DESIGNING A REAL-TIME STRATEGY GAME ABOUT SUSTAINABLE ENERGY USE

A Thesis

by

LARS ANDREAS DOUCET

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2010

Major Subject: Visualization Sciences

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Approved by:

Chair of Committee,	Vinod Srinivasan
Committee Members,	Philip Galanter
	Scott Slough
Head of Department,	Tim McLaughlin

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ABSTRACT

Designing a Real-Time Strategy Game
about Sustainable Energy Use. (May 2010)
Lars Andreas Doucet, B.E.D., Texas A&M University
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This thesis documents the development of a video game about sustainable energy use that unites fun with learning. Many other educational games do not properly translate knowledge, facts, and lessons into the language of games: mechanics, rules, rewards, and feedback. This approach differs by using game mechanics in new ways to express lessons about energy sustainability.

This design is based on the real time strategy (RTS) genre. Players of these types of games must manage economic problems such as extracting, refining, and allocating resources, as well as industrial problems such as producing buildings and military units. These games often use imaginative fantasy elements to connect with their audience, including made-up economic numbers and fictional resources such as magic crystals which have little to do with the real world. This thesis' approach retains the fantasy elements and gameplay conventions of this popular genre, but uses numbers, resources, and situations based on research about real-world energy production. The intended result is a game in which the player learns about energy use simply by trying to overcome the game's challenges.

In addition, a combined quantitative/qualitative study was performed, which shows that players of the game learned new things, enjoyed the game, and became more interested in the topic of energy use.

To my precious wife, Emily, who enchants and enlightens me every day and forever

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CHAPTER I

INTRODUCTION

A. Fun and Games

All games are learning machines. They give us a mental obstacle course with opportunities for success or failure at every turn. With each failure comes an urging to try again, and in so doing we eventually learn how to succeed. With each success comes a sense of triumph, which motivates us to accomplish the next challenge, and the cycle continues until mastery is achieved and the game is won. Writer and game designer Raph Koster notes that the joy that we receive from games - what we casually call "fun"- is essentially tied to the reward system the brain uses to learn. "Fun from games arises out of mastery. It arises out of comprehension. It is the act of solving puzzles that makes games fun. In other words, with games, learning is the drug" [1]. He goes on to say that fun is quite often the very evidence of learning:

> That's what games are, in the end. Teachers. Fun is just another word for learning. One wonders, then, why learning is so damn boring to so many people. It's almost certainly because the method of transmission is wrong. We praise good teachers by saying that they "make learning fun" [1].

The game becomes a formal system of challenges to stretch the brain, coupled with rewards to encourage the player to seek out the next learning high. In this sense, all games are educational - at the bare minimum, a game must teach the player how to play that game. Traditional games whose only goal is fun are content to merely teach the player how to solve virtual problems with little to no bearing on real life. What many game designers do not realize is that they hold a powerful learning tool in their hands, which they use to induce the experience we call "fun" in the player's brain. This tool cuts both ways, however

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The journal model is *IEEE Transactions on Automatic Control.*

- games can just as easily use the brain's exploratory reward system to induce learning and critical thinking.

B. Serious Lessons

Games have been used as vehicles for understanding since the beginning of human civilization [2], but the recent advent of electronic multimedia has led to the rise of explicitly educational video games. The one most people have contact with is "edutainment," the fusion of "entertainment" and "education."

Often, edutainment titles take the form of a multimedia program that sprinkles facts and/or quizzes in between each level of a simple game. I.Q. Interactive's *Lose Your Excuse!* [3] is a good example of this kind of edutainment title (see Chapter II, section C for full discussion of this game). This approach is largely ineffective as the game mechanics have nothing to do with the learning material. A slightly more effective approach is to attach a standard arcade game mechanic to a simple learning goal, as is demonstrated in Davidson & Associates *Math Blaster Episode I: In Search of Spot* [4]. In this game, the player pilots a spaceship and must complete an equation such as $(7 + 2 = ?)$, by firing upon an object displaying the correct number (see Figure 1). Since entertainment is an equal goal to education, the game has plenty of extra features that have nothing to do with math, such as enemy ships to fight against, and bonus levels full of asteroids to blast. There are other approaches to edutainment, but most of them fit this general pattern of haphazardly mixing learning content with gameplay.

