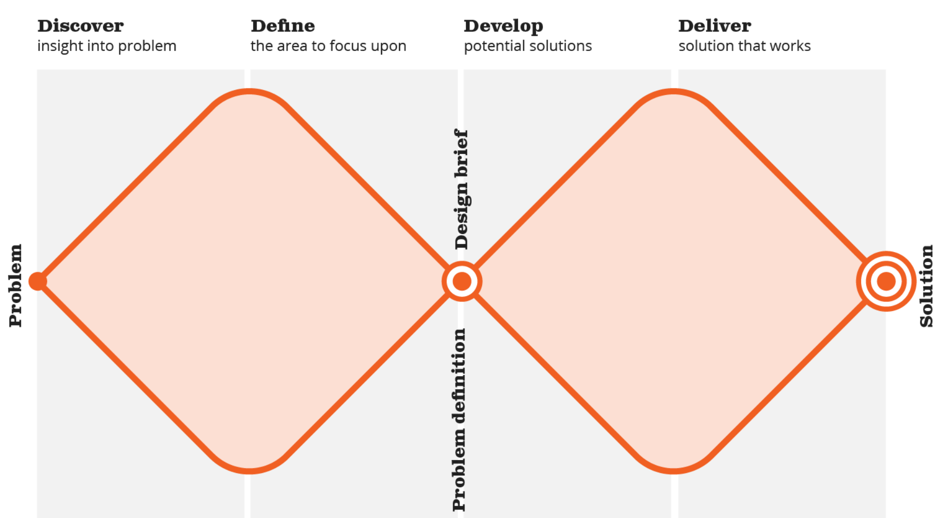


**Fig 29** Double Diamond Design Process
(Adeo, 2019)

Figure 29 shows the Double Diamond Design Process, which defines four specific sections of the design process. These include the discover section which is where the designer gains insight into the problem, the Define section narrows the designer's focus, the Develop section where the designer produces potential solutions, and the Deliver section where the designer presents a solution that works (Adeo, 2019).

This guideline is meant to help the designer during both the Define and Develop section. During the Define section, the designer can use the guideline rubric to grade current products and produce a competitive landscape to determine where their product should fit. The designer can benefit from the guideline in the Develop stage by following the rubric to produce many viable concepts for a specific consumer group.

## 4.2 Choosing Your Market

In this guideline, the electric bicycle market has been broken down into three distinct consumer groups: *The Commuter*, *The Aging Cyclist*, and *The Adventure Seeker*. Each of these consumer groups stands to benefit from what an electric bicycle can offer. Each one of these groups has distinct needs and bicycle designs can drastically differ depending on which group you are designing for.

### 4.2.1 Who Are You Designing for?

#### The Commuter

As more and more people move into urban areas and rely less and less on automobiles, the emerging trend of commuter cycling has created a distinct electric bicycle consumer group. The commuter needs a bicycle that is comfortable and efficient for medium to long rides. The commuter needs a bicycle that is reliable and easy to service. This consumer might also need the bike to be versatile and to be able to carry bags or groceries. As the trend of commuting on bicycles continues to grow, the commuter consumer group will be a driving force in the electric bicycle market.

## The Aging Cyclist

The aging cyclist consists of an older consumer group that generally just wants to get out and ride a bicycle. This consumer group is looking for a bicycle that is easy to use and can give them a good workout without wearing out their body. This rider needs a design that is suited for comfort for short to medium rides. This bicycle should be easy to mount and dismount and offer levels of assistance that will allow anyone to be able to ride. This bicycle should be lightweight and feel stable as well as instill confidence in the rider. The riding experience should be an overly pleasant one that makes the aging cyclist want to continue to ride their bicycle.

## The Adventure Seeker

The cyclist who is always pushing for more performance and constantly pushing the boundary of what their bicycle can do, falls under the category of the adventure seeker. This consumer is confident in their abilities and demands the best performance from their bicycle. Whether riding down steep off-road terrain or taking corners at maximum speed the bicycle should be able to handle whatever the adventure seeker throws at it. Bicycles for this consumer will lead the industry in innovation and technology to maximize ability.

This guideline will consider each of these user groups to help make informed design decisions. After choosing a user group to pursue, designers should follow the outline to achieve a well thought out electric bicycle design.

### 4.3 Determining the Best Drivetrain

#### 4.3.1 Electric Motor

When choosing a motor for an electric bicycle, designers must consider a few different factors. These factors can include cost, power output, range, and in some cases even state or local laws.

Electric bicycles are generally classified into three separate classes. *Class 1* bicycles are limited to a top speed of 20 miles per hour and can only be pedal assist. *Class 2* bicycles are limited to the same top speed as a class 1 but can have some sort of throttle as well. *Class 3* bicycles can reach speeds of 28 mph but are only allowed to be pedal assist. These classifications can vary slightly based on the designers' location and the location of the intended market, so it is advised to always check local ordinances regarding electric bicycles (Bosch, 2020).

There are a few different types of motors that are currently being utilized in electric bicycles. *Hub motors* are the most common and the most cost-effective solution for a manufacturer. As seen in Figure 30, hub motors are located within the wheel and can be on the *front or rear* wheel of the bicycle. Hub motors are exceedingly popular for consumers looking to convert a traditional bicycle to an electric bicycle due to the relative ease of installation. Although hub motors are easy to manufacture and install, they are not as easy to service and are often replaced if they begin to malfunction (Lopez, 2021).

*Mid-drive motors*, as seen in Figure 31, differ from hub motors in a few different aspects. A mid drive motor is designed within the frame at the bottom bracket and assists with turning the crankset as opposed to the wheel itself. Mid drive motors are often lighter than hub motors and due to the mounting location, offer a more stable bicycle with better distribution of weight.

Although more expensive than a hub motor, mid drive motors are gaining popularity within the industry due to their efficiency and ease of service (Lopez, 2021).

Table 1 shows a rubric for choosing the most appropriate type and location for the motor for the three user groups outlined in the section 'Who Are You Designing For.'

**Fig 30** Example of a Rear Hub Motor
(Ricker, 2020)

**Fig 31** Example of a Mid-Drive Motor
(Bosch, 2020)

Hub Motor (Front)

Pros

- Cost effective
- Easy to convert a traditional bicycle

Cons

- Can feel unstable at higher speeds
- Bicycle can feel “front heavy”
- Can negatively effect steering

Hub Motor (Rear)

Pros

- Cost effective
- Easy to convert a traditional bicycle
- More efficient positioning than front

Cons

- Hard to service
- Bicycle can feel “rear heavy”
- Limits gearing compatibility

Mid Drive Motor

Pros

- Most efficient option
- Lighter than hub motors
- More stable weight distribution

Cons

- Most expensive option
- Harder to design around
- Does not work well with a throttle

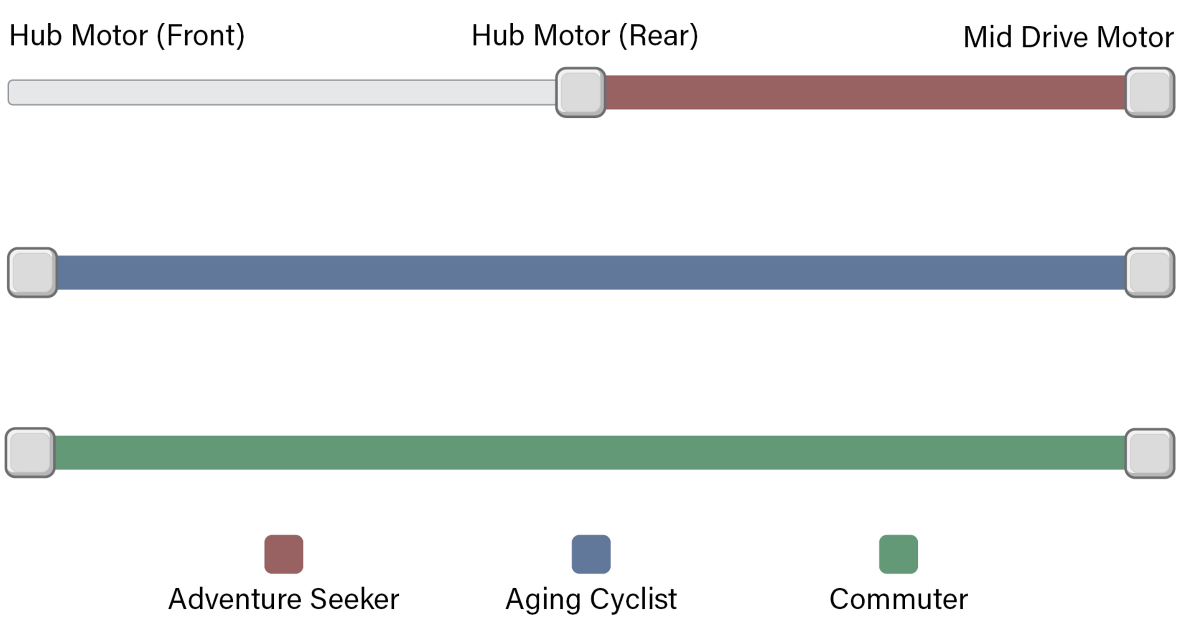


**Table 1** Electric Motor Rubric

### 4.3.2 Battery

After deciding on a motor, the designer must then choose a suitable battery pack to adequately power the motor. Motors are generally measured by volts and watts (e.g., 48V 500W motor). Voltage is a measure of electric potential while wattage is a measure of power. For instance, a 48V 500W motor can handle an electrical charge of 48V and will produce 500W of power at that same electrical charge (Raposa, 2012).

The electrical ratings of the motor are important to know when trying to build or choose a compatible battery pack. Most battery packs in production now consist of lithium-ion cells due to their power density to weight ratio as well as the ability to be easily and reliably recharged. Battery packs are measured in volts and watt hours, with some larger packs being measured by kilowatt hours (e.g., 48V 1KWh). The voltage rating will tell the max electrical current produced by the battery pack while the watt hour rating gives the max power consumption for one hour of use (Raposa, 2012). For instance, a 48V 1KWh battery pack can power a 48V 500W motor at max power for two hours in perfect conditions.

With that being said, the most important and tangible factor for the consumer is the overall range of the bicycle. When choosing a battery pack, the designer must consider the expected performance and intended use of the bicycle to make the right choice. An adventure seeker will need a more powerful battery pack to handle more intense terrain and climbing while a commuter will need to know that their battery pack will last for longer distances. An aging cyclist might not need as much range as that of a commuter and will appreciate a lighter bicycle despite a shorter range. See the recommendations for battery power recommended for the three user groups in Table 2.

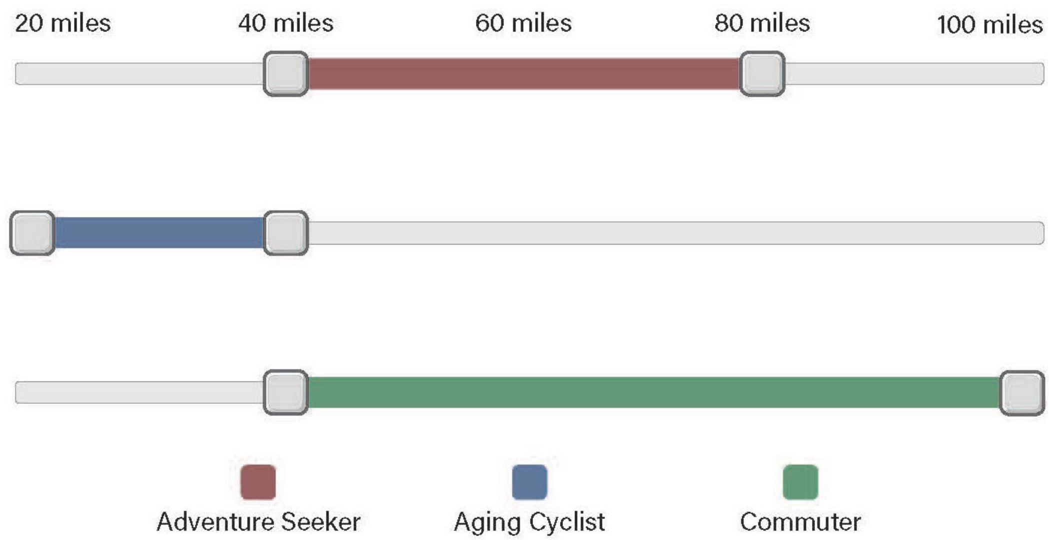


**Table 2** Battery Power Rubric

### 4.3.3 Battery Location

Another thing to consider with the battery pack is how it is incorporated into the design of the bicycle. Electric bicycle conversion kits usually have the battery pack mounted to a rear rack on the bicycle with production electric bicycles focusing more on designing a frame around a battery pack. Battery packs can often be found on the downtube of the bicycle, or other main tubing of the frame, and can be *removable* or *non-removable* (see Figs 32-33). There are advantages and disadvantages to each design choice and the intended purpose of the bicycle must be considered when making the design decision. While a commuter or aging cyclist might appreciate the ability to remove the battery pack for ease of charging or security, an adventure seeker needs a battery that is going to be able to handle heavy vibrations and rough terrain without losing connection or being damaged. This can be achieved through a non-removable battery pack or a heavily engineered removable battery pack. See the recommendations for battery packs in Table 3.

Removable Battery Pack

| Pros | Cons |
| --- | --- |
| • Able to be charged separately from bicycle<br>• Added security benefit | • Connections can wear out over time<br>• More exposed to weather and moisture |

Non Removable Battery Pack

| Pros | Cons |
| --- | --- |
| • More durable and protected<br>• Added stiffness to frame | • Harder to replace if needed<br>• Must be able to bring the bicycle to the charger |

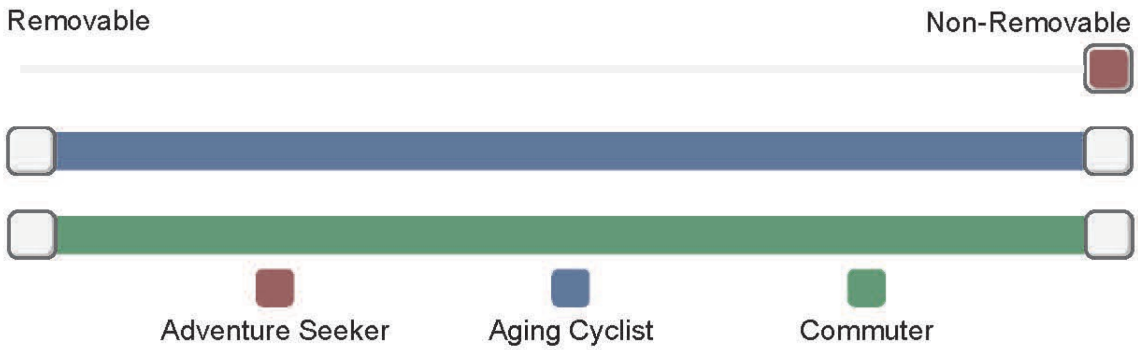


**Table 3** Battery Pack Rubric


**Fig 32** Example of a Removable Battery Pack
(Ricker, 2019)


**Fig 33** Example of a Non-Removable Battery Pack
(Fretz, 2020)

### 4.3.4 Gearing

The gearing on a bicycle consists of at least one gear in the front (chainring) and at least one gear on the rear wheel (cog). The chainring and the cog create a specific gear ratio depending on how many ‘teeth’ each gear has. Gear ratios will determine how easy or hard it will be to spin the rear wheel under load. Most bicycles will offer multiple chainrings and multiple cogs in order to be able to shift gear ratios depending on riding conditions. Shifting is achieved with the use of derailleurs that move the chain to the different gears. These derailleurs are more commonly cable driven but as of recently can be electronically driven (Denham, 2019).

The cassette consists of multiple gears, generally between 7 and 12 ‘speeds’, in order to give a generous amount of gear ratios for the rider. Cassettes are referenced by their number of speeds and the lowest and highest tooth count (e.g., 7s 11-32 or a 12s 11-46). The lower tooth count allows for a faster gear and the higher tooth count allows for a better climbing gear. The higher number of gears, or speeds, allows for more transitional gears between the highest and lowest gear which in turn allows for smoother shifting and better rider cadence. A drivetrain with more gears is generally more expensive than a drivetrain with less gears (Denham, 2019).

