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Introduction

Over the past fifteen years, cellular telephone subscriptions in the United States have increased dramatically. At the same time, growing concerns over oil supplies have increased public consciousness of energy efficiency. By comparing the energy use of cell phones to that of traditional landlines, the most energy efficient type of telephone can be determined. Major factors include:

- Power used while charging
- Power used while idle
- Time charging each day
- Time idle each day
- Energy to manufacture and transport the phone
- Lifespan of phone
- Total number of phones

These values, many of which depend on the type of telephone, allow for a comprehensive analysis of the energy consequences of the cell phone revolution. This model quantifies the effects of cellular and landline telephones on power consumption. Several aspects are investigated, each with its own specifications.

Problem Statements

1. Model the energy consumed due to telephone use in the current United States during the transition to a predominantly cell phone based society, and during the following steady state.
2. Determine the most energy-efficient way to provide telephone service in a country without existing communications infrastructure, and describe social influences on phone preference.
3. Estimate the number of barrels of oil wasted in the United States when fully charged cell phones are plugged into the charger, as well as when the chargers are plugged into the wall but not the phones.
4. Estimate the number of barrels of oil wasted by all battery chargers that are left plugged in when they are not actively charging a device.
5. In the optimal situation from #2, project the telephone energy requirements over time as the population and economy change. In particular, find the number of barrels of oil used each decade for the next half-century.

Assumptions

- Cell phones and landline phones compete for the same market.
- Residential, commercial, nonprofit, and government telephones are included in the total number of phones.
- The total number of phones is averaged by household.
- Every cell phone comes with a charger and lithium ion battery [1].
- A cell phone's battery will not be replaced, it will be discarded with the phone.
- Overcharging or undercharging a lithium ion battery does not affect its life or performance [6].
- Nickel hydride batteries are used in cordless phones [7].

- The total energy used in manufacturing a landline phone is half that of manufacturing a cell phone.
- A person may own more than one telephone.
- In any household with cell phones, each of its m members will have their own cell phone.
- Every person within the population is part of a household.
- A charger is an item used to recharge batteries, including those within electronic devices such as laptop computers, cell phones, and cordless phones. Appliances such as televisions, refrigerators, and microwaves are not included, as they are not rechargeable devices.
- The fixed energy required to construct telephone infrastructure, when averaged over the duration of the phone system, is negligible.

Important Variables:

The important variables within this model include :

- H, the number of households in the country
- Z_{Cell}, the number of cell phones per hundred people
- $Z_{Landline}$, the number of landlines per hundred people
- N_{Cell}, the number of cell phones
- $N_{Landline}$, the number of landline phones
- Population
- Power drawn by each type of phone when idle
- Power drawn by each type of phone when charging or active
- $W_p = 3.0128$, ratio of primary energy input at a power plant to energy drawn off the grid [9]
- On average, a cell phone's battery must charge for one hour a day [2]
- 75% of landline phones are cordless and 25% are corded
- The average lifespan of a corded landline phone is 20 years
- The average lifespan of a cordless landline phone is 10 years
- Cell phones last 1.5 years [3,4], whereas lithium ion batteries and chargers last 3-4 years [5]
- Each landline connection will have an average of m phones connected to it
- m = 2.37, members in the average household [8]

Part 1: Existing Infrastructure

Transition

The United States has a mixture of cell phones and traditional landline phones. Currently, 84% of the United States population has a cell phone subscription with 15.8% of U.S. households owing only cell phones [10]. The U.S. is currently in a period of transition from the exclusive use of landlines toward the exclusive use of cell phones. During this transition, cell phones and landline phones compete for consumers. The target market is the entire population, which grows over time. As such, the number of cell phones and landlines per hundred people is time dependant, as seen in Figure 1.

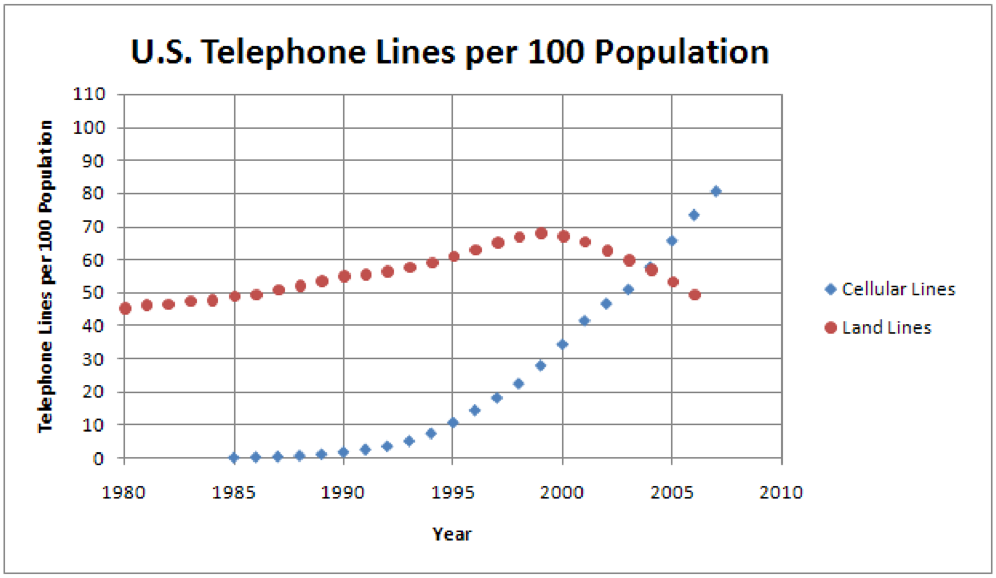

Figure 1 : Historical Data for Phone Ownership in the United States

As cell phones became popular, the number of landlines decreased. This suggests the data can be described with a differential Competing Species model [11, 12, 13]. The competing species model describes two species that both require a single finite resource, and impede each other from acquiring it. The system of equations for this model appears in Equations 1 and 2, which cannot be solved analytically. In these equations, x is the population of one species, y is the population of the other species, and a_1 and a_2 are the unconstrained growth rates of the populations. The ratios a_1/b_1 and a_2/b_2 are the maximum populations for each species. The final coefficients, c_1 and c_2, are competition factors accounting for the negative effect each species has on the growth of the other.