There are many drawbacks to edutainment. Dr. Mitchel Resnick of the MIT Media Laboratory dislikes its condescending carrot-and-stick approach to learning:

> So why don't I like edutainment? The problem is with the way that creators of today's edutainment products tend to think about learning and education. Too often, they view education as a bitter medicine that needs the sugar-coating of entertainment to become palatable. They provide entertainment as a reward if you are willing to suffer through a little education [5].

Fig. 1. Math Blaster Episode I: In Search of Spot (SNES)

The other downside to edutainment is that by giving equal weight to both entertainment and education, there is a risk that the educational content is watered down, or otherwise suffers as too many concessions are given to the entertainment side of things. Educators and game designers in the "serious games" movement seek to move past these limitations, often by dropping entertainment as a goal completely. Clark Abt is widely considered the seminal writer on the topic, author of the ground-breaking book *Serious Games* in 1977. Abt describes his purpose thusly:

> We are concerned with serious games in the sense that these games have an explicit and carefully thought-out educational purpose and are not intended to be played primarily for amusement[2].

Abt was speaking of card and board games, but video games have become the prevailing format since then. Abt was deeply involved with military simulations and war games during the height of the cold war, and was interested in how games could be used to investigate complicated subjects, including those outside the military sphere. His approach uses the game medium as a rule-based system used to model, explore, or otherwise understand real-world phenomena, with little concern for entertaining its players.

There is quite a bit of overlap between edutainment and serious games, but there are

general trends that separate them. Edutainment titles often focus on simple learning concepts and are targeted towards children, while serious games deal with more complex subject matter and are targeted towards adults, often in a university setting. The Minnesota Educational Computing Consortium (MECC)'s game *Odell Lake* [6] is a good example of a serious game. This game seeks to model the predator/prey relationships between the different organisms inhabiting the real-world Odell Lake in the state of Oregon (see Chapter 2, section A for full discussion of this game). *Odell Lake* could also be considered an example of edutainment since many people (including children) have found it entertaining, but since its primary goal is education and it does not add any extra features purely for entertainment's sake (as Math Blaster does), it better fits the mold of a serious game.

1. "Fun/Learning" Preferred to "Entertainment/Education"

Discussions of edutainment and serious games often use the terms "entertainment" and "education." As commonly understood, entertainment carries the subtext of "meaningless diversion" and education that of "formal instruction." Dr. Resnick notes how the uncritical use of these terms directly affects the quality of the work:

> When people think about "education" and "entertainment," they tend to think of them as services that someone else provides for you. Studios, directors, and actors provide you with entertainment; schools and teachers provide you with education. New edutainment companies try to provide you with both. In all of these cases, you are viewed as a passive recipient. That's a distorted view. In fact, you are likely to learn the most, and enjoy the most, if you are engaged as an active participant, not a passive recipient.
>
> So I prefer to focus on "play" and "learning" (things that you do) rather than "entertainment" and "education" (things that others provide for you). My preference is for "playful learning" rather than "edutainment." It might seem like a small change, but the words we use can make a big difference in how we think and what we do[5].

With this understanding, it is easy to see why edutainment titles are often condescending and simplistic. On the other hand, Koster's insight into how fun and learning are linked

has profound implications for serious game designers. Those that try to eliminate "entertainment" as a design goal risk undermining their game's own learning potential should they also eliminate *fun*. A boring game is ineffective no matter how much it has to teach, simply because nobody wants to play it.

This thesis therefore prefers the dialectic of (fun/learning) to (entertainment/education). This is not mere semantic quibbling - as Dr. Resnick has said, the words we use shape the way we think, and the false dichotomy of "entertainment" and "education" has greatly undermined the success of this field. Regardless of whether education and entertainment can work together or not, fun and learning are closely intertwined, as Koster has shown. For a serious game designer, teaching the player interesting and valuable things through gameplay can and should work hand-in-hand with making that gameplay as much fun as possible. A serious game designer is not practicing a wholly different discipline than a traditional game designer (defined here as one whose only goal is "fun"), because a serious game cannot be successful in teaching lessons and skills to the player unless it builds that on a solid foundation of fun.