The chainring(s) are mounted onto the drive side crankarm and play a larger role in the overall gear ratio. A bicycle generally has between one and three chainrings with the single chainring becoming a more popular choice since the addition of cassettes with more gears. A larger chainring (e.g., 50 tooth) will be a faster gearing than a smaller chainring (e.g., 32 tooth), while the smaller chainring will be better at climbing (Denham, 2019). While a drivetrain with three chainrings will offer three different ratios for different scenarios, a drivetrain with one chainring will offer a small to medium sized chainring with more gears in the cassette.

While most bicycles use a *chain driven drivetrain* there has been a recent trend of using *belt driven drivetrains*, especially for higher torque electric bicycles (see Figs 34-35). A belt offers more strength and durability when compared to a typical bicycle chain. While a chain allows for shifting to and from different gears, a belt cannot be shifted. A belt drive system is limited to a single chainring as well as a single rear cog (Denham, 2019).

Another way of shifting gears which has become more popular due to the limitations of belt drive systems, are *internally geared hubs*. With an internally geared hub, the hub itself can change gears inside of the wheel hub itself all while being driven by a single rear cog. Internally geared hubs generally range from two to eight gears but cannot quite offer the wide range of ratios that a traditional cassette can. While internally geared hubs can offer more durability due to less exposure, they are also quite a bit more tedious and expensive to service when needed (Denham, 2019).

While either drivetrain can work for most situations, the belt driven system might be a better choice for both the aging cyclist and the commuter due to the simplicity and weight savings. The gear ratios offered by internally geared hubs should offer enough for any of the scenarios that these consumers might face. If cost is a driving factor, a chain driven system with a lower number of gears might be a good solution.

For the adventure seeker, a wide range of gear ratios is a must for all the different riding scenarios that may happen. A chain driven system with a higher number of gears and a wider cassette ratio might be the best option for this consumer, at least until internally geared hubs can match the ratios offered by a cassette.

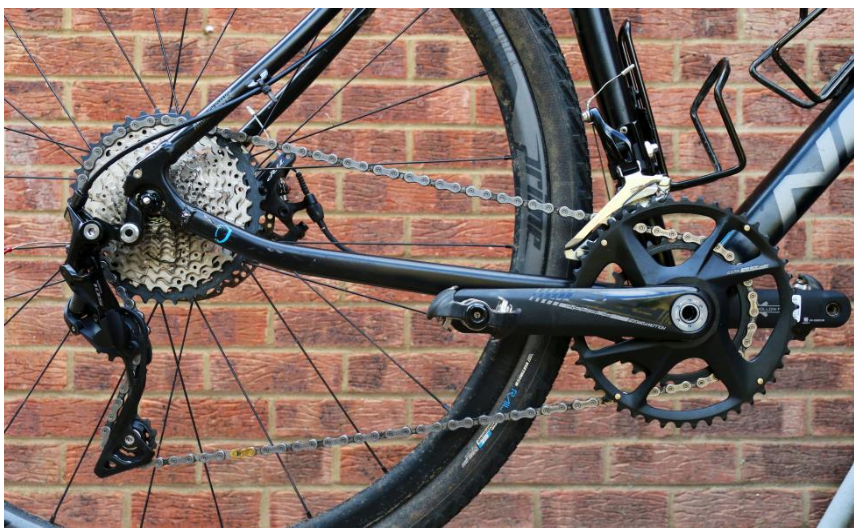

**Fig 34** Example of a 2x11 chain driven drivetrain
(Stevenson, 2020)


**Fig 35** Example of an internally geared belt driven drivetrain
(Toll, 2020)

### 4.4 Using the Right Wheels

#### 4.4.1 Wheel Diameter

Wheel size is one of the more important decisions to make when designing any type of bicycle. Wheel size plays a huge role in the look and feel of the bicycle. The proper wheel size can boost both the performance of the bicycle and the confidence of the rider.

Wheel diameters can range from as small as 10 to 12 inches and up to 29 inches. Generally, wheels that are 24 inches or smaller in diameter are reserved for children's bicycles unless used on a non-traditional or novelty design bicycle. Fig 36 shows images of wheel sizes above 24 inches that includes 26-inch, 27.5 inch (650b), and 29 inch (700c).

26-inch wheels have been used on bicycles for quite some time. In fact, 26-inch wheels were considered standard on most bikes up until about 10-15 years ago. 26-inch wheels are great for climbing and allow for efficient pedaling and acceleration. Where the 26-inch wheel struggled was on rougher downhill terrains. The 29-inch wheel was introduced to fill the need for a wheel that could perform well on such terrain. The 29-inch wheel was able to roll over obstacles with ease and offer more stable steering at higher speeds but did not perform as well with climbing and ease of pedaling (Yan, 2016).

If the intended purpose of the bike is to be well rounded or versatile, a 27.5-inch wheel might be the best option. Although a 27.5-inch wheel does not climb as well as a 26-inch wheel or descend as well as a 29-inch wheel, it tends to be a good mixture of both sizes and has a lot to offer a rider looking for a versatile bicycle.


**Fig 36** From left to right: 29” wheel, 27.5” wheel, and 26” wheel
(Yan, 2016)

It is important to note that a frame is designed around a specific wheel size. Choosing the right wheel size is a crucial early step in designing any bicycle (see Table 4).

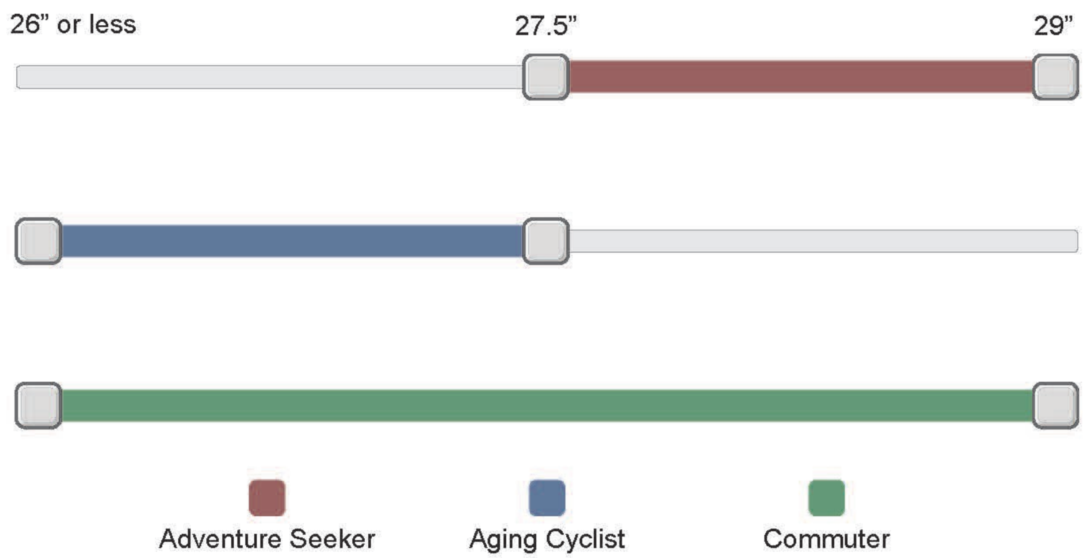


**Table 4** Wheel Size Rubric

### 4.4.2 Tires

While tires are a consumable on a bicycle and are often changed either due to wear or rider preference, choosing the right tires for a design is crucial for the look and feel of the bike.

The main consideration when choosing a tire is the intended use of the bicycle and the riding conditions. A rider who only rides on dry sunny days can get by with a tire that has minimal tread pattern and rolling resistance, while a rider who intends on riding rain or shine will need a tire with a tread pattern that is designed to disperse water and create solid traction with the ground. A wider wheel can give the rider confidence, stability, and comfort but will also increase rolling resistance and overall weight.

While an *aging cyclist* might prefer a wider tire with more comfort and stability (Fig 37, a *commuter* needs a slightly narrower tire that will perform well in all conditions and that allows them to keep up with traffic (Fig 38). An *adventure seeker* will need a wider tire with a well engineered tread pattern that can handle extreme terrain and offer superior traction in all conditions (Fig 39). See the rubric in Table 5 as a guide towards choosing the correct tire for the user group.

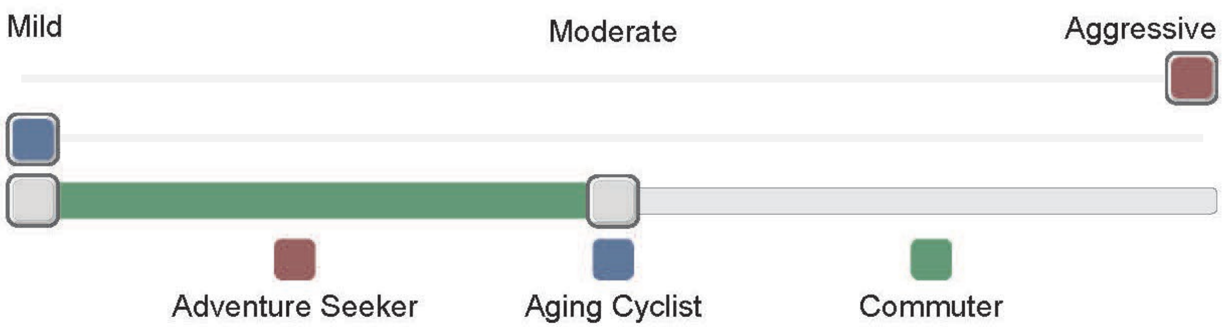


**Table 5** Tire Rubric

**Fig 37** Tire Tread 1
(Wheel World, 2020)

**Fig 38** Tire Tread 2
(Overholt, 2021)

**Fig 39** Tire Tread 3
(Kirkman, 2020)

### 4.4.3 Brakes

Braking is the most important aspect of a bicycle's design. A lot of thought goes into how much braking power a bicycle needs to be safe to ride. Too little braking power and the bicycle will not stop in a safe distance while too much braking power can result in the rider being thrown from the bicycle. There is a balancing act required to prevent either of these scenarios. There are a few different braking styles that must be considered when choosing the wheels as the brakes interact directly with the wheelset (Fig 40).

*Rim brakes* use a set of calipers to grab the outside edge of the rim to slow the wheel down. The wheel being used must have a brake track on the outer edge of the rim itself. Rim brakes are easy to service and offer ample stopping power, especially on lighter bikes (Denham, 2019).

*Disc brakes* use a rotor (disc) that is mounted to the wheel hub itself. This rotor is grabbed by a set of calipers to stop the wheel. Disc brakes offer better performance and can either be *cable driven or hydraulic* (Denham, 2019). Hydraulic disc brakes offer the most stopping power of all the options. Disc brakes are better for heavier bikes traveling at higher speeds. Table 6 shows a rubric for braking types recommended across the three user groups.


**Fig 40** Examples of rim brakes *(left)* and hydraulic disc brakes *(right)* (Gray, 2021)

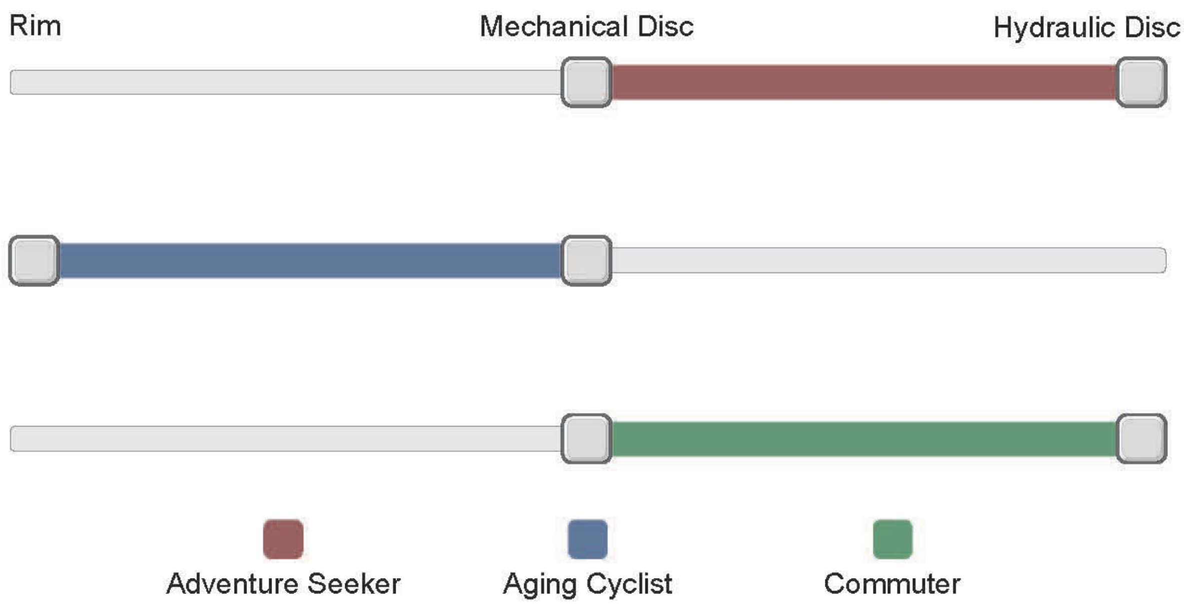


**Table 6** Brake Rubric

## 4.5 Designing the Frame

### 4.5.1 Understanding the Frame

This section of the guideline focuses on critical aspects of a bicycle frame's geometry and how each aspect effects the riding characteristics of the bicycle. Depending on which consumer market is being considered for the design, the frame geometry can differ quite a bit. A difference of just a few degrees within any part of the frame can change the feel of the entire bicycle. Heavy consideration must be given to the rider and the intended use of the bicycle to design a frame that is going to perform well and give the rider confidence.

An aging cyclist needs a bicycle that is easy to pedal and comfortable to ride. A commuter needs a bicycle that, while comfortable, is both nimble and efficient. An adventure seeker needs a bicycle that can handle any terrain or challenge that the rider faces. Following this guideline will give the ride characteristics that each consumer market needs for their bicycle. Fig 41 shows the elements that make up a frame.

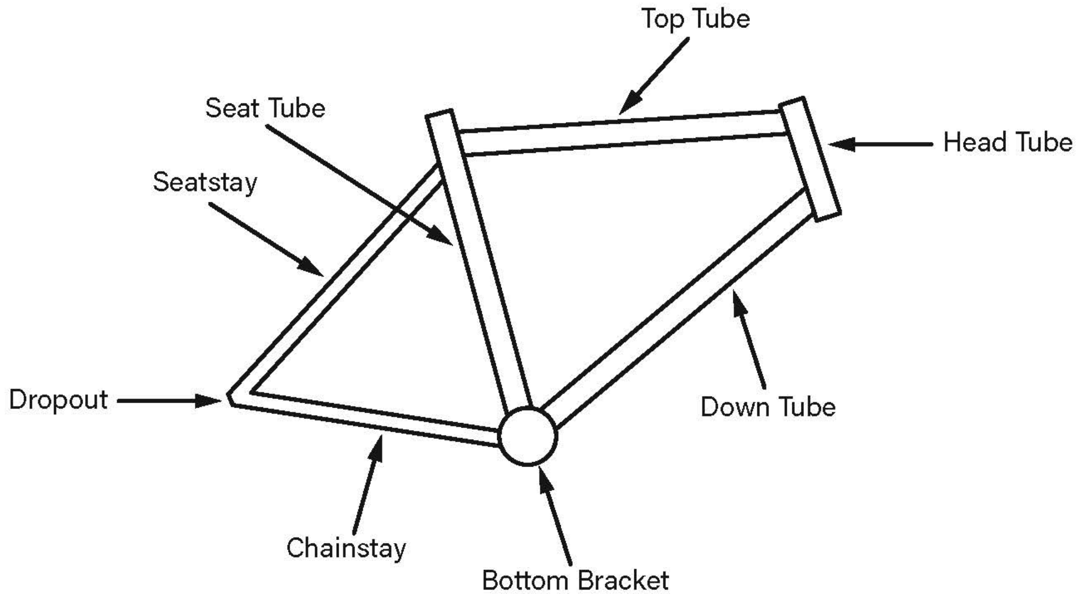


**Fig 41** Full Frame Diagram

### 4.5.2 Choosing the Material

The material that the bicycle frame is made from can have a huge effect on the feel and overall ride quality of the bicycle as well as the cost. Bicycle frames are generally made from either *steel*, *aluminum*, or *carbon fiber* and on some occasions even *titanium*. The cheapest options to use are steel and aluminum while the more expensive options are carbon fiber and titanium.