Eq. 1

$$\frac{dx}{dt} = x(a_1 - b_1 x - c_1 y)$$

Eq. 2

$$\frac{dy}{dt} = y(a_2 - b_2 y - c_2 x)$$

For the purposes of this model, the two species are cell phones and landlines. The resource in question is market share, the proportion of the population of the United States which is willing to purchase phones. When total phone ownership exceeds the equilibrium value, one of the two types of phone will have to die out, or become obsolete. The competition model can be applied by taking Z_{Cell} as the number of cell phones per hundred people in the U.S. and $Z_{Landline}$ as the number of landlines per hundred people in the U.S.. Appropriate coefficients for this model were determined graphically by solving the equations numerically in MATLAB [14]. The results can be seen in Equations 3 and 4.

Eq. 3

$$\frac{dZ_{Cell}}{dt} = Z_{Cell}[.315 - \left(\frac{.315}{110}\right) Z_{Cell} - (4.77 \times 10^{-4}) Z_{Landline}]$$

Eq. 4

$$\frac{dZ_{Landline}}{dt} = Z_{Landline}[.21 - \left(\frac{.21}{100}\right) Z_{Landline} - (2.50 \times 10^{-3}) Z_{Cell}]$$

With these coefficients, the model fits the historical data accurately from 1995, when cell phones reached a penetration level of ten per hundred people, to 2006, the last year data for both phone types was available. The graphical solution and its projection through 2030 appears in Figure 2. This model predicts that the market will support up to 1.1 cell phones per capita, or up to 1.0 landlines per capita. Based on an average of 2.37 telephones connected to each landline, there is a maximum of 2.37 landline phones per person. Included in these numbers are residential, commercial, nonprofit, and government owned phones. The "Cell Phone Revolution" is taken as the time period from 1995, when cell phones first reached a saturation of 0.1 per capita, through 2025, when landlines drop below a saturation of 0.1 per capita.

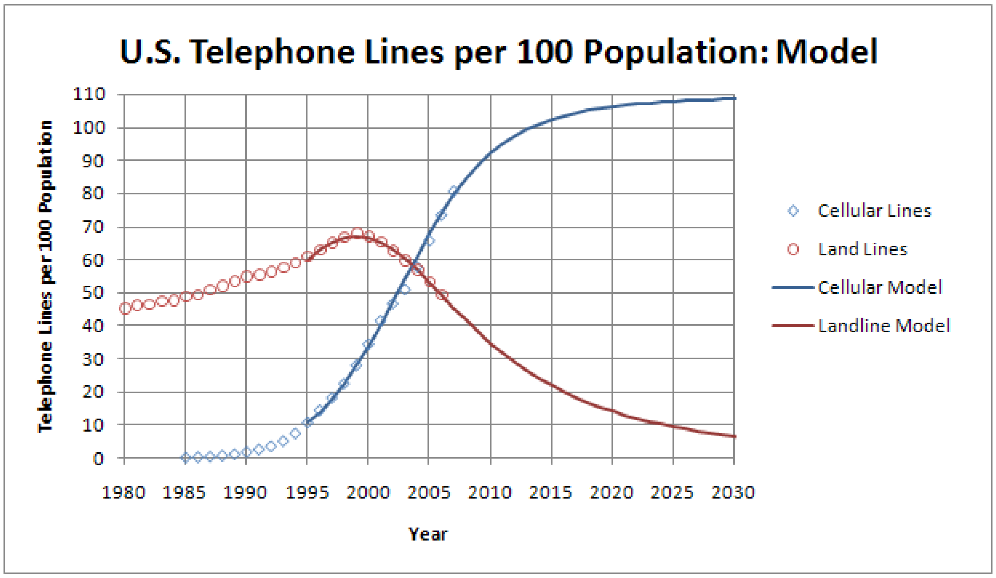

Figure 2: Historical data and Competition Model

Using this model, the total number of cell phones and the total number of landline telephones can be predicted for any future year. Appendix A shows the projected number of cell phones and landlines phones per capita from 1995 through 2035. These numbers are used to determine the energy requirements in terms of gigawatt-hours per day (GWh/day). The power needed for each type of phone is listed in Table 1. For these purposes, a cordless phone is a landline telephone with either batteries or electronics, which draws constant power from the electrical grid. A corded phone gets all its power from the telephone line. The energy to manufacture, ship, and dispose of a cell phone equals 180-MJ, or 50,000-Wh. All power quantities are listed in terms of rate of primary energy use, which accounts for the fact that for every watt-hour drawn from the grid, 3.0128 watt-hours worth of fuel were used to produce it [9]. This accounts for inefficiencies in the power generation and distribution systems [15]. The three cell phone types listed correspond to the power required for their chargers when idle.