It is essential also to understand the difference between entertainment and fun. Entertainment seeks merely to capture and keep attention, whereas fun (at least for the purposes of this thesis) is the brain's reward for successfully understanding something new. Many games in this field waste precious resources on elaborate cut-scenes, overly detailed graphics, complex narratives, and many other non-game features in service to entertainment. Properly used, these can seek to direct the player's attention, provide extra feedback, set the context for the game, and do many other useful things. Improperly used, they suck up development time and resources and bore or distract the player. Ultimately, they have little to do with both learning and fun, are extraneous to the central game design itself, and should therefore be considered secondary features. If the goal is entertainment, a flashy multimedia experience with occasional user input will do. But if the goal is fun and learning, what

is needed is a compelling and inherently *fun* system of rules, feedback, and interaction that drives the player forward to explore, overcome, and learn. Multimedia polish can always be added later, so long as the designer remembers to first and foremost "find the fun[1]."

2. "Applied Gaming" Preferred to "Serious Games"

In this regard, the term "serious" in "serious games" is problematic, as "serious" carries with it connotations that imply "boring," the opposite of fun. Dr. Vinod Srinivasan of Texas A&M University's Visualization Laboratory has introduced the term "applied gaming" to refer to the use of game design or game-related technology (such as a game engine), towards any end (educational, serious, or otherwise) other than a game simply for its own sake. Applied gaming thus encompasses a wide spectrum of pursuits. Its definition covers everything from an interactive 3D walk-through of ancient Rome made with the Unreal Engine, to a training tool for surgeons, to a game about horse breeding, and much more. This mimics the term "applied science." In this sense, traditional game design could be thought of as "pure game design," mimicking "pure science," where the focus is on the design of games where fun is the only end. "Applied" and "pure" game design thus become descriptive companion terms that cast no judgment on one another. "Applied gaming" equally carries the message of "serious games" - to use games as a means to some other end - without the implied scorn for "fun" and the narrow field of topics that comes with the loaded term "serious."

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[1] Aphorism attributed to Nintendo's legendary game designer Shigeru Miyamoto, the creator of Mario

C. Purpose

This thesis documents the development of a real-time strategy (RTS) video game entitled *Super Energy Apocalypse* (*SEA*) that teaches players about sustainable energy use and the intricacies of an energy economy. The game approximates real-world data from the American energy economy, with a specific focus on Texas when national data is unavailable or incomplete. This data was used to create a model for the game's economy (see Appendices D & E for more detail on how real-world data was translated into game numbers). Two versions of the game were produced - one simply titled *Super Energy Apocalypse* (versions 1.0-1.2), and a later, improved follow-up entitled *Super Energy Apocalypse : RECYCLED* (version 1.7). For the purposes of this thesis *Super Energy Apocalypse* or the acronym *SEA* shall refer to the game in general. Versions 1.0-1.2 shall be collectively referred to as the "alpha version" or *SEA1*, and version 1.7 shall be referred to as the "final version", or *SEAR*.

D. Significance

The goal of this game is to help players understand the basics of energy use and the relationship between transportation, fuel, natural resources, power plants, the economy, and pollution. None of these issues can be taken in isolation, and they can only truly be understood as a systemic whole. For instance, ethanol-based fuel is often promoted as being better for the environment than gasoline because it has lower emissions at the tailpipe. However, the entire process for producing ethanol – growing, processing, shipping, distilling-results in a negative energy balance, higher overall emissions, and even consumes fossil fuels [7]. This is the sort of lesson that could be effectively demonstrated through interactive game play.

A second goal of this thesis is to serve as a model for translating real-world topics into game mechanics. The significance to applied game designers is obvious, but the benefit

to pure game design should not be overlooked – the real world is ripe with problems and situations that could easily inspire game mechanics that are interesting for their own sake. Often the question of "game balance" is already present in real-world trade-offs and dilemmas that have no perfect solution. This could provide new creative fuel for traditional, "pure" game designers.

CHAPTER II

BACKGROUND AND RELATED WORK

There are countless other titles that touch on similar themes as this thesis both in and out of the educational sphere. Specifically, other games about energy and pollution have started to appear, especially in the last year. For the sake of brevity a representative sample of games that address education, persuasion, and explicit environmental lessons were chosen. The sample selected herein spans the decades from the birth of video games to modern day.

A. Simulation Games

A common approach to designing games with an intent to teach is to build a game around an interactive simulation that models a real-world system. The idea is that the player will learn about the real-world system by playing with the simulated version.