If the cost of the bicycle is a driving factor, *steel or aluminum* is probably best for the design. Steel and aluminum cost about the same for manufacturing but each have distinct advantages and disadvantages. Steel is stronger than aluminum and absorbs bumps a little better but also weighs more and can rust over time if exposed. Aluminum is lighter than steel and will not rust over time but is not as strong and is more prone to crack or damage with impact.

If cost is not a selling point but rather the weight of the bicycle, *carbon fiber or titanium* would be a better choice. Carbon fiber has a great strength to weight ratio which allows for a faster and more stable design. Carbon fiber also allows for better flexibility for the designer as it allows for more organic shapes to be produced. Titanium is the strongest option to use and produces very stable frames that will not corrode or crack over time. While titanium is much lighter than steel or aluminum, it is not quite as light as carbon fiber. When compared to carbon fiber, titanium is also about 5 times more expensive to use.

There are also styling advantages to each of the materials that must be considered. Steel and titanium frames are generally straight or slightly tapered tubing to get the most strength out of the material. This leads to very simple or traditional styling when using this material. Aluminum can be hydroformed into somewhat organic shapes which help strengthen the frame while using a weaker material. Carbon fiber can be molded in a way that can create extremely organic shapes that are both lightweight and extremely rigid.

## Steel and Titanium

Steel has been used in bicycle frames for many, many years. Steel is known for being very strong and durable material for frames. Steel is relatively inexpensive and easy to work. There are many different grades of steel which varies the weight and strength of the tubing. Higher quality steel tubing can drastically reduce the overall weight of the frame while also increasing strength (Briggs, 2019).

Steel is limited by the ability of the material to be formed. Due to this, steel is often worked in extruded tubing for best results (Fig 42). Tubing can also be tapered to increase stiffness for certain tubes on the frame (Briggs, 2019).

**Fig 42** Examples of Steel Tubing Capabilities
(Briggs, 2019)

Titanium is very similar in abilities to steel while being much stronger and lighter. Titanium is an exotic material and is very costly but offers a material stronger and lighter than carbon fiber. Titanium has been used for bicycle frames since the early 1990's and got its start on mountain bike frames due to its stiffness and ride quality (Beebenson, 2020).

Titanium is also limited in its ability to be formed and worked. Extruded tubing can be straight, bent, or tapered to strengthen the frame. Titanium is a very difficult material to weld and requires a master craftsman to accomplish the job (Fig 43).

**Fig 43** Examples of Titanium Welds
(Beebenson, 2020)

**Aluminum**

Aluminum is a very popular choice for bicycle frame building due to being cost effective, lightweight, and easily formed and shaped. Aluminum can be used in straight, bent, or tapered tubing as well as in more organic shapes produced with hydroforming. Aluminum in a straight tube is not as strong as steel but the ability to be hydroformed allows a frame that can be just as strong while being lighter and cost effective.

**Fig 45** Example of Hydroformed Aluminum Tubing
(CX Magazine, 2016)

Fig 45 shows an example of hydroformed aluminum tubing. The chamfers and edges created during the forming process exponentially stiffen the entire frame. Designers have more creative freedom when working with a material that can be shaped. Aluminum is also not affected by rust in the same way that steel is and is also able to be recycled easily.

## Carbon Fiber

Carbon fiber is an incredibly strong material that is extremely popular in the bicycle industry. Carbon fiber offers a strength to weight ratio that is unmatched in a readily available material. Formed in layers in a mold, carbon fiber can be formed into very organic shapes.

**Fig 45** Example of a Carbon Fiber Bicycle Mold
(CyclingTips, 2020)

Carbon fiber frames are formed by applying multiple layers of carbon fiber and resin inside of a multi-piece mold (Fig 45). The inside of the frame is filled with removable airbags to push everything into the mold. Once cured, the frame is checked for proper alignment on a bicycle frame alignment stand (Fig 46) Building a carbon fiber frame is a very time intensive process and can cost quite a bit of money to get the tooling needed.

Combinations of materials are often used to balance cost and value for the consumer. A popular combination in modern road bikes is to use an aluminum frame with a carbon fiber fork to keep the overall cost of the bike lower while using carbon fiber to the consumer’s benefit.

Table 7 is a rubric to follow when choosing frame materials based on the user groups.

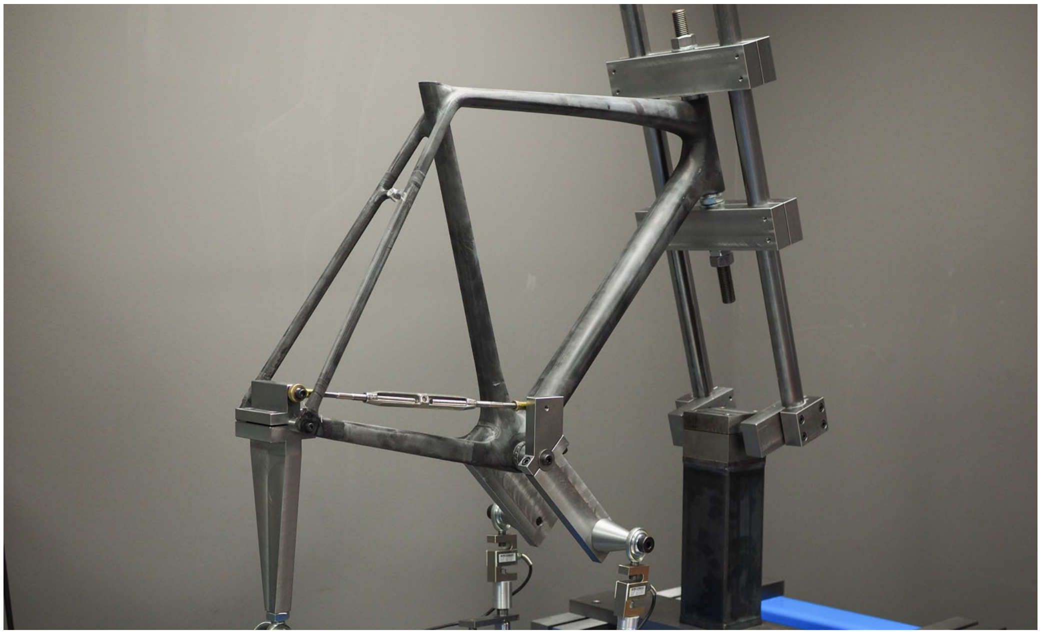

**Fig 46** Bicycle Frame Alignment Stand
(CyclingTips, 2020)

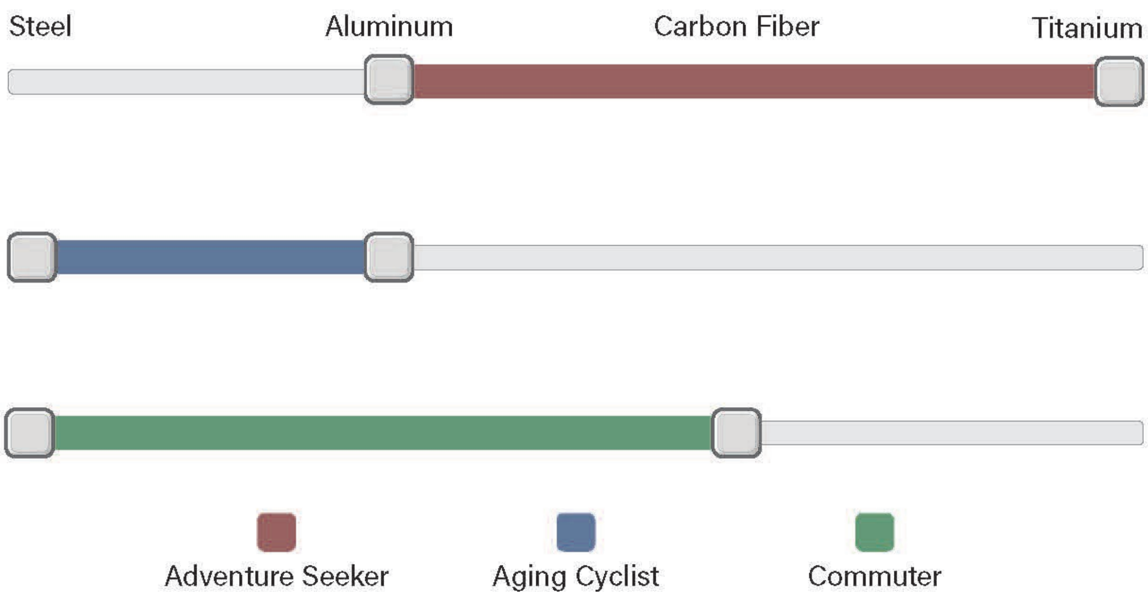


**Table 7** Frame Material Rubric

### 4.5.3 Suspension

Whether or not a bicycle has any sort of suspension should be considered based on the intended use of the bicycle. Bicycles can be classified into three different suspension types: *rigid*, *hardtail*, and *full suspension*. Table 8 gives recommendations for the type of suspension needed by the various user groups defined in this guideline.

A *rigid bicycle* is designed with no suspension and allows for a very static riding position due to the bicycle geometry not changing while under load. A rigid design allows for good pedaling efficiency, as none of the rider's energy gets absorbed unnecessarily by suspension.

A *hardtail bicycle* is designed with a suspension fork but will have a rigid frame. A suspension fork will add weight to the bicycle but will allow better handling of obstacles and offer a more comfortable ride. A *full suspension* bicycle is designed with both a suspension fork and a rear shock. Full suspension bicycles offer the best handling of rougher terrains but lose the most pedaling efficiency out of the three options. Note that on a hardtail and a full suspension bicycle the frame geometry will change as the suspension sags under load.

For a rider who plans on staying on pavement and smooth surfaces, a *rigid* design may be best. For a rider who spends time on both pavement and light trails, a *hardtail* design may be the right choice. If a rider spends most, if not all, of their time on rough terrain, a *full suspension* design is probably the best option.

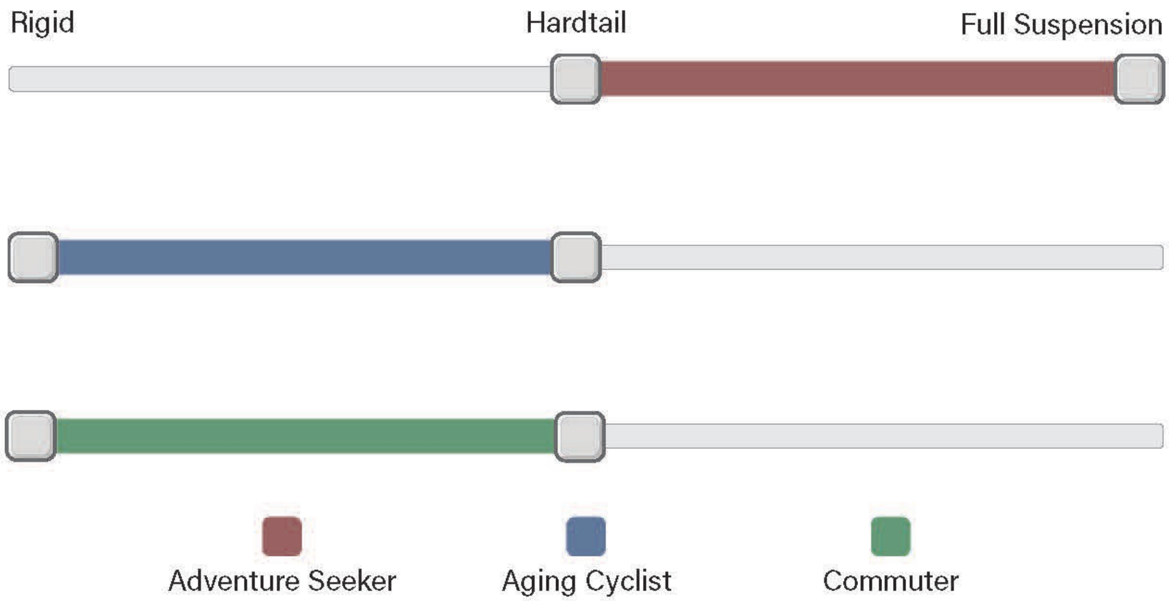


**Table 8** Suspension Rubric

#### 4.5.4 Head Tube Angle

The measured angle from a horizontal through the center of the head tube is known as the *head tube angle* (Kavanagh, 2016).

Head tube angles (Fig 47) can range from *around 62 degrees to around 74 degrees* and are referred in the terms of *slack* and *steep*, respectively. Both steep and slack head tubes have pros and cons to their design, and each have drastic effects to the overall feel and ride quality of the bicycle (Denham, 2019).

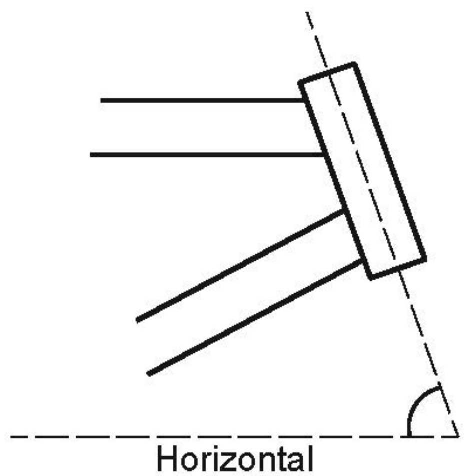


**Fig. 47** Head Tube Angle

A bicycle with a steep head tube angle will have a tighter wheelbase and feel more upright. This will also make the steering more responsive and will give the bicycle a tighter turning radius. The bicycle will also have better pedaling efficiency and climbing performance. A steep head tube angle can sometimes feel twitchy or unstable at higher speeds. The rider can also have the feeling of being too far over the handlebars if they are not used to a similar riding position. A steep head tube angle also struggles with absorbing bumps at higher speeds due to the steep angle of the fork (Denham, 2019).

A bicycle with a *slack head tube angle* will have a longer wheelbase which will make the bicycle feel more stable at moderate to high speed. This bicycle will also be better for more aggressive terrain since it will be better for absorbing bumps at any speed. A slack head tube angle will result in a slower and less responsive steering feel. Due to the longer wheelbase caused by the slack head tube, the bicycle will have a wider turning radius. A slack head tube will also worsen the pedaling efficiency and reduce the climbing performance of the bicycle (Denham, 2019).

Other factors to consider when deciding on the head tube angle are your chosen wheel size and whether the bicycle is rigid or has some type of suspension. A larger wheel size can be more accommodating to a steeper head tube angle as a larger wheel will help roll over obstacles with more efficiency. A smaller wheel can help increase the climbing efficiency of a bicycle with a slack head tube angle while also tightening the turning radius.

On a bicycle with suspension, rider weight must be considered. A bicycle with full suspension will slacken when the rear shock is under load while a bicycle with just a suspension fork will steepen under load. A rigid bicycle will hold true to the desired angle. Table 9 is a rubric to follow when deciding on a head tube angle for a frame based on the user groups.