Table 1: Primary Power Levels

	Idle (W)	Active (W)	Active Hours (h)	Fixed (Wh)	Life (days)	Daily Energy (Wh)
Corded Phone	0	0.452	1	25000	7200	3.92
Cordless Phone	5.12	10.24	2	25000	3600	140.11
Cell Phone (avg)	0.904	15.06	1	50000	540	128.44
Cell Phone (new)	0.301	15.06	1	50000	540	114.59
Cell Phone (5-star)	0.090	15.06	1	50000	540	109.74

The number of active hours corresponds to call time for corded phones, charging time for cell phones, and the charging time for cordless phones. The manufacturing energy for a landline phone is assumed to be half that of a cellular phone due to its less-complex circuitry. A cordless phone has half the life of a corded phone because it is more likely to get lost or broken. The final column of Table 1, showing lifetime average power per device in watt-hours per day, is calculated using Equation 5.

Eq. 5

$$P = (IdleWatts)(24 - HoursActive) + (ActiveWatts)(HoursActive) + \frac{Fixed}{Life}$$

The daily energy use for each type of phone is calculated using equation 6.

Eq. 6

$$DailyEnergy = (P_{CellAvg})(N_{Cell}) + \left(0.75(E_{Cordless}) + 0.25(E_{Corded})\right)(N_{Landline})$$

At present, there are 271,856,247 cell phones [20] and 276,867,152 land phones, meaning the United States produces 64.3 GWh per day for telephones. Figure 3 shows the total power produced for telephones during the transition period from 1995 through 2030. A baseline projects what power levels would have been needed if cell phones had not become popular.

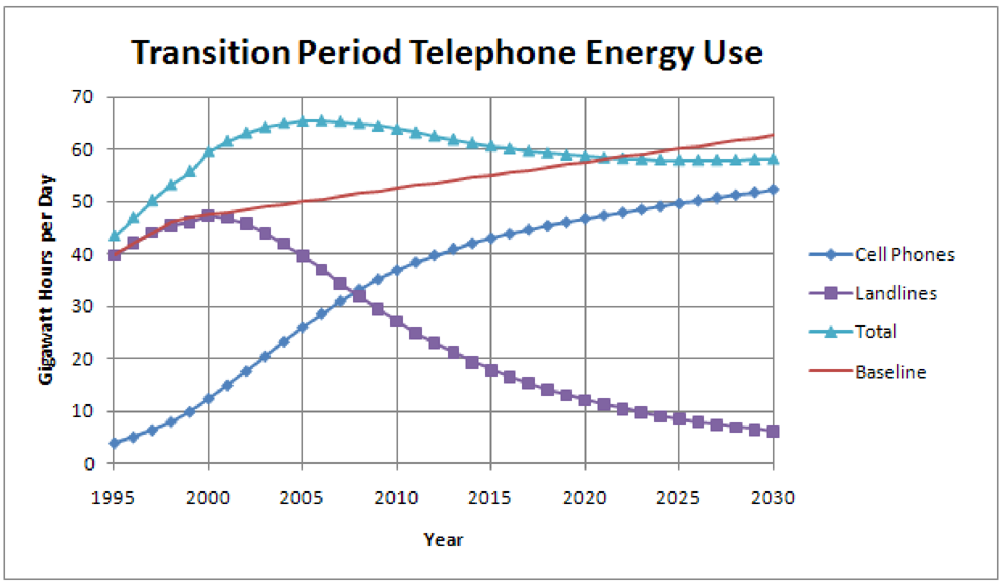

Figure 3: Power Produced for Telephones during Transition Period

As seen above, the power used by landlines begins to decline as cell phone power usage grows. The net change in power production during this transition is initially positive. After the year 2021, the transition state becomes more energy efficient than the projected baseline, as seen in Figure 4. This occurs because cell phones require less primary energy per day than landlines.

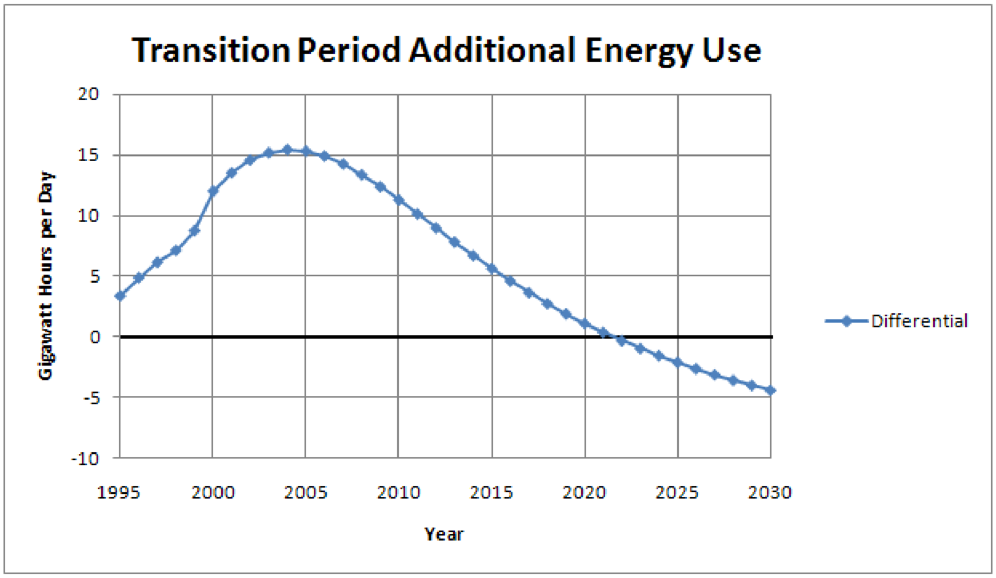

Figure 4: Difference in Power Generated for Telephones during Transition

Over the course of the transition period from 1995 to 2025, an additional 84,040 GWh of energy must be produced for telephones. However, starting in 2022, annual energy savings will result.