1. Odell Lake

Odell lake is a simple game released for the Commodore 64 and Apple IIgs in 1986[6]. The game casts the player in the role of one of 6 different types of fish that inhabit the real-world Odell lake in Klamath County, Oregon. The game is a turn-based affair that lets the player encounter other species in the lake, to which the player must respond with an action. The player can respond in several ways: trying to eat the other creature, ignore it, chase it away, escape into the deep, or escape towards the surface. What happens next depends on the relationship between the player's fish and the encountered creature. For instance, if the player attempts to eat the encountered creature and it is in fact the player's prey, points are awarded, but if the encountered animal is the player's predator, the player dies and the game is over. There are a few nuances to the gameplay - for instance, a player receives more

points for ignoring a low-preference food than eating it (in order to leave it as sustenance for animals that fish does like to eat), and eating certain small fish is risky since they might actually be fisherman's bait. In the end, though, the game boils down to learning by trial-and-error and memorizing the relationships between the different organisms. As simple as it is, this game does effectively teach the complex way each of these species is related to one another by letting the player play through scenarios and discover for themselves the optimal survival strategy for each fish. For instance, a Chub is at the bottom of the food chain, eating only insects and algae, and must run away from large fish, whereas a Mackinaw Trout eats nearly everything it comes across, and only fears Otters and Osprey. The game encourages the player to try out each kind of fish, which reinforces the learning of their relationships to one another, since the player gets to see what it looks like both as the predator and as the prey. This encounter-based system is actually quite similar to that used in *Pokémon* [8], and the ideal maneuver chart for *Odell Lake* bears a striking resemblance in structure to the ideal attack chart for various types of *Pokémon* creatures (see Figures 2 & 3). *Odell Lake* demonstrates how a simple simulation of a concept can be turned into a game that presents complex information about a real world system in an accessible way, just as *Pokémon* gets children to enjoy memorizing an endless serious of facts and statistics about fictional pet monsters simply by playing the game.

2. SimCity

Whereas *Odell Lake* is a good general example of teaching a system through simulation, there are other simulation games that also touch specifically on energy use, making them particularly relevant to this thesis. An early example is *SimCity*, in which the player builds a simulated city and tries to keep its people happy and productive [9]. The city needs power, and the game provides the choice of coal or nuclear power plants. The city also needs transportation, which can come in the form of either roads or railways. Each of

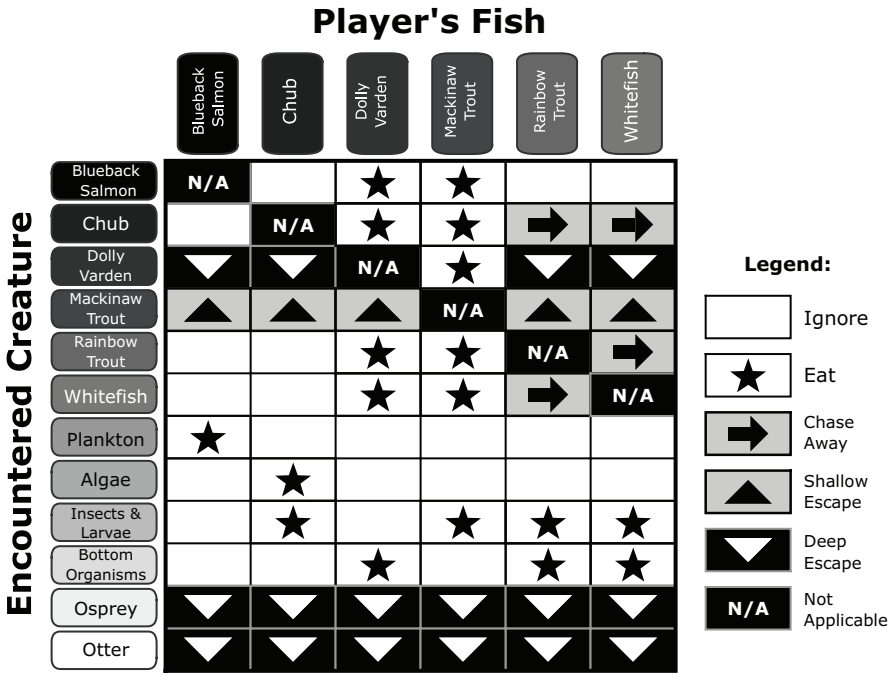

Fig. 2. Odell Lake (above) Ideal Encounter Chart (below)