Steep Head Tube

| Pros | Cons |
|---|---|
| • Quicker steering response<br>• Better cornering and tighter turning radius<br>• Works well on flat terrain<br>• Improved pedaling efficiency and climbing performance | • Can feel twitchy or unstable at higher speeds<br>• Rider can feel too far over the handlebars<br>• Struggles with absorbing bumps at moderate to high speed |

Slack Head Tube

| Pros | Cons |
|---|---|
| • Absorbs bumps better at all speeds<br>• Longer wheelbase increases overall stability<br>• Increased steering performance at higher speeds<br>• Works well on rough terrain | • Slower and less responsive steering at lower speeds<br>• Worsened pedal efficiency and overall climbing performance<br>• Wider turning radius |

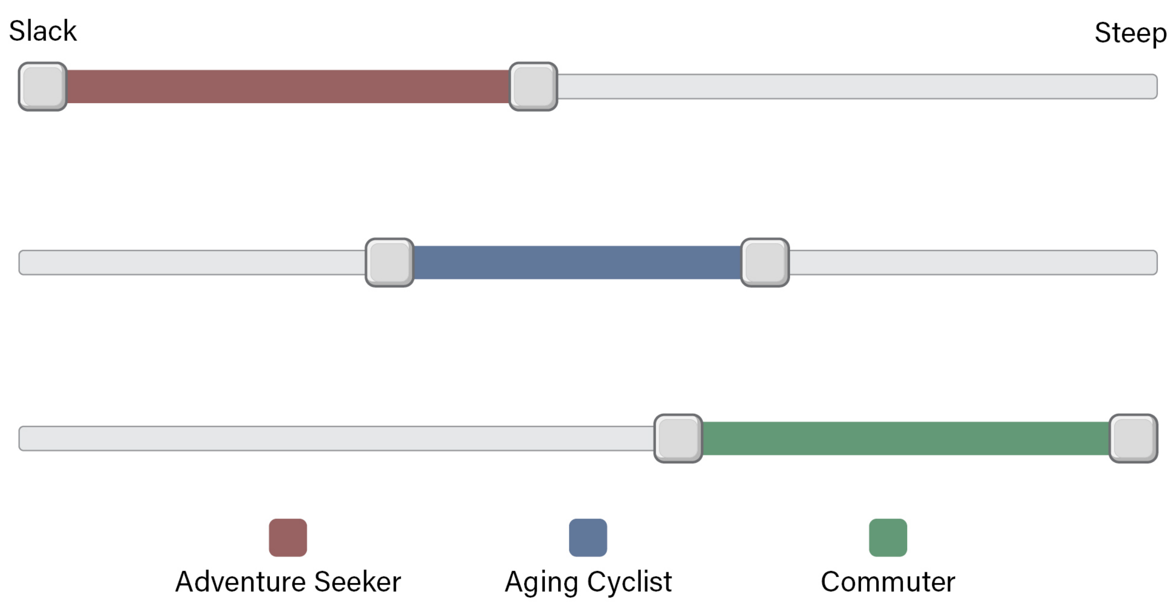


**Table 9** Head Tube Angle Rubric

### 4.5.5 Seat Tube Angle

The *seat tube angle* is the measured angle of the seat tube relative to the ground (Kavanagh, 2016).

Seat tube angles can range from the *high 60 degrees to around 80 degrees* (Fig 48). The seat tube angle can affect reach, pedaling efficiency, and positioning on the bicycle. Like the head tube angle, seat tubes are referred in terms such as *slack* and *steep* (Denham, 2019).

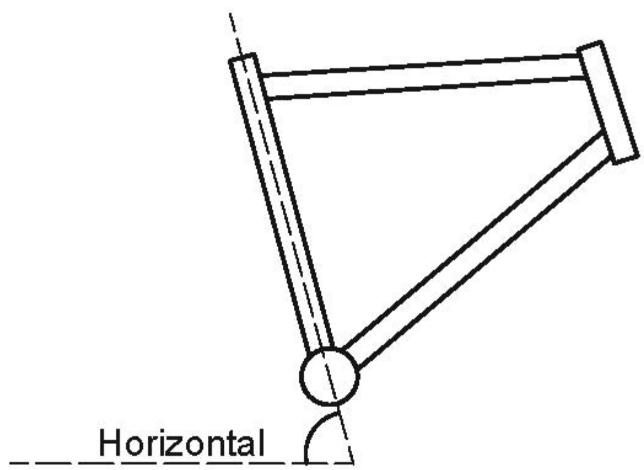


**Fig 48** Seat Tube Angle

Seat tube angles can be described with two different measurements. These two measurements are the *actual seat tube angle* and the *effective seat tube angle.* While the actual seat tube angle is the measured angle of the seat tube relative to the ground, the effective seat tube angle takes an imaginary straight line from the top/center of the seat tube to the center of the bottom bracket and then measures the line relative to the ground (Kavanagh, 2016).

Effective seat tube angle comes into play whenever the seat tube itself has an intentional bend to give the rear wheel clearance on full suspension bicycles under load. When designing a bicycle with any type of suspension, it is important to keep in mind that the geometry of the frame changes when the bicycle is under load. On a full suspension bicycle the seat tube will *slacken under load* while the seat tube on a bicycle with only a suspension fork will slightly *steepen under load.*

The seat tube angle and length generally are referenced when determining the frame size for the bicycle. For instance, a 54cm road bicycle frame gets the 54cm from the seat tube length.

Different size frames of the same model bicycle are generally scaled based on the seat tube length, so as the seat tube gets longer or shorter, so does the top tube, down tube, and head tube.

Note that when choosing the seat tube diameter or shape, designers must also consider the diameter and shape of the *seat post* itself as it will need to be compatible with the seat tube. Seat posts are the mounting point for the saddle and fit inside of the seat tube. The seat post can be raised or lowered depending on rider height and preference. While most seat posts are cylindrical, there are a few examples of  'aero seat posts' that are designed for better aerodynamics. While most seat posts are straight, they can also be designed with a rear offset to increase the reach of the bike. Table 10 is a rubric to follow when choosing the angle of the seat tube for a frame based on the user groups.

Steep Seat Tube

| Pros | Cons |
| --- | --- |
| • Better pedaling efficiency for climbing and speed<br>• Reduces muscle fatigue<br>• Improves the aerodynamics of the rider's position. | • Not suitable for rougher or downhill terrain<br>• More aggressive positioning reduces overall comfort |

Slack Seat Tube

| Pros | Cons |
| --- | --- |
| • More upright positioning can increase rider comfort<br>• Better suited for rougher and downhill terrain<br>• Can accomodate a wider range of rider heights | • Decreased pedaling efficiency for climbing and speed<br>• Worsened aerodynamics due to the upright riding position |

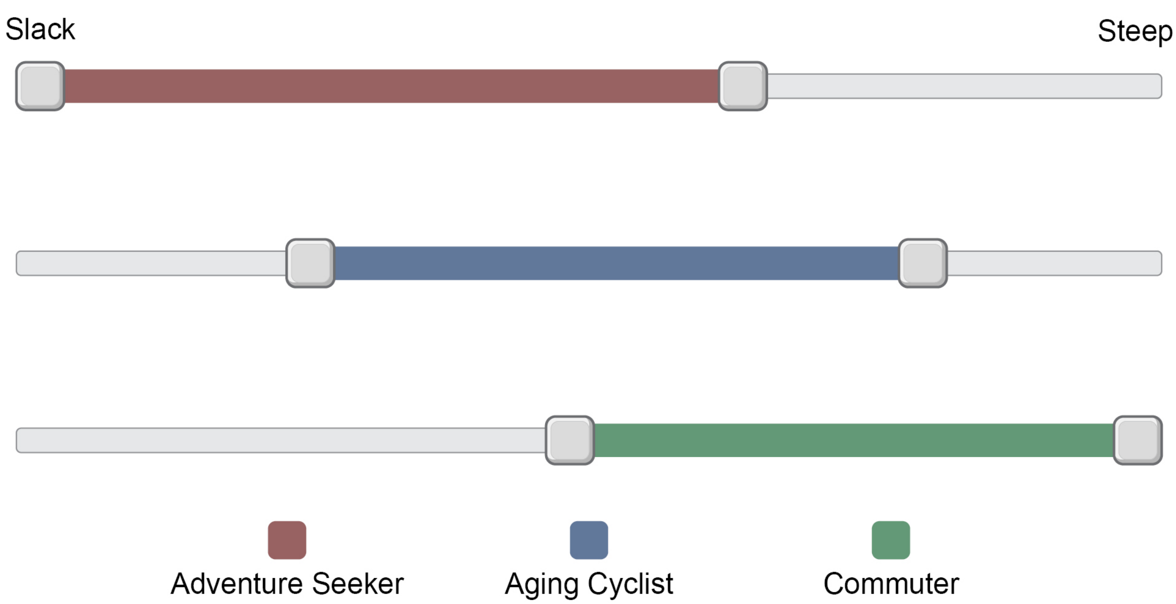


**Table 10** Seat Tube Angle Rubric

### 4.5.6 Reach and Stack

The top tube length is generally measured as *effective top tube* or *ETT*. The effective top tube length is the measurement from the top of the head tube at center, along a horizontal, to the center of the seat tube or seat post (Kavanagh, 2016).

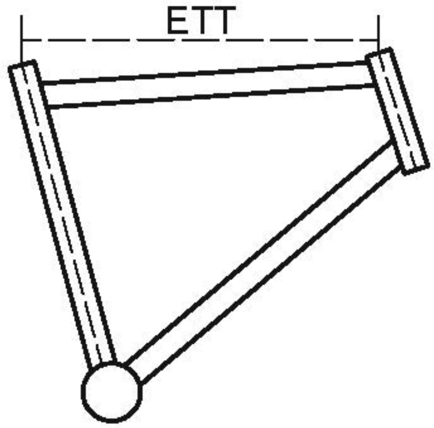


**Fig 49** Effective Top Tube Length

The ETT (Fig 49) should follow a proportion to the seat tube length and be scaled accordingly for different sized frames. Sizing on a bicycle is important for the rider to pedal efficiently and to be able to control the bicycle. ETT is more important of a measurement when designing a more traditional bicycle frame but is less important on a more organic design. Even on a more organic design, ETT measurements can give a general idea of the bicycles reach. *Reach* and *stack* are both important factors when designing a bicycle frame.

The *reach* of the bicycle is a far more reliable way of determining a bicycle's size and character. While the ETT is affected by both the angle of the head tube and the angle of the seat tube, the reach is unaffected by these angles. Reach is measured as a horizontal line from the center of the bottom bracket to the top of the head tube at center (Kavanagh, 2016).

If a rider is on a bicycle with too much reach (Fig 50), they can feel as if they are leaning too far forward over the bicycle which can be unstable. If a rider is on a bicycle with too short of a reach, they can feel as if they are too far over the handlebars which can also feel unstable.

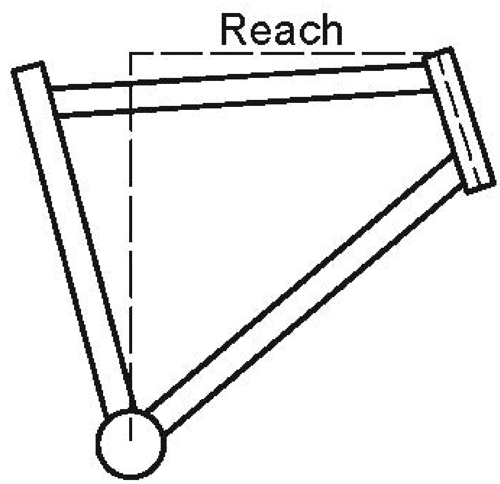


**Fig 50** Reach

The *stack* (Fig 51) of the bicycle is similar to the reach but not directly tied to it. Stack is measured as a vertical line from the center of the bottom bracket to the top of the head tube (Kavanagh, 2016). Stack can give an idea of how tall the bicycle will feel.

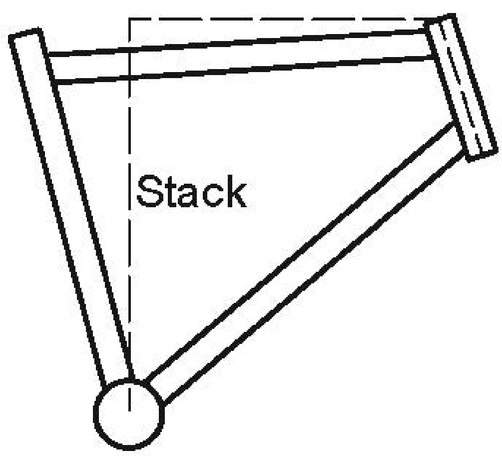


**Fig 51** Stack

### 4.5.7 Bottom Bracket Height/Drop

The positioning of the bottom bracket is measured in either *bottom bracket height* or *bottom bracket drop* (Fig 52-53).

*Bottom bracket height* is the measurement from the center of the bottom bracket to the ground. *Bottom bracket drop* is the distance that the bottom bracket sits below the center of the wheels (Kavanagh, 2016).

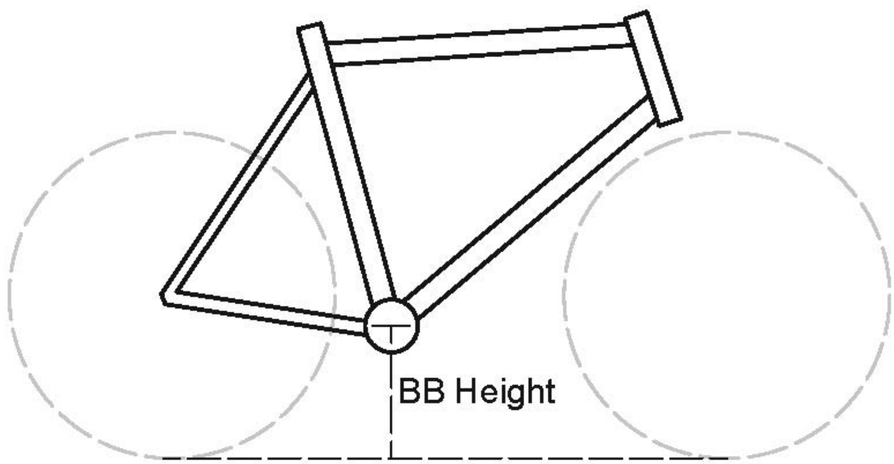


**Fig 52** Bottom Bracket Height

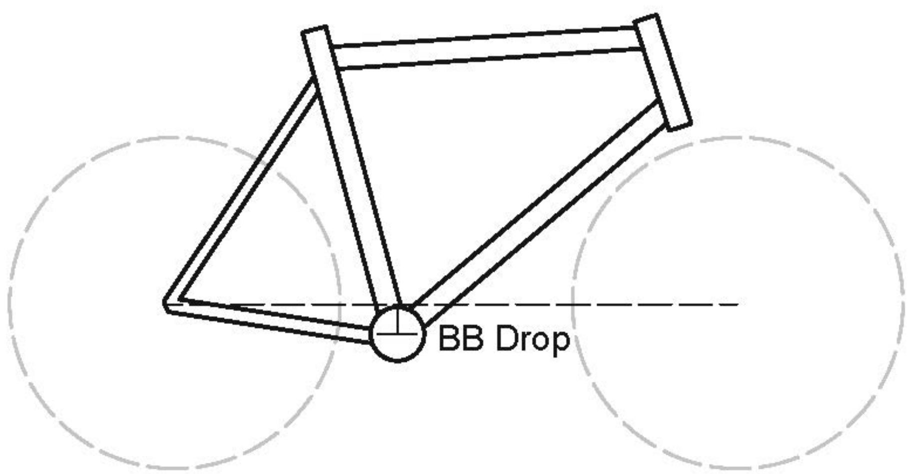


**Fig 53** Bottom Bracket Drop

The height of the bottom bracket can affect multiple aspects of the frame geometry and how the bike handles. A lower bottom bracket height will lower the center of gravity which improves overall stability, especially at higher speeds. While a higher bottom bracket gives the bicycle better clearance over rougher terrain (Denham, 2019). Road bicycles generally have a bottom bracket height around 10.5 inches while mountain bicycles average around 12-13 inches. Bicycles with full suspension will have a lower bottom bracket under load due to rider weight (Denham, 2019). Table 11 is a rubric to follow when determining bottom bracket height based on the user groups.