Steady State

The steady state occurs when the entire market for telephones is satisfied. Based on the model of the transition period, this will only include cell phones. When that occurs, and the two types of phones are in equilibrium, the limiting value of 1.1 cell phones per person.

Table 2: Population and Household Data

Factor	Value
H	126,316,181 households in US [8]
m	2.37 members / household

Using current population figures shown in Table 2 above, the total power requirements for the steady state are calculated based on the data in Table 1. The steady state power needs for the United States are shown in Table 3. More energy efficient chargers decrease the load.

Table 3: Power Requirement for Steady State by Charger Efficiency

Device	Energy Cost (Gigawatt Hours/Day)
Cell Phone (Average)	42
Cell Phone (New)	38
Cell Phone (5-star)	36

Part 2: No Existing Infrastructure

Optimal State

To determine the optimal system for providing telephone service in a country roughly the same size as the United States, but lacks existing communications infrastructure, the power requirements of each type of phone are compared. The fixed energy required to construct telephone infrastructure, averaged over the duration of the phone system, becomes negligible. The limiting values for landline and cellular phone penetration are 2.37 and 1.1 phones per person respectively, the same as in the United

States. The energy needed per day is the population multiplied by the phone penetration factor, and the energy per day per phone. Figure 5 shows the projected power requirements for the country over time.

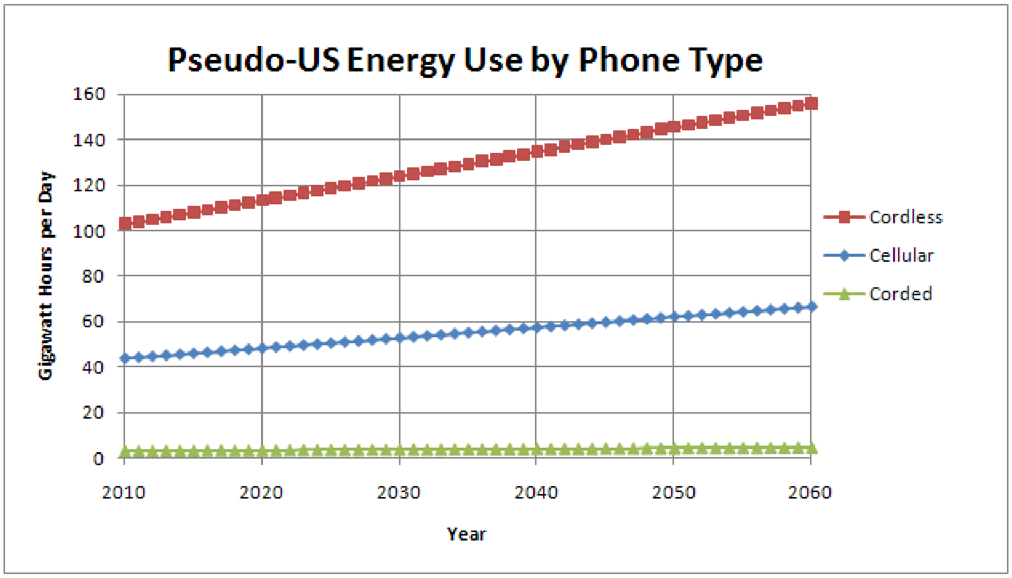

Figure 5: Telephone Power Need Forecast for Saturated Market

From these data, corded landline phones are the most energy-efficient, using about 3.2 gigawatt-hours of energy per day. However, universal use of corded phones is not a realistic scenario. When landline infrastructure is present, 75% of landline phone are assumed to be cordless, and 25% corded. Also, there are three levels of cell phone chargers to consider: the current average charger in the U.S., the more-efficient chargers currently being manufactured, and the energy-conserving 5-star chargers which are not yet common [21]. Calculating the energy use of these in the saturated market results in the power requirements shown in Figure 6.