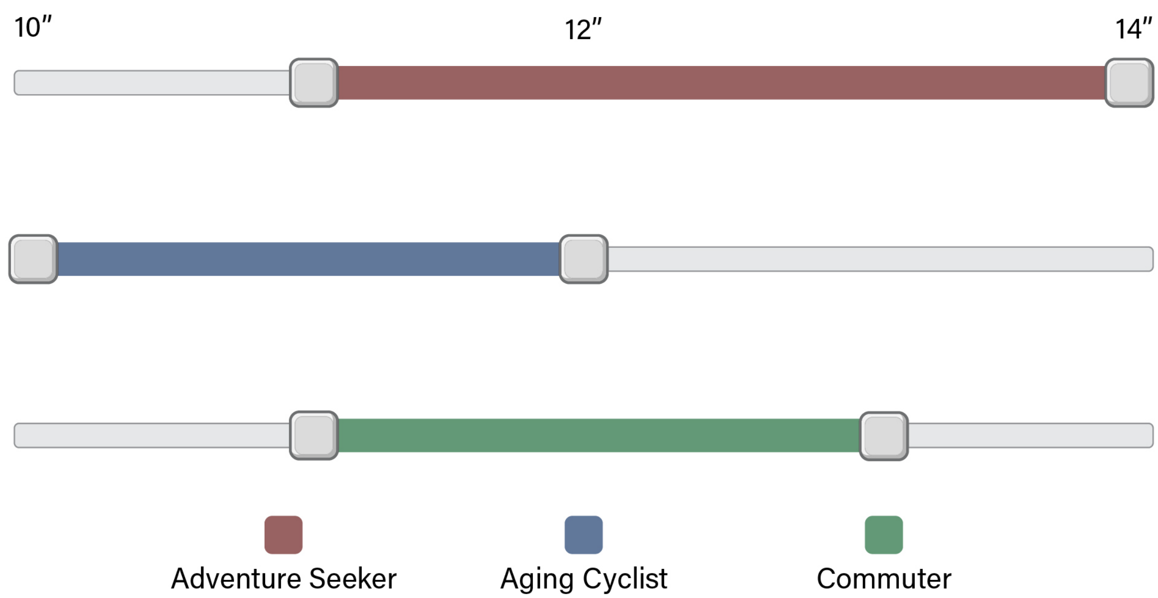


**Table 11** Bottom Bracket Rubric

### 4.5.8 Chainstays

The *chainstay length* is the measurement from the center of the bottom bracket, along the chainstay, to the center of the rear axle (Kavanagh, 2016). The chainstay length (Fig 54) does not affect bicycle fitment but does affect the handling characteristics of the bicycle as it directly affects the bicycles *wheelbase*.

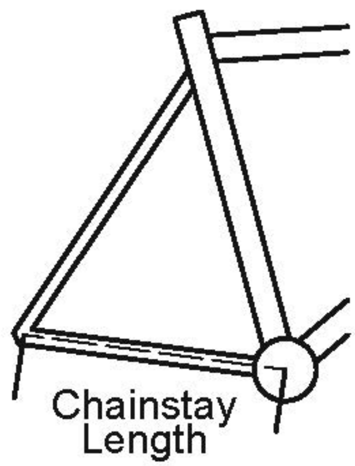


**Fig 54** Chainstay Length

A *longer* chainstay will extend the wheelbase of the bicycle which will make the bicycle feel more stable at higher speeds. A *shorter* chainstay will give the bicycle a more responsive steering as the wheelbase will be shorter. A chainstay must be long enough to provide adequate tire clearance (Denham, 2019). Table 12 is a rubric to follow for chainstay lengths based on the user groups.

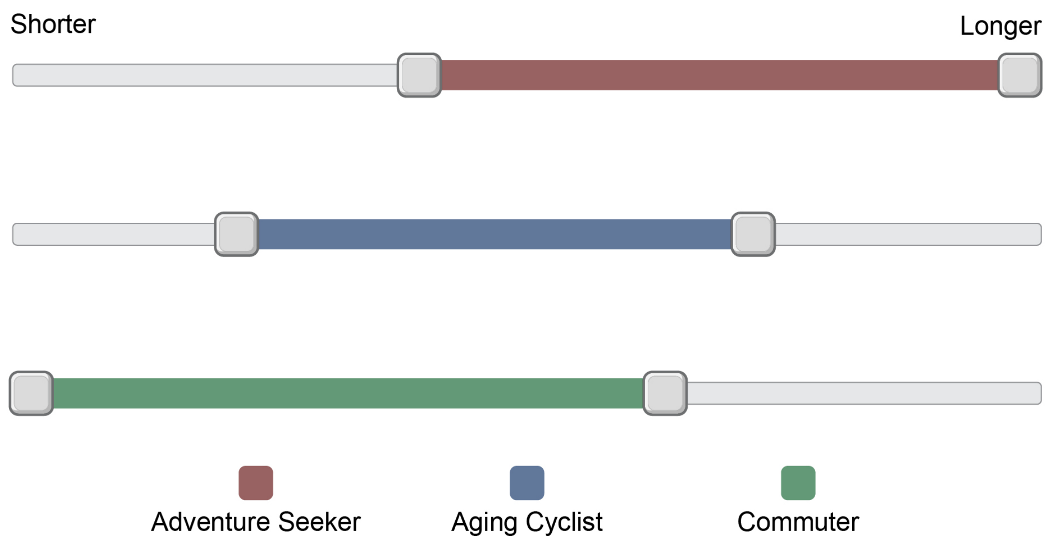


**Table 12** Chainstay Length Rubric

### 4.5.9 Seatstays

The *seatstay angle* is the measured angle of the seat stay taken from a horizontal line (Kavanagh, 2016). The seatstay angle (Fig 55) does not directly affect the bicycle fitment but does have an impact on the pedaling efficiency and the rigidness of the frame.

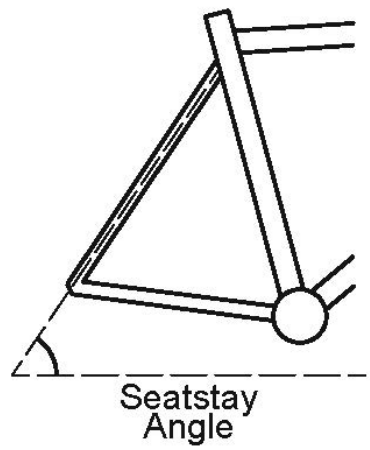


**Fig 55** Seatstay Angle

A seatstay with a *wider angle* will give the frame more give and will result in a more comfortable ride but reduce overall pedaling efficiency. A seatstay angle with a *tighter angle* will significantly stiffen up the frame and increase pedaling efficiency but will not absorb bumps as well. Full suspension bicycles can take advantage of a tighter seatstay angle due to the rear shock adding absorption (Denham, 2019). Table 13 represents a rubric to follow when deciding on the seat stay angle for the frame based on the user groups.

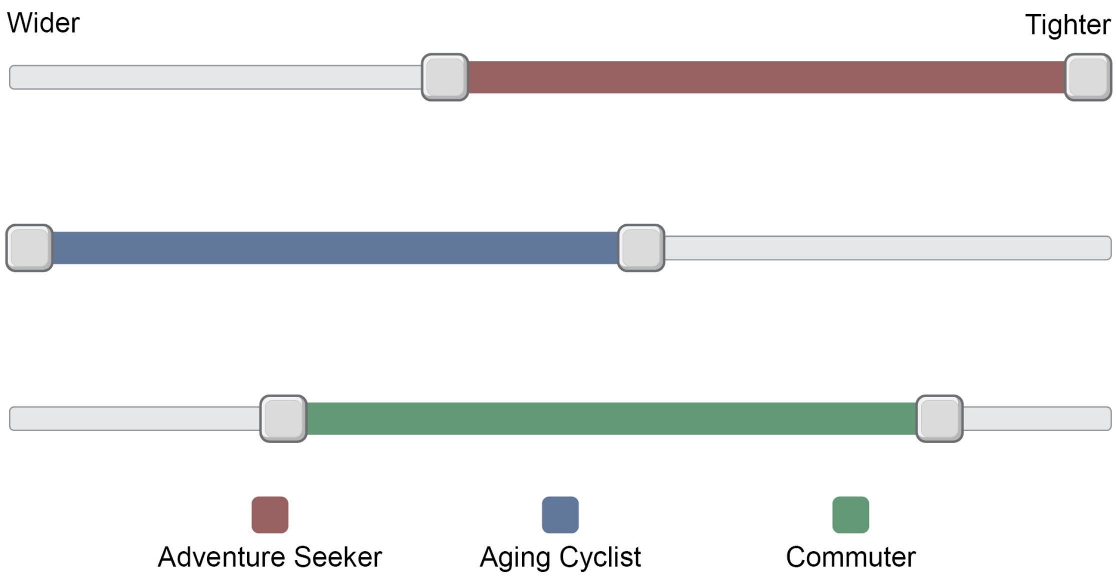


**Table 13** Seatstay Angle Rubric

## 4.6 The Cockpit

### 4.6.1 Handlebars

There are multiple styles of handlebars that each influence the look, feel, and performance of the bicycle. Handlebars are one of the most critical components of a bicycle and can have a drastic effect on any rider's confidence. The main factors to consider when choosing a pair of handlebars are the *rise or drop*, the *sweep*, and the *length or width* of the bars.

The *rise or drop* of the bars are the measurement of the height from where the bars are mounted to the stem. A riser bar will have a positive measurement and will sit higher than the stem while drop bars will have a negative measurement and sit below the stem.

The *sweep* is the backward bend of the bars towards the rider and helps with the overall ergonomics of the handlebars by ensuring the wrists are not overstretched.

The *length or width* of the bars is the measurement from each end of the handlebars to determine how far apart the rider's hands are positioned.

Handlebars are generally classified by the amount of rise or drop that they have which in turn leads to the terms *riser bars*, *flat bars*, and *drop bars*. Note that each style of handlebar can vary in their sweep and width (see Figs 56-57).

*Riser bars* are handlebars that rise on either side and can range from as little as 10mm of rise to upwards of 10-12 inches of rise. The more rise that the bars have, the more upright the positioning of the rider. Too much rise can reduce pedaling efficiency and stability (Ashoor, 2017).

*Flat bars* are, as their name implies, flat. Flat bars put the rider a little further over the front wheel when compared to riser bars, which can increase pedaling efficiency and traction. With both flat bars and riser bars, the width of the bar can have a dramatic effect on the stability of the bike. Narrower bars can feel more responsive while wider bars can feel more stable (Ashoor, 2017).

*Drop bars* are measured in how far below the stem the bars “drop”. Generally, drop bars range from a 125mm drop up to a 135mm drop. Depending on rider confidence and positioning, a shallower or deeper drop can affect the way a bicycle will handle. Drop bars are the best option for pedaling efficiency but can deter a lot of inexperienced riders. The width of drop bars is generally based off the rider’s shoulder width and can range from around 38cm to around 46cm. Drop bars can also flare out to provide more comfort and stability (Ashoor, 2017). Table 14 is a rubric to follow when choosing handlebars based on the user groups.

**Fig 56** Examples of Flat and Riser Handlebars
(Thomson, 2015)

**Fig 57** Example of Drop Handlebars
(Thomson, 2015)

Riser Bars

| Pros | Cons |
|---|---|
| • Comfortable upright riding position<br>• Can help absorb bumps by reducing weight on front wheel | • Too much rise can have adverse effects at higher speeds<br>• Loss of pedaling efficiency |

Flat Bars

| Pros | Cons |
|---|---|
| • Increased pedaling efficiency and traction<br>• Feels very stable on flat and uphill terrain | • Can be uncomfortable for older riders<br>• Reduces ability to absorb bumps due to more weight on front wheel |

Drop Bars

| Pros | Cons |
|---|---|
| • Best option for pedaling efficiency and climbing<br>• Very stable when riding and turning at higher speeds | • Aggressive riding position can deter a lot of riders<br>• Worst option for absorbing bumps |

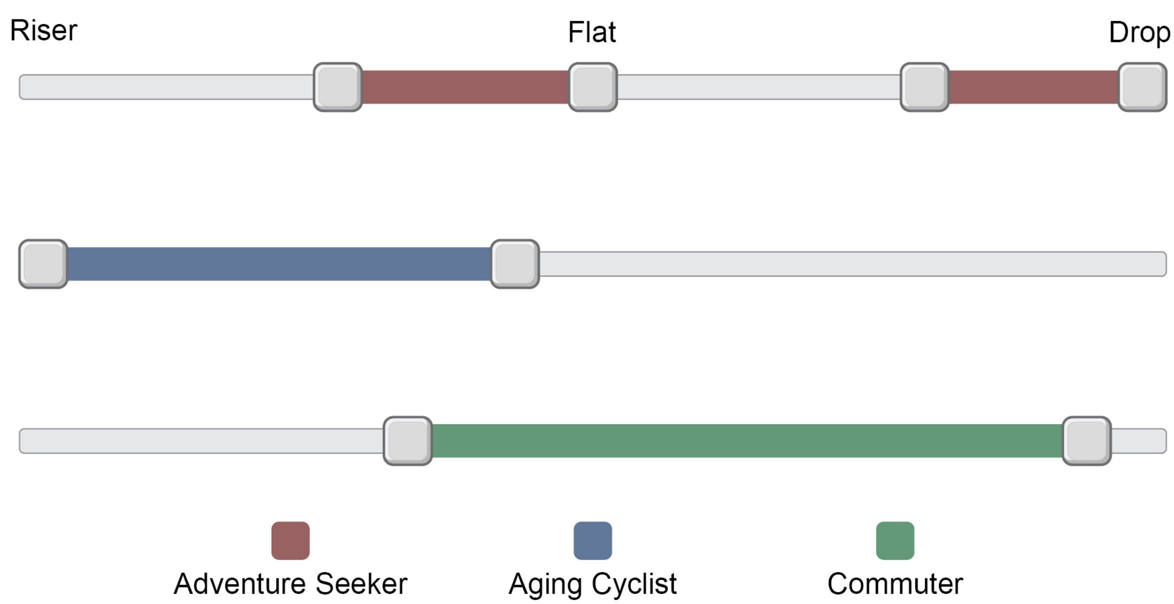


**Table 14** Handlebar Rubric

### 4.6.2 Display

The display on an electric bicycle can give the rider valuable information such as speed, range, mileage, or even GPS location. Most electric bicycle displays are mounted onto either side of the handlebars to give the rider a good view of the needed information. Some displays are a little more subtle, less informative to not distract the rider and only give the most important information.

Fig 58 shows an example of a handlebar mounted display screen. This display is mounted in the center of the handlebar which gives the cockpit a nice balanced feel but can reduce the rider's ability to press any buttons that might be on the screen due to the centralized location. This display gives the rider plenty of important information such as speed, assist level, range, mileage, and the current time. The commuter might benefit greatly from a display as they need the most heads-up information out of any of the consumer groups. Fig 59 shows an example of a more subtle approach to an information display. This display is integrated into the top tube of the bicycle and only gives minimal information to reduce distraction or even reduce cost. This display only gives the rider an assist level indicator and a battery percentage indicator. This type of display would benefit the adventure seeker and aging cyclist due to the simplicity and unobtrusive design.

Other forms of display could even utilize smart devices such as phones or watches to give the rider enough information to be able to confidently ride their bicycle without worrying about running out of battery or having mechanical issues. Table 15 represents a rubric to follow when introducing a display to a concept based on the user groups.

**Fig 58** Example of a handlebar mounted display (Tredz, 2020)

**Fig 59** Example of an integrated top tube display (Rhode, 2020)

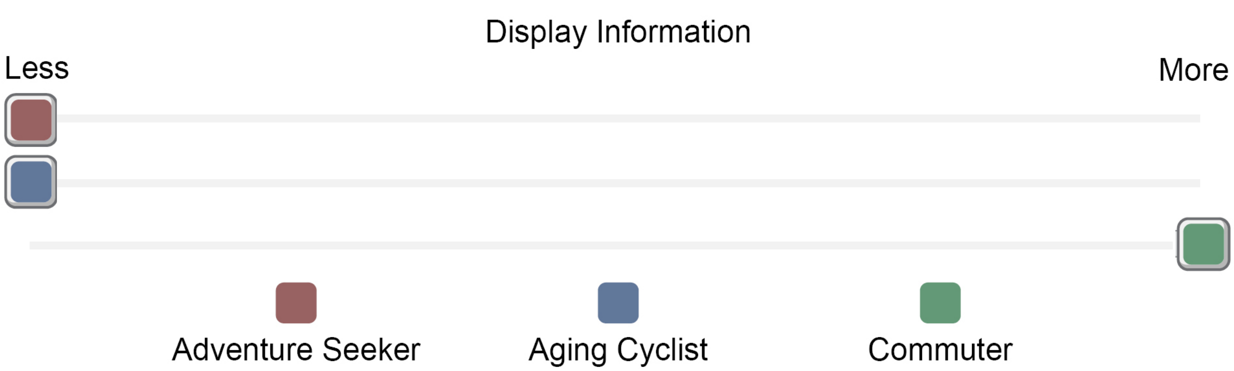


**Table 15** Display Rubric

## 4.7 Styling

### 4.7.1 The Commuter

When designing for the commuter, the designer has more freedom to explore different ideas. The commuter market is generally a younger demographic who are living in more populated urban areas. This demographic includes young professionals who commute to and from work, as well as friends who are looking to explore the city a little more easily.

Areas with large youth populations have tended to experience greater changes over the last several years. College towns have consistently led the list of cities that have experienced the greatest surge in bicycle commuting since the mid-2000s (Dutzik & Ingles, 2017).

Commuters have different needs than other users which need to be considered. What does a commuter carry with them during their commute? Can they bring it inside? Does it need to be able to store away or be portable? Considering the daily needs of the commuter, these consumers will spend a lot of time on these vehicles. The designs in this category can be very diverse. These consumers are looking for a product that helps reflect who they are.


**Fig 60** Evelo Electric Bicycle
(Propeller Design, 2016)

Fig 60 shows an electric commuter bicycle by Evelo. This bicycle is a compact design showing typical geometry with a smaller wheelset. This concept focuses on clean design, familiarity, and portability.

**Fig 61** The Denny Cycle
(Connor, 2021)

Fig 61 shows the winning design from the Oregon Manifest's Bike Design Contest. This concept is the work of the winning team of two design firms, Teague and Sizemore Bicycle. This project, named Denny, focused on the woes of the bicycle commuter and aimed for a thoughtful concept (Connor, 2021). This design features somewhat typical frame geometry, 27.5-inch wheels, integrated front rack, and a multi-use handlebar. The compact nature of the top tube design allows for a more portable bicycle, while maintaining a larger wheel diameter for more comfortable riding. The integrated front rack gives the rider plenty of space for storage and is cleverly fixed to the frame for extra support. The handlebars easily detach and serve as a bike lock for added convenience and security as shown in Fig 62.


**Fig 62** The Denny Cycle Handlebar Lock
(Connor, 2021)

**Fig 63** "Quinn" By Coast Cycles
(Gray, 2015)

Fig 63 shows an electric bicycle concept by Coast Cycles. This bicycle's design is centered around the idea of storing a personal bag between the rider's legs. This is an innovative way of carrying storage in place of a more traditional rack design. The location of the bag also helps balance the weight of the bicycle which results in a more stable ride. The overall design focus seems to be on a familiar and compact bicycle that is easy to ride and service.


**Fig 64** Gocycle Folding Electric Bicycle
(Gomez, 2019)


**Fig 65** Gocycle Folding Electric Bicycle *(folded)*
(Gomez, 2019)

Fig 64 and Fig 65 shows a folding electric bicycle concept by GoCycle. This design focuses on extreme portability for the tightest of living and/or working spaces. The Gocycle can be folded and stored in a large tote bag and can even be left freestanding while folded thanks to the center stand (Gomez, 2019). The integrated headlight and the wheel design give the bicycle a very modern look that is appealing to a lot of consumers.

When designing for the commuter cyclist, the designer is left with the most amount of creative flexibility when compared to the aging cyclist or the adventure seeker. The designer has more freedom to create an atypical bicycle frame and experiment with different drivetrain options. There is more freedom to experiment with proportion, size, and overall form.

Designs under this category of consumer should have a look and feel that gives the rider confidence in the quality of the bicycle. The geometry and fit of the bicycle should give the rider the feeling that they are able to safely ride on bike paths or in traffic. The bicycle should be able to be stored, charged, and used with ease.

### 4.7.2 The Aging Cyclist

When designing for the aging cyclist, the product needs to be both comfortable and have a certain level of familiarity. This consumer may only ride this bicycle one to three times per week, but ease of use is critical. The aging cyclist will typically ride shorter routes either by themselves or in a small group. It is thoughtful to design a bicycle that is easier to mount for someone who may have knee or hip issues like many senior citizens do.

These designs will be a little more moderate in styling when compared to the other categories since familiarity is extremely important when inspiring confidence in an elderly rider. These designs can still have creative and innovative solutions but need to follow the visual language of a traditional bicycle.

**Fig 66** OKO Electric Bicycle
(OKO Cycles, 2019)

Fig 66 shows the OKO bicycle. This concept shows clean Scandinavian design along with a very typical bicycle frame. The integrated fenders add a nice feature for the rider who wants to stay clean. The lightweight, low-entry frame allows an easier time to mount and dismount the bicycle which is perfect for older riders or riders with mobility issues.

The OKO bicycle is not the most compact design, but the aging cyclist does not necessarily need a smaller bicycle. The aging cyclist needs a bicycle that is lightweight and easy to move or transport when needed. These bicycles will most likely be stored inside of a garage.

**Fig 67** Leaos Solar Electric Bicycle
(Leaos, 2015)

Fig 67 shows the Leaos Solar Electric Bicycle. This step through design speaks for comfort and quality with the geometry of the frame and the fit and finish of everything else. The experimentation of different materials on the frame give a nod to an older era of design and can attract an older demographic. The geometry of the frame and the use of a mid-drive motor lead to a design that is well balanced with a low center of gravity. The step through frame also allows the bicycle to be easily used and controlled by the aging cyclist.


**Fig 68** 2021 Specialized Como 5.0
(Specialized Bicycles, 2021)

Figs 68-69 show the 2021 Specialized Como SL. The Como features riser handlebars and a padded saddle to offer comfortable and stable riding experience. The integrated battery in the downtube allows for compact tubing and a lighter overall bicycle. The mid-drive motor with a belt drive system allows for little to no regular maintenance. The integrated top tube controls give just enough information to be easy to read and easy to use without overwhelming the rider.

**Fig 69** 2021 Specialized Como 5.0 Display
(Specialized Bicycles, 2021)

To design a successful electric bicycle for the aging cyclist, the bicycle must be easy to ride and be designed for overall comfort and stability. The bicycle must inspire confidence in the rider by feeling familiar. The bicycle will probably be used for shorter leisure rides, so speed and range are not a huge priority, and can be swapped for a lighter overall bicycle.

The styling must avoid looking aggressive or fast, and instead must look high quality and reliable. The overall aesthetic of the bicycle should be inviting and minimal. Muted or unisex color options should be used to broaden appeal.

### 4.7.3 The Adventure Seeker

The Adventure Seeker is someone who wants to push their bike and themselves further than before. This consumer wants to climb mountains faster and descend with confidence; they want to explore more rural areas and let their bike take them to new places. These needs lead to more robust designs that break the mold of what a bike can do. These consumers are looking for performance and durability over ease of use.

This consumer can be looking for a bicycle to compete with or a bicycle to explore with, so the quality of the product is extremely important to ensure safety and durability.

**Fig 70** Onyx Motorbike with DRT Kit
(Onyx Motorbikes, 2020)

Fig 70 shows the Onyx Motorbike upgraded with the DRT kit. The Onyx does a great job of blurring the line between bicycle and motorcycle and is capable of going anywhere. The Onyx comes with a 20 miles per hour top speed, which makes it a class 2 electric bicycle, but is programmable up to 50 miles per hour, which then classifies it as a motorcycle in most states.

The Onyx has a 75-mile range in its factory settings, which means it has quite a bit of battery power (Onyx Motorbikes, 2020).

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**Fig 71** Standard Onyx Motorbike
(Onyx Motorbikes, 2020)

Fig 71 shows the off-road capabilities of the Onyx and shows that it has enough range to explore. The adventure seeker is looking for a bicycle that is capable and powerful and looks the part. Suspension is often the center of attention in this category and a bicycle's capability is often judged by the suspension set-up. Low-quality or absent suspension will not give the rider the ability to conquer rougher terrain at higher speeds.

## 4.8 Final Details

### 4.8.1 Color

While the color of a bicycle alone will not make the bicycle successful, it can sure go a long way to making the bicycle unsuccessful. Color can be important to a consumer, especially on a relatively expensive product. Colors can be a representation of personality and people can have strong feelings towards or against certain colors.

Color trends are always changing, and it can be hard to keep up with or predict the patterns. The bicycle industry seems to look at other similar industries for color inspiration, which can be quite effective if given enough thought. Industries such as automotive, powersports, or even consumer electronics can have distinct color trends that do well in the bicycle industry. Which industry’s color trends to research will be determined by the designer’s targeted audience (see Figs 72-74).

Adventure seekers seem to like aggressive designs and looking into the powersports industry could be a good source of inspiration. Bright colors with sharp contrast and graphic designs seem to be a popular trend. For the aging cyclist, the automotive industry could be a good place to look for color ideas. The automotive industry researches their color choices very intently and can target certain age groups with a vehicle design. Commuting on a bicycle seems to be a lifestyle choice so researching lifestyle brands, especially in consumer electronics, can be a great way to predict color trends for the commuter target group.

**Fig 72** Example of powersports color trends
(Tuttle, 2021)


**Fig 73** Example of automotive color trends
(Salyer, 2021)

**Fig 74** Example of consumer electronics color trends
(Gallagher, 2021)

# Chapter Five
# Application of Design Guideline

## 5.1 Identify The Market

When applying this guideline towards a design, the first thing the designer must decide is who they are designing for. This guideline showcases three different consumer groups to choose from: The Commuter, The Aging Cyclist, and The Adventure Seeker. Depending on which consumer the designer chooses there will be a rubric for the design to follow. In the application of this guideline, a design for each consumer group has been illustrated.

## 5.2 Ideation

Every designer has a different process, but most designers start their creative process with rapid ideation sketches. These sketches are meant to be quick and loose. They should move from idea to idea to see if anything begins to take shape (see Fig 75).

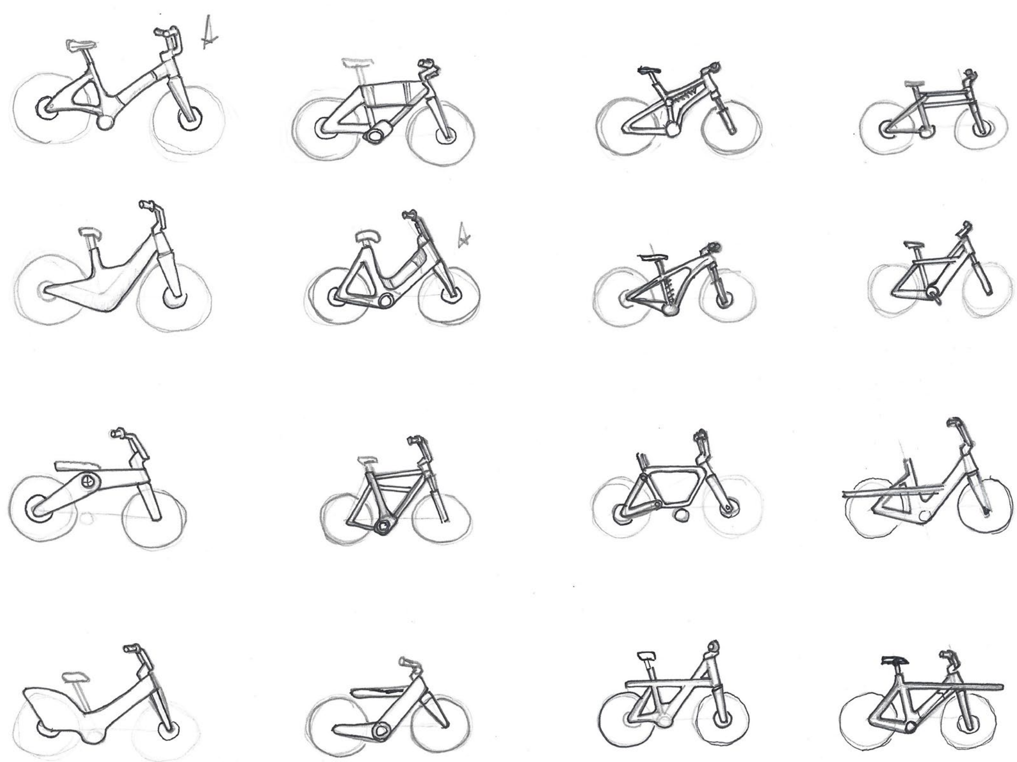

**Fig 75** Quick Initial Ideation Sketches

Once a design begins to emerge, the designer should move to more detailed sketches to iron out the dimensions, angles, and scale of the bike (Fig 76). If using the appropriate rubric, the bicycle will begin to take shape as the designer makes decisions. It is also important during this step to gather and implement the measurements of all the components to reduce any clearance or fitment issues later.

**Fig 76** Iterative Sketches

Once a path forward emerges, the designer moves into CAD to start working with actual dimensions and angles.

## 5.3 Solution

### 5.3.1 The Adventure Seeker

To start designing a frame, the designer must determine a wheel size for the bicycle. A 29-inch wheelset is acceptable for an adventure seeker concept. Once the wheel size is established, the designer can determine the wheelbase and begin to outline the rest of the frame geometry. Following the rubric will allow the designer to quickly make informed decisions when choosing the proper angles and dimensions within the frame (Fig 77).

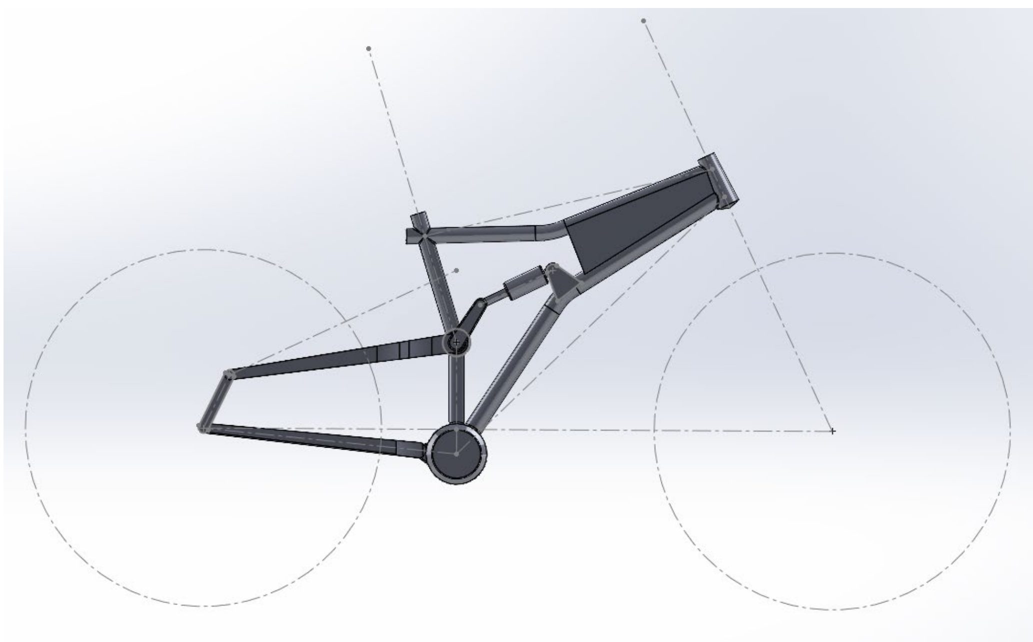

**Fig 77** Adventure Seeker Frame Geometry

For this design, titanium was the material chosen for the frame due to its high strength/weight ratio. A full suspension platform was chosen in for superior downhill performance. A slack 67 degree head tube was used in order to give the bicycle a longer wheelbase and better downhill handling. The seat tube was then set to 69 degrees in order to give the bicycle a more efficient pedaling positioning for better climbing. A bottom bracket height of just over 12 inches allows for obstacle clearance while keeping the overall center of gravity low. A longer chainstay of 500mm was used to help tire clearance under full load as well as increase the overall wheelbase for a bicycle that feels more planted to the ground. With such a long wheelbase and chainstay, the bicycle is sure to feel sturdy but might not be as responsive as one would like. A tighter chainstay angle was implemented in order to help make the bike more pedal responsive and give the rear suspension a tighter, more reactive feel. Table 16 represents the frame choices made in this implementation that are illustrated in Figs 78-80.