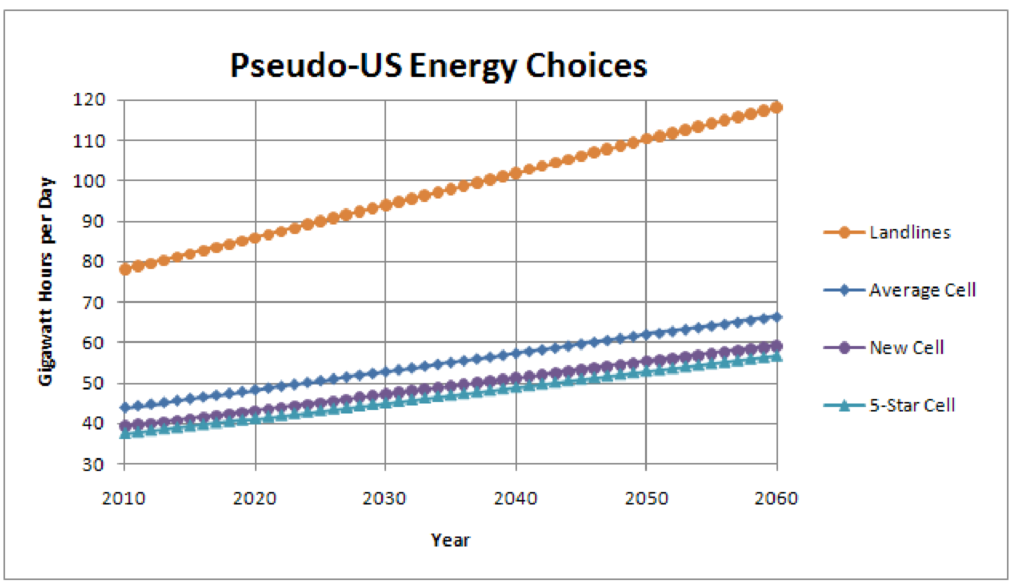

Figure 6: Accurate Telephone Power Forecast for Saturated Market

From an energy perspective, it is most beneficial to create the infrastructure for a cell phone communication system. Passing legislation to decrease the amount of waste that chargers create could be used to make this state even more energy efficient.

Additional Factors

Outside of impacts on energy consumption, there are still numerous other factors that determine which type of phone will be favored by the general population. Cell phones provide greater mobility while increasing safety, especially while travelling alone or in a small group. It also allows older children to have increased independence, without putting themselves in danger [22]. Impromptu scheduling changes and emergencies can be more easily handled with immediate communication available. From a business standpoint, cell phones can make employees easier to reach. This can increase productivity by allowing employees to perform their jobs while not physically in the office. Cell phones are also used to replace watches, cameras and alarm clocks, which may impact their overall energy usage and price in comparison to the energy used by a separate phone, watch, camera and alarm clock [23].

Cell phones also have negative consequences. In particular, it is suspected that cell phones contribute to brain cancer and tumors due to the radiation that leaves both the cell phones and the cell towers [24, 25]. In addition, cell phones can interrupt family life, straining relationships between different generations. Adults who use cell phones for work sometimes let it interfere with their family life, while children become attached to their cell phones as a means of contacting peers, leading to more peer-based and fewer family-based activities [26]. The nature of a cell phone can also limit the ability to contact a group, such as a family. Instead of making a single call, it may be necessary to call each member separately, wasting time and effort, since there is no universal means of communication. In addition, cell phone rings often interrupt important events, such as family dinners, movies, classes, sporting events, and concerts, decreasing people's enjoyment of the experience. They are also a distraction to people while at work [27]. Cell phones can increase response time for emergency vehicles, because the cellular position is much more difficult to track than that of a landline [28]. Cell phones generally have higher prices, more expensive plans, and a shorter lifespan than landline phones [29]. They are also more likely to be lost or stolen due to their transportable nature. In addition, battery life is limited, and with more cell phones in existence, there will likely be fewer pay phones or landlines in public places in case of emergencies.

Part 3: Effects of Cell Phone Charger Negligence

Often, cell phones are left overnight to charge, and in the morning when they are unplugged the charger is left plugged into the wall, still drawing current. This practice wastes energy as cell phones only need to be charged for a portion of the night. In order to determine the maximum amount of wasted energy by cell phone users in the United States, both of these negligent practices were taken into account, as shown in Equation 7. W_t is the total amount of wasted energy generated by cell phones through overcharging (W_o) and failing to unplug the charger when not in use (W_u).

Eq. 7

$$W_t = W_v + W_u$$

In order to quantify this, it is necessary to create models for both types of waste. The general format for the equation for any type of waste from a charger can be written as seen in Equation 8. The waste (W) is based on the number of households (H), the average number of chargers per house (C), the average amount of power drawn during this time (P), and the hours per day of wasteful practice (h). There are also conversion factors for the waste due to power plants (W_p), and the conversion of watts to barrels of oil. The value of L is 1.1phones per person at the steady state.

Eq. 8

$$W = HCBW_pPhL$$

In order to use this equation to determine the amount of waste due to the over-charging of cell phones, the amount of time that the cell phone users wasted must be calculated using the difference in the time charged and the charging time needed as shown in Equation 9. The power also needs to be customized for this type of waste (P_v).

Eq. 9

$$W_v = HCBW_pP_v\left(h_{charging} - h_{needed}\right)L$$

The second form of waste can be modeled in a similar manner as shown in Equation 10, and will require the number of hours to be the number of hours that the charger is in the idle state (h_{idle}). The power consumption will also need to be specified (P_u).

Eq. 10

$$W_u = HCBW_pP_uh_{idle}L$$

This results in an overall model for the waste from cell phones in terms of barrels of oil, as shown in Equation 11.

Eq. 11

$$W_c = HCBW_p\left(P_uh_{idle} + P_v\left(h_{charging} - h_{needed}\right)\right)L$$

In order to calculate the total waste of cell phones, each of the following values had to be assigned. The appropriate value for each can be seen in Table 4.

Table 4: Cellular Charger Waste Components

Factor	Value
H	126,316,181 households in US [8]
C	2.37 Cell Phone Chargers/ household (one per person) [8]
B	1 barrel of oil /(1.6998x 10^6Wh) [30, 31]
W_p	3.0128 [9]
P_u	0.3 Watts [9, 17 ,18]
h_{idle}	16 hours
P_v	0.845 Watts [32]
$h_{charging}$	8 hours
h_{needed}	1 hour
L	1.1 (cell), 2.37 (landline)

As noted, many of these values were reported or were calculated from reported data. The only values that were approximated were the values for the time spent charging per day. It was noted that many times people leave their cell phones charging all night while they sleep. Assuming that this is always the case, all cell phones would be charged for approximately eight hours a night, as noted above. As assumed earlier, each cell phone will only require 1 hour of charging per day. If the charger is left plugged in, all of the remaining time, 16 hours a day, would also be wasted as the charger is in the idle state. Using these values and assumptions, all of the cell phones within a country the size of the United States would waste the equivalent of 6254 barrels of oil per days due to careless cell phone use.