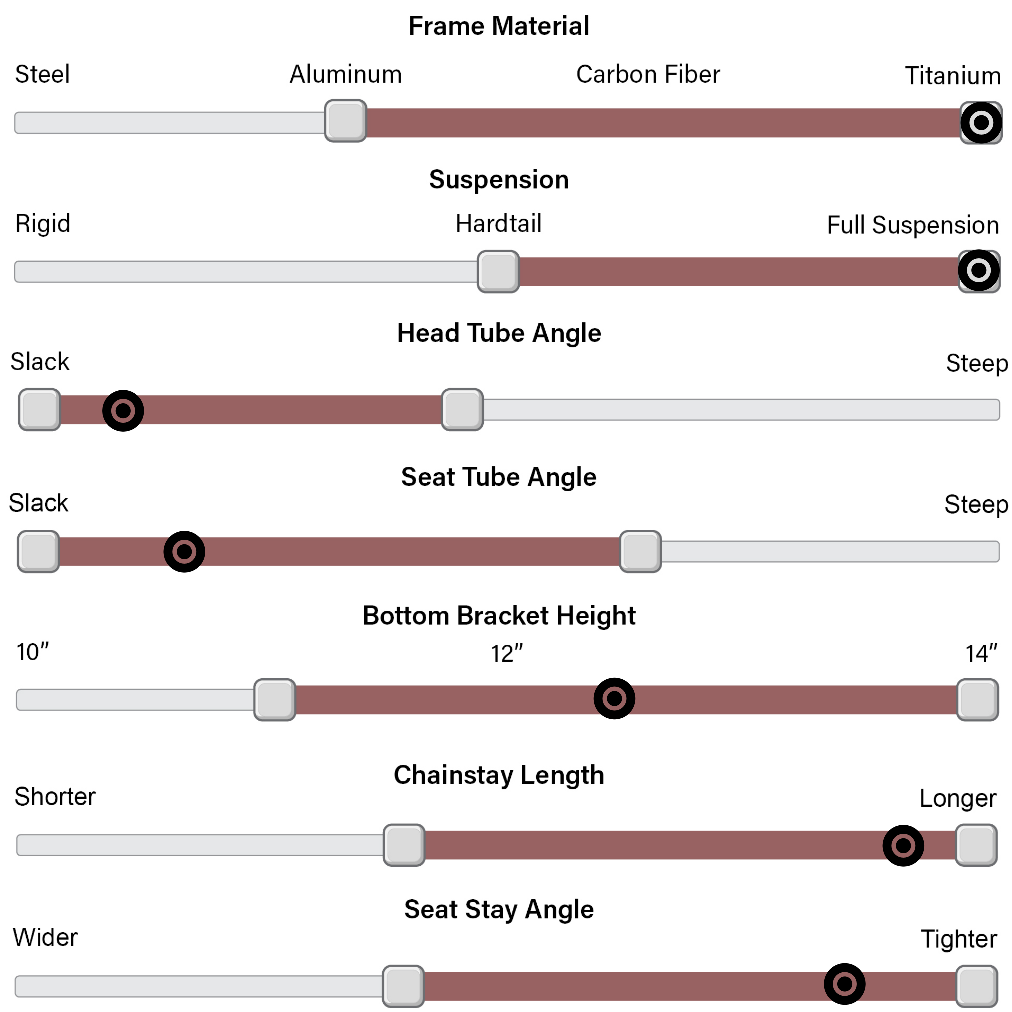


**Table 16** Adventure Seeker Frame Rubric

**Fig 78** Adventure Seeker Concept Render 1

**Fig 79** Adventure Seeker Concept Render 2

**Fig 80** Adventure Seeker Concept Render 3

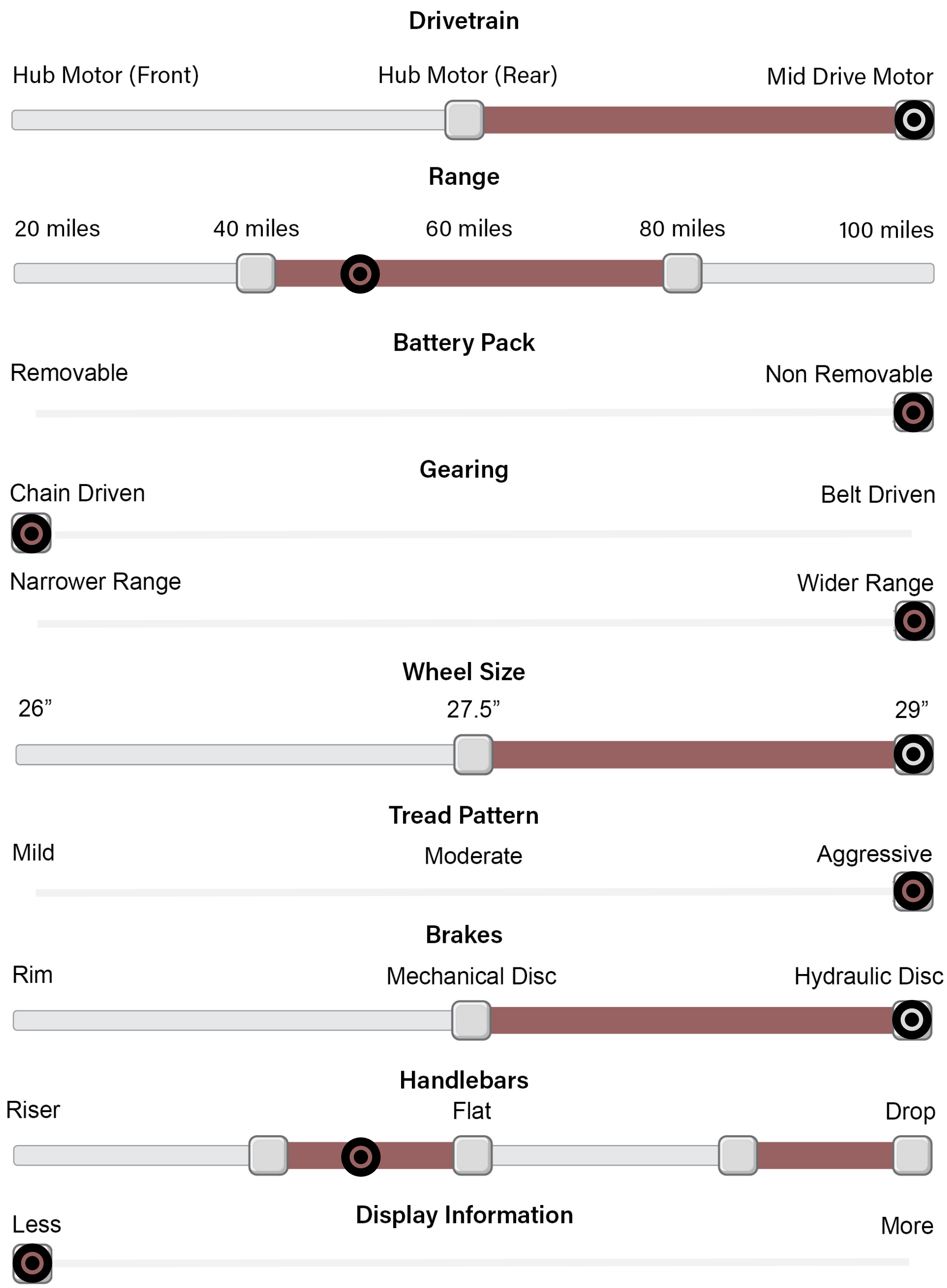


**Table 17** Adventure Seeker Components Rubric

The motor chosen is an efficient, lightweight, mid-drive motor to take full advantage of a smaller non removable battery pack capable of 50 miles of riding. The drivetrain is a wide range chain driven option for better climbing. Hydraulic disc brakes were chosen for superior braking in the roughest of conditions. Handlebars with a slight rise were chosen in order to give the rider a more upright riding position and a minimal display was chosen in order to reduce rider distraction. Table 17 shows the choices of components for the Adventure Seeker.

### 5.3.2 The Aging Cyclist

For the Aging Cyclist concept, comfort and ease of use are priorities. A 27.5-inch wheelset was chosen to give the bike a lower overall height while not giving up pedaling efficiency. A step through frame design was chosen to make the bicycle easier to mount and dismount.

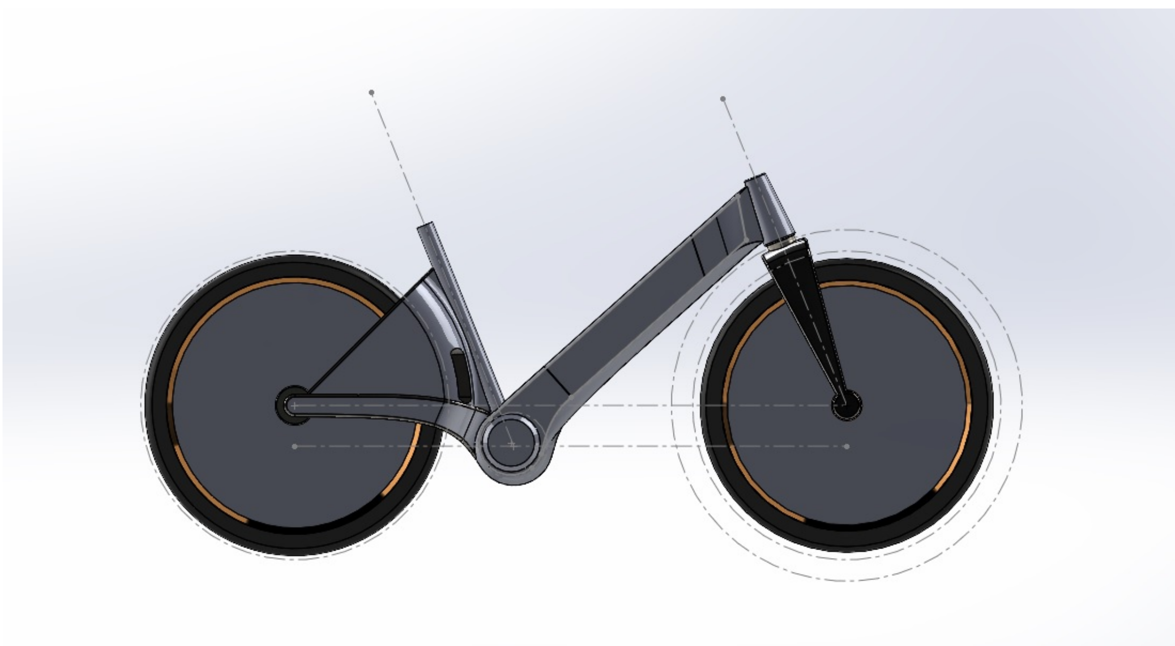

**Fig 81** Aging Cyclist Frame Geometry

For this frame (Fig 81), aluminum was the material used due to its ability to be easily formed, relatively low weight, and cost effectiveness. A rigid platform was used in order to increase pedaling efficieny and ease of use on pavement. A 70 degree head tube was used in order to strike a balance between comfort and capability. A 70 degree seat tube was used in order to get the riders hips and knees in a more comfortable alignment without sacrificing pedaling efficiency. A lower 11 inch bottom bracket gives the bicycle a more stable feeling due to the lowered center of gravity. A shorter 450mm chainstay length was used to make the bike feel more resposive and a wider seat stay angle was used to absorb some of the vibrations from the road. Table 18  shows the frame choices for this design and Figs 82-84 show the implementation of the choices.

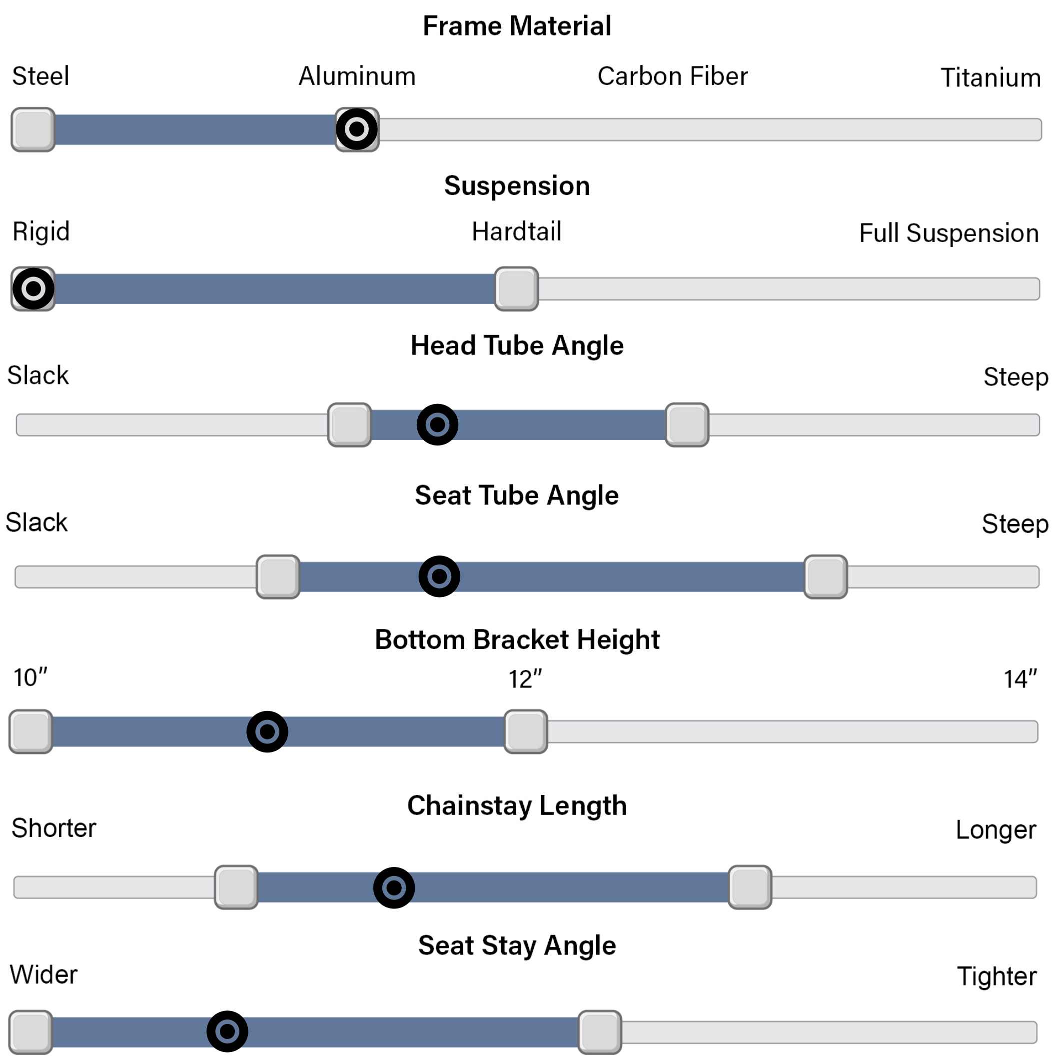


**Table 18** Aging Cyclist Frame Rubric

**Fig 82** Aging Cyclist Concept Render 1

**Fig 83** Aging Cyclist Concept Render 2

**Fig 84** Aging Cyclist Concept Render 3

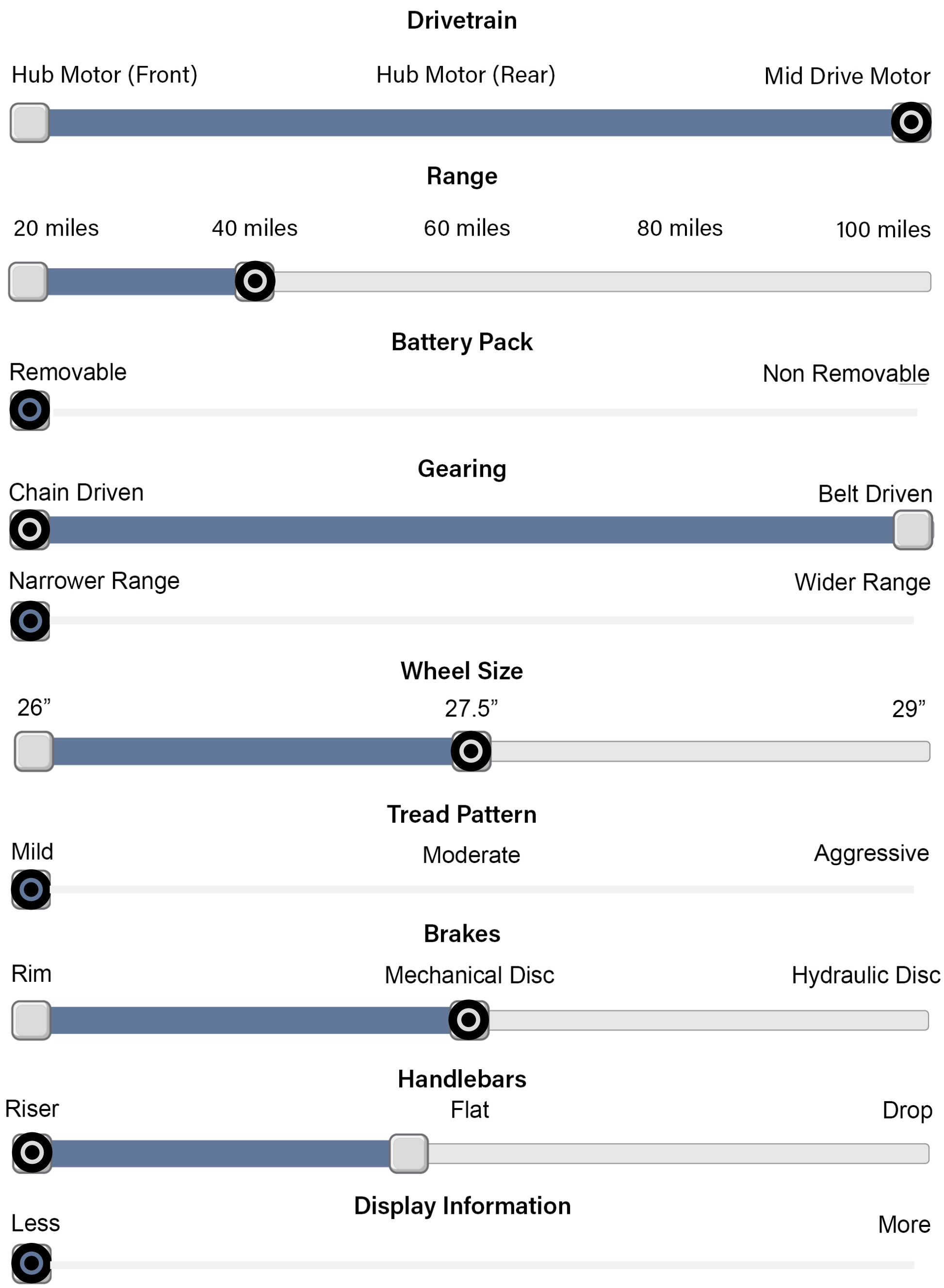


**Table 19** Aging Cyclist Components Rubric

The motor chosen is a mid-drive motor in order to reduce the overall weight of the bike while keeping the weight balanced. The drivetrain is a narrower range, chain driven option to give the rider an easier time keeping a similar cadence. Mechanical disc brakes were chosen to accommodate for a heavier bike. Handlebars with a 6-inch rise were chosen to give the rider an upright, comfortable riding position and a minimal display was chosen to reduce rider distraction. Table 19 illustrates the choice of components in this implementation for the Aging Cyclist.

### 5.3.3 The Commuter

For the Commuter concept, pedaling efficiency and ease of use are the focus. The bicycle must be easy to ride yet fast and capable enough to ride with traffic. A 29-inch wheelset was chosen to be faster and to better handle any obstacles found on the road (Fig 85).

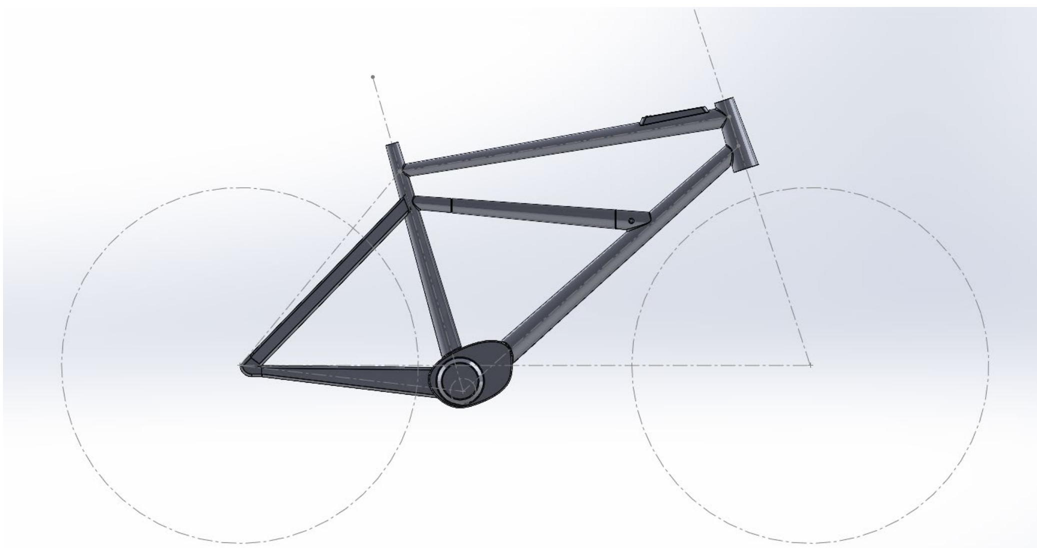

**Fig 85** Commuter Frame Geometry

For this frame, high quality steel is the chosen material due to its strength and its ability to be formed into tapered tubing. Tapered tubing offers superior strength when compared to straight tubing. A 73 degree head tube angle was used to increase the overall speed and efficiency of the bicycle. A 73 degree seat tube angle was used to also increase the pedaling efficiency. A 13-inch bottom bracket height was used to help clear any obstacles and keep the riders feet higher during sharp turns. A longer 480mm chainstay was used to help offer stability at higher speeds and a tighter seat stay angle to increase stiffness and pedaling efficiency. Table 20 shows the frame choices for this iteration that are also shown in Figs 86-88.

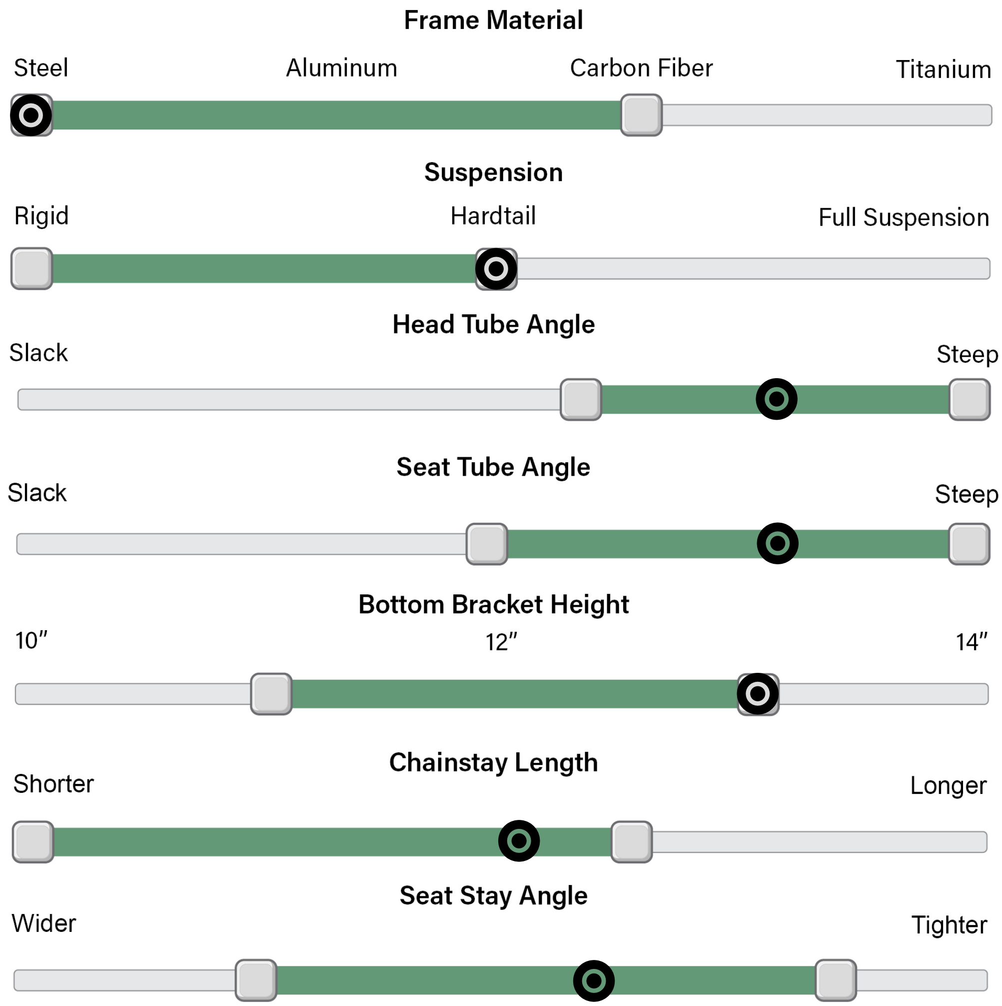


**Table 20** Commuter Frame Rubric

**Fig 88** Commuter Concept Render 1

**Fig 89** Commuter Concept Render 2

**Fig 90** Commuter Concept Render 3

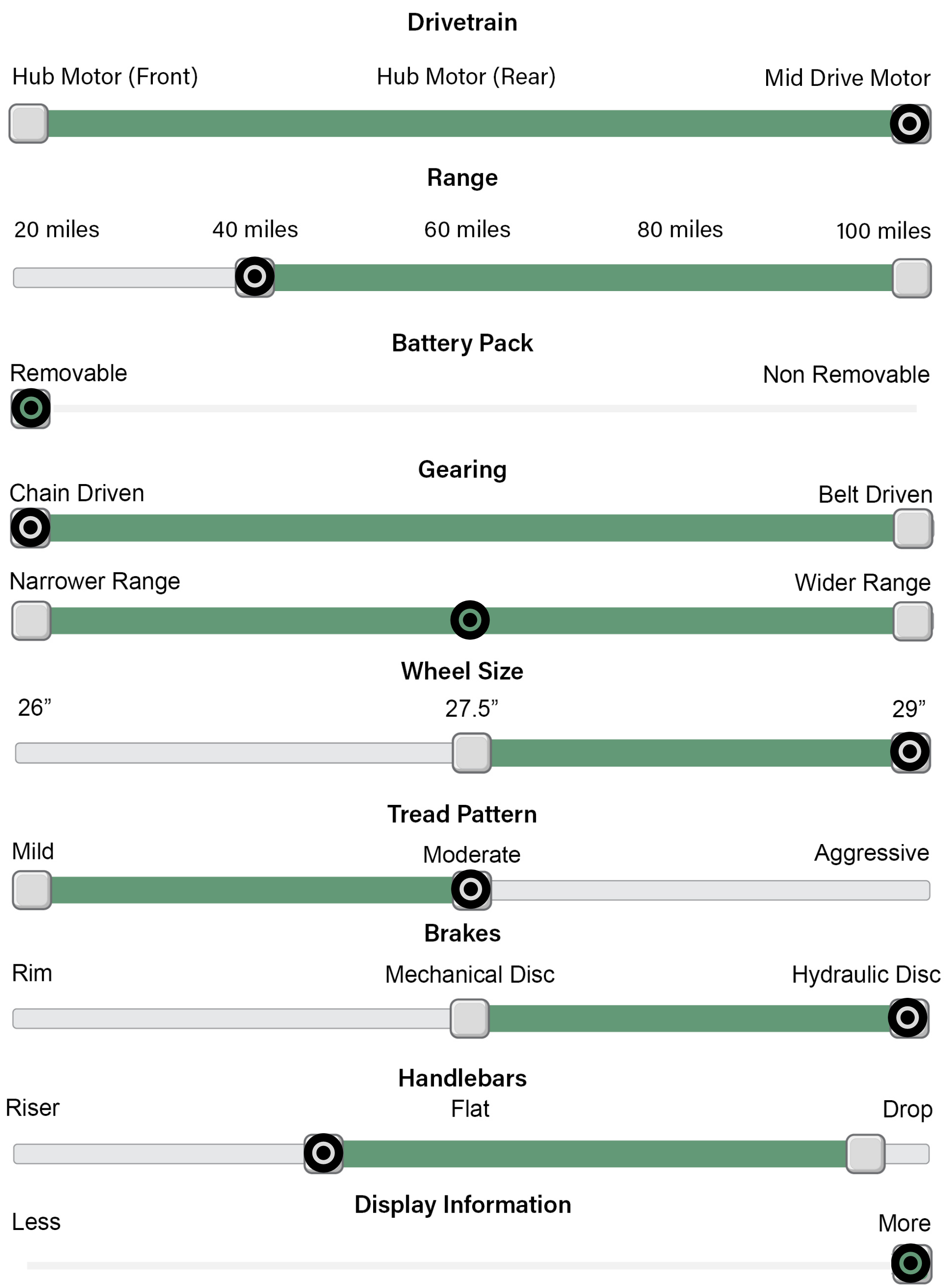


**Table 21** Commuter Components Rubric

Table 21 illustrates the choices for the commuter iteration of this design implementation. The motor chosen is a lightweight, energy efficient, mid-drive motor to reduce the overall weight of the bike while keeping the weight balanced. A smaller removable battery pack was chosen to make charging easy to do wherever the rider may be. The drivetrain is a mid-range, chain driven option to give the rider a good balance of climbing and speed. Hydraulic disc brakes were chosen for superior braking performance in all riding conditions. Handlebars with a slight rise were chosen to give the rider a comfortable yet efficient riding position to help the rider feel stable on the bike at higher speeds. An integrated top tube display is used to give the rider enough information to get where they need to go safely.

# Chapter Six
# Conclusion

## 6.1 Summary of Study

Transportation is getting a makeover. The electric vehicle transformation is taking place before our very eyes. The way people are traveling around their country, state, or even neighborhood is changing. The electric bicycle market is one of the fastest growing industries and it is up to designers to make sure that the success of the market continues. This study aimed to research what has already been done and has compiled results into an easily digestible guideline for any designer to use. If used correctly, this guideline will help the designer target a specific consumer group and design a practical, well thought out product for that consumer.

Chapter One discusses the reason and importance of the study as well as the limitations in the current market. This chapter is meant to inform the reader as to why the time was spent compiling all this information.

Chapter Two is the culmination of design and market research on electric bicycles, motorcycles, and scooters. This research allowed the guideline to focus its aim and pinpoint a direction for the designer.

Chapter Three presented a case study on the most popular vehicle of all time, the Honda Super Cub. The Super Cub was so well designed that it was able to attract consumers from many different demographics. With over 100,000,000 units sold there are many lessons to be learned from the Super Cub. The case study reviewed the design decisions made as well as the marketing strategies involved with the development of the Super Cub.

Chapter Four explains a guideline that gives designers a rubric to follow that allows for creative freedom but results in competent bicycle designs. The guideline covers critical aspects of bicycle design such as frame geometry and componentry. The guideline also gives the designer insight into styling cues and user interface. The guideline focuses on three distinct consumer groups, The Commuter, The Aging Cyclist, and The Adventure Seeker. Each consumer group has specific needs within the electric bicycle industry which the guideline covers.

## 6.2 Recommendations for Further Studies

The bicycle industry is constantly pushing forward in terms of technology. As technology progresses, new studies will be needed to keep the design guideline up to date. Focus group studies can be conducted to assess the overall effectiveness of the guideline outside of a rubric. The guideline, with more research, can be expanded to include irregularities such as tandem bicycles, recumbent bicycles, and even tricycles. These are much smaller markets right now but could increase in the future.

## 6.3 Synopsis

This study offers designers who may not have experience designing bicycles to gain a good understanding of the underlying geometry and proper componentry for an electric bicycle and provides the designer a rubric to follow to ensure a practical design. This study compiles research of the overall electric bicycle market to give the designer a solid foundation on which to build a design. The study breaks down the electric bicycle market into three distinct consumer groups: The Commuter, The Aging Cyclist, and The Adventure Seeker. These distinctions allow the designer to focus their efforts and target a specific cycling demographic with fundamental understanding of the distinctions themselves. The guideline is then implemented with a design application to discover its effectiveness and ability to produce good bicycle designs.

## 6.4 Findings

The findings of this study show that there is a need for improvement within the electric bicycle industry. The study shows that there needs to be a shift in focus to better target the needs of the consumers who benefit the most from the technology. As the demand increases, more designers are needed to produce competitive products within the space. This guideline provides a valuable resource for designers who are newer in the world of bicycles.

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