Part 4: Effects of Battery Charger Negligence

Waste due to battery chargers applies to many types of electronics beyond cell phones. In order to measure overall waste due to battery chargers, many similar types of waste need to be taken into account. In this case, three types of chargers were considered. First, the cell phone charger, as previously discussed was analyzed. Additionally, the waste due to a cordless phone charger was analyzed, as well as the waste due to various other forms of chargers, such as those of laptops, and MP3 players. The overall waste for all types of chargers (W_T) was modeled as the sum of the wastes of the waste due to one type of phone charger and all other chargers; cell phone (W_c), cordless phone (W_l) and other types of chargers (W_o), as shown in Equations 12a and 12b.

Eq. 12

$$W_T = W_c + W_o$$

$$W_T = W_l + W_o$$

The waste due to the cell phones can be applied as calculated in Part 4. The waste due to cordless phone and other chargeable items are applied in similar manners, although only waste due to the charger being left idle should be accounted for, as seen in Equations 13 and 14. The values of power usage and hours left charging differ from those in the previous equations.

Eq. 13

$$W_l = HC_l BW_p P_l h_l L$$

Eq. 14

$$W_o = HC_o BW_p P_o h_o L$$

Therefore, the overall waste can be modeled, in terms of barrels of oil, as in Equation 15. The top equation corresponds to the waste in a cordless phone dominant state, while the second models waste in a cell phone dominant state.

Eq. 15

$$W_T = HC_l BW_p P_l h_l L + HC_o BW_p P_o h_o L$$

$$W_T = HCBW_p \left(P_u h_{idle} + P_v\left(h_{charging} - h_{needed}\right)\right) L + HC_o BW_p P_o h_o L$$

The numerical solution for this model at the current time can be determined by substituting the values found in Table 5.

Table 5: All Charger Waste Components

Factor	Value
H	126,316,181 households in US [8]
B	1 barrel of oil /1.6998x 10^6Wh [30,31]
W_p	3.0128 [9]
C_l	2.37 Cordless Chargers / Household [8]
P_l	1.7 Watts [16]
h_l	21 hours / day
C_o	3.318 Chargers per household
P_o	0.3 Watts
H_o	16 hours
C	2.37 Cell Phone Chargers/ household (one per person) [8]
P_u	0.3 Watts [9, 17 ,18]
H_{idle}	16 hours
P_v	0.845 Watts [32]
$H_{charging}$	8 hours
h_{needed}	1 hour
L	1.1 (cell), 2.37 (landlines)

The majority of the data seen in the above table is actual data from studies and reports. A few pieces of data were reasoned. For instance, the number of hours that a cordless phone would be idle was based on the assumption that the phone would be charging for 2 hours a day, and used for 1 hour a day. It would therefore be idle for 21 hours /day [2]. In addition, the amount of power drawn by all other adapters was assumed to be constant and to be approximately the same as that of the average cell phone charger (0.3W) [9, 17, 18]. The number of chargers per household was based on the product of the average number of people in the household and an approximation for the number of chargers that would be present and used within the house on a normal basis. This data resulted in an average waste of about 48,600 barrels of oil per day for all chargers within a cordless phone dominated U.S., compared to 9,956 barrels of oil in a cell phone dominated U.S.. This data is shown in Table 6 below.

Table 6: All Charger Total Waste

Charger Type	Barrel of Oil/day
Cell Phone	6,254
Cordless Phone	44,895
Other	3,702
Total (Cell Phone State)	9,956
Total (Cordless State)	48,600

Part 5: Effects of Economic and Population Growth

Based on the assumption that all m members of H households within the Pseudo U.S. owns a phone, the changes in economic status will not affect the total energy used by phones. In order to determine the energy usage projected over the next fifty years, a model was developed for the population of the Pseudo United States, which is assumed to equal the population of the actual United States. Based on data from the U.S. Census Bureau[33, 34, 35, 36, 37, 38 ,39, 40], Microsoft Excel was used to create a regression describing population, $T_{Population,}$ as a function of time, X_{Year}, as seen in Figure 7 and Equation 16:

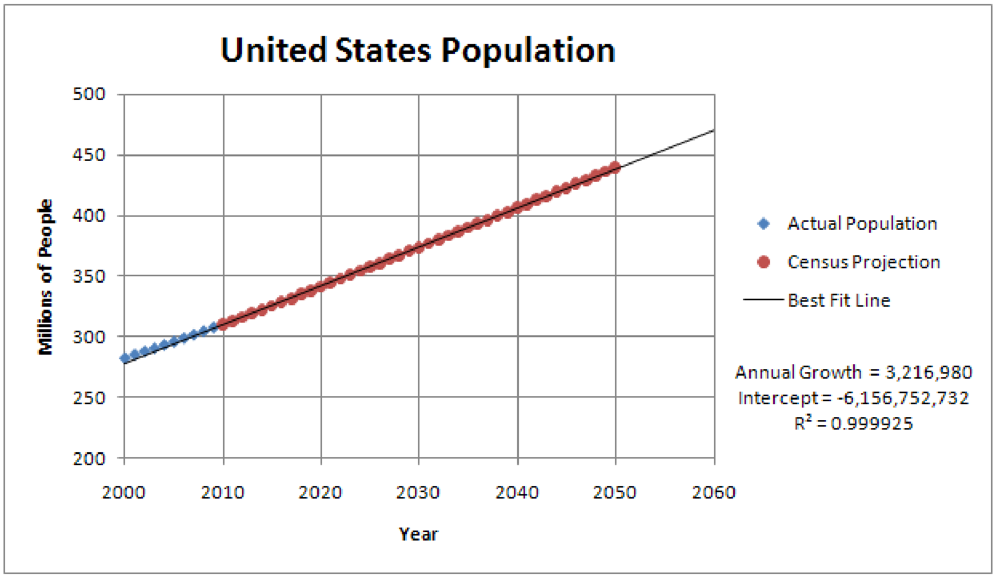

Figure 6: Accurate Telephone Power Forecast for Saturated Market

Eq. 16

$$T_{Population} = 3216980X_{Year} - 6156752732$$

With an R^2 coefficient of .9999, this model accurately matches the U.S. Census Bureau's predictions for population growth into the future. This model of population growth can be used in conjunction with the energy equations developed in Part 1 to determine the total energy used by the Pseudo U.S. at any given time X_{Year}. In order to find the total energy used over each 10 year period, we can integrate the population function from $X_{Year\ n}$ to $X_{Year\ (n+10)}$ and multiply by the energy equations, denoted as E_{Phone}, as seen in Equation 17.

Eq. 17

$$E_{Used} = 365(E_{Phone} \int_{X_{Year\ n}}^{X_{Year\ (n+10)}} T_{Population}\, dX_{Year})$$

Under the optimal scenario where cell phones with 5-star chargers saturate the market, the energy used for phone service each decade is listed in Table 7

Table 7: Total Phone Energy per Decade

Decade	Barrels of Oil
10s	84,038,439
20s	92,237,469
30s	100,562,475
40s	109,025,120
50s	117,424,011

The total number of barrels of oil that must be provided to power plants over the next 50 years for this scenario is then 503,287,514.

Analysis of the Model

Verification

In order to truly verify this model, one would have to obtain data for the next ten years, and compare the actual results to the predicted. Historical data cannot be used to verify this model, because data regarding the consumption of energy due to phone usage is not readily available. It was possible to verify the competition model for the data graphically. Most of the statistics used could be verified through additional research.

Strengths

- **Simplicity** – This model is simple enough that it entails a small amount of mathematical skill to operate. In addition, it is easily converted into an electronic form, such as Microsoft Excel or MATLAB, and can therefore be visually displayed so that nearly no mathematical knowledge is necessary to understand the model.
- **Developed from historical data –** Population trends and the competition model were based off of real data from the US Census Bureau and the CTIA Wireless Association.
- **Extendable** – In order to include additional factors, the model could be extended with additional terms with little impact on the functionality in the energy equations.
- **Flexibility –** The equations used in this problem could be applied to other competing products which use energy, if an appropriate competition model can be created.
- **Closed form solution-** With the appropriate data, this model will generate numerical and graphical solutions.
- **Calculation time-** Due to the simplicity of the calculations, this model can be solved in a relatively short amount of time.
- **Includes Variations** – This model accounts for cell, corded, and cordless phone usage, as well as a combination of the three. This allows for a more complete analysis.
- **Considers Outside Factors –** This study considers the implications of mobility and convenience for a realistic approach to energy efficiency.
- **Energy Production Costs-** The costs from this model took into account the inefficiencies of power generation by looking at total energy produced instead of looking at total energy consumed. This signifies that the number of barrels of oil would be the actual number of barrels that would need to be burned in order to power these phones.

Weaknesses

- **Forecasting -** does not account for any changes in technology over the time period.
- **Infrastructure Costs -** The initial infrastructure cost was assumed to defray to zero over time in order to decrease the number of inputs needed for the model. In reality these costs could potentially have an effect, especially in the short term.
- **Infrastructure Maintenance Costs –** The infrastructure maintenance and operations costs were not accounted for due to lack of data. For a more robust model, another term could be added to the energy equation to account for this energy consumption. Examples include the power used by each cell phone tower, approximately 1kW-10kW, and the average power used to repair telephone lines damaged by storms.

- **Assumptions –** Due to lack of data availability, several simplifying assumptions had to be made in order to create a solvable model. In addition, some values used in the calculations had to be estimated.
- **Inputs –** This model requires a large amount of data, some of which is difficult to obtain.

Conclusion

The compilation of these factors suggests that landlines are the most energy-feasible option only when all phones are corded phones running power straight off of the phone line. Otherwise, the most efficient means of providing telecommunication is through cell phones. This is based on:

- The steady state of the country with existing infrastructure would be between 36 and 42 gigawatt hours per day of energy.
- With no established infrastructure, it would be more energy beneficial to have corded phones running off of phone lines (3.2 gigawatt hours / day), but other factors, such as the preference for cordless technology, suggests that a cell phone infrastructure may be a safer investment.
- Cell phone and other charger negligence would cause a maximum of 9,956 kWh per day to be wasted. Cell phone charger negligence would cause a maximum of 6,254 kWh per day to be wasted, while cordless phone negligence would result in a waste of 44,895 kWh per day.
- The analysis of the telecommunications industry for the future shows that cell phones will be the most viable option, as they will only require 503,287,514 barrels of oil for the next fifty years.

Due to the social benefits of cell phones, as well as their energy efficiency relative to cordless phones, a cell phone dominant state should be accepted in the current infrastructure. Despite the fact that cell phones are less efficient than corded landline phones, they are more accepted by the general public.

Glossary

Chargers – Devices used to help batteries regain their power supply. These include, but are not limited to those used for cell phones, laptop computers, rechargeable batteries, cordless phones, and MP3 players.

Corded Phone – A phone that only uses a small amount of power from the phone line to function, but is not mobile and is hindered by the length of the cord.

Cordless Phone - A phone that has a dock that is connected to a landline. It can only be used over a small distance and has no cord and therefore must rely on a battery to run.

Household- As described by the US government census report, “a household includes all the persons who occupy a housing unit. A housing unit is a house, an apartment, a mobile home, a group of rooms, or a single room that is occupied (or if vacant, is intended for occupancy) as separate living quarters. Separate living quarters are those in which the occupants live and eat separately from any other persons in the building and which have direct access from the outside of the building or through a common hall. The occupants may be a single family, one person living alone, two or more families living together, or any other group of related or unrelated persons who share living arrangements” [41].

Idle State (charger) – encompasses the time when a charger is plugged in but has no electronic device connected to it. While in this state, it will be using power, but will not be performing any desired function.

Landline – A physical phone line that runs into a house to provide service.

Steady State –The state at which cell phone usage and landline usage is in equilibrium. In these cases, this is expected to occur at the extremes where there are only cell phones or only landline phones.

Transition period – The amount of time during which both cell phones and landline based phones will be in use. During this time, it is possible that some people may have both. The Competing Species Model used here predicts a transition period from 1995 to 2025.

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Appendix

Year	Population	Cell Phones	Model cells per 100 pop	Landlines	Model landlines per 100 pop
1980	226,542,250			102,216,367	
1981	229,465,744			105,559,222	
1982	231,664,432			107,519,214	
1983	233,792,014			110,612,689	
1984	235,824,908			112,550,739	
1985	237,923,734	204,000		115,985,813	
1986	240,132,831	500,000		118,289,121	
1987	242,288,936	884,000		122,789,249	
1988	244,499,004	1,609,000		127,086,765	
1989	246,819,222	2,692,000		131,504,568	
1990	248,765,170	4,369,000		136,114,201	
1991	252,153,092	6,390,000		139,412,884	
1992	255,029,699	8,893,000		143,341,581	
1993	257,782,608	13,067,000		148,106,159	
1994	260,327,021	19,284,000		153,446,946	
1995	262,803,276	28,154,000	11.00	159,658,662	60.00
1996	265,228,572	38,195,000	14.12	166,445,580	63.04
1997	267,783,607	48,706,000	17.93	173,866,799	65.30
1998	270,248,003	60,831,000	22.47	179,849,045	66.68
1999	272,690,813	76,285,000	27.76	185,002,911	67.13
2000	282,171,936	97,036,000	33.74	188,499,586	66.64
2001	285,039,803	118,398,000	40.29	185,587,160	65.25
2002	287,726,647	134,561,000	47.24	180,095,333	63.06
2003	290,210,914	148,066,000	54.35	173,140,710	60.20
2004	292,892,127	169,467,000	61.36	165,979,938	56.83
2005	295,560,549	194,479,000	68.04	157,037,503	53.13
2006	298,362,973	219,652,000	74.21	146,848,926	49.27
2007	301,290,332	243,428,000	79.73		45.40
2008	304,059,724		84.56		41.63
2009	307,146,362		88.70		38.03
2010	310,233,000		92.18		34.68
2011	313,232,000		95.08		31.58
2012	316,266,000		97.47		28.74
2013	319,330,000		99.43		26.17
2014	322,423,000		101.03		23.85
2015	325,540,000		102.34		21.75
2016	328,678,000		103.41		19.86
2017	331,833,000		104.29		18.16
2018	335,005,000		105.02		16.63
2019	338,190,000		105.63		15.25
2020	341,387,000		106.14		14.00
2021	344,592,000		106.56		12.88
2022	347,803,000		106.93		11.85
2023	351,018,000		107.24		10.93
2024	354,235,000		107.51		10.08
2025	357,452,000		107.74		9.31
2026	360,667,000		107.95		8.61
2027	363,880,000		108.13		7.97
2028	367,090,000		108.28		7.38
2029	370,298,000		108.43		6.85
2030	373,504,000		108.55		6.35
2031	376,708,000		108.67		5.90
2032	379,912,000		108.77		5.48
2033	383,117,000		108.87		5.09
2034	386,323,000		108.95		4.74
2035	389,531,000		109.03		4.41

2036	392,743,000				
2037	395,961,000				
2038	399,184,000				
2039	402,415,000				
2040	405,655,000				
2041	408,906,000				
2042	412,170,000				
2043	415,448,000				
2044	418,743,000				
2045	422,059,000				
2046	425,395,000				
2047	428,756,000				
2048	432,143,000				
2049	435,560,000				
2050	439,010,000				
2051	441,273,248				
2052	444,490,228				
2053	447,707,208				
2054	450,924,188				
2055	454,141,168				
2056	457,358,148				
2057	460,575,128				
2058	463,792,108				
2059	467,009,088				
2060	470,226,068				

Population data 1980-2008, 2010-2050 [33, 34, 35, 36, 37, 38, 39, 40]

Population data 2009 and 2051-2060 found by linear regression

Cell phone data 1985-2007 and landline data 1980-2006 [42, 43, 44]

Cell phones and landlines per 100 population found by competition model