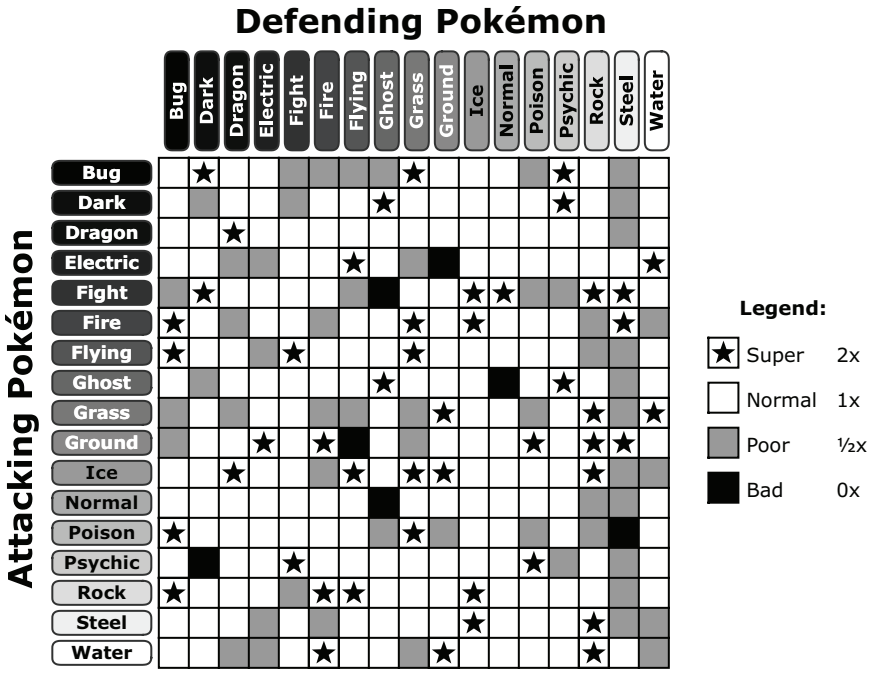

Fig. 3. Pokémon Fire Red (above) Attack Effectiveness Chart (below)

these choices comes with a trade-off, usually in the form of "cheap but dirty" for coal plants/roads and "clean but expensive" for nuclear plants/railways, respectively. Nuclear plants have a small chance of melting down and releasing deadly radiation, but this only occurs if the player overloads the plant by having it serve too large a population, which is easily avoided. Also, the player is required to build industrial zones if he wants his city to thrive, which produce a fixed amount of pollution. There are only a few ways to deal with this-a common approach is to build them on the edge of the map where half the pollution leaves the game's system and is not counted . The only other solution (besides simply not building polluting facilities) is to build parks, whose greenery helps to reduce the smog by a small amount. Citizens complain and leave town if pollution is too high, so players have to strategically spread out their pollution sources and hope for the best. *SimCity* provides a very simple pollution simulation, but does well by creating a dilemma for the player – pollution is a necessary side-effect of growth, and cannot be overcome trivially. This forces the player to take pollution seriously, and limits the city's growth.

3. SimCity 2000

The sequel, *SimCity 2000*, goes much further by adding a plethora of new power sources, including coal, hydroelectric, oil, gas, nuclear, wind, solar, as well as hypothetical future sources, such as microwave and fusion [10]. These are all modeled in much greater detail than SimCity, with relative costs and outputs corresponding to their real-world counterparts. Also, certain "gotchas" are included with each power source; wind power depends on altitude, and microwave plants (a station that receives microwave radiation from an orbital satellite with solar collectors) have a small chance of becoming "un-synched," turning their satellite into a death ray which burns up areas of the city. Fusion power is not available until the player's city reaches the year 2050, and although expensive, solves the energy problem once and for all with no emissions or adverse effects. *SimCity 2000* provides a much more

in-depth energy model but ultimately undermines a message of conservation by promising that magic future technology will do away with the current lackluster trade-offs. By not requiring the player to balance modern energy choices, the player is free to simply wait for the future to happen, bringing with it the promise of clean, limitless energy.

Both games are completely unstructured in the normal play mode; the player simply builds a city and sees what happens. Supplementing this is a mainstay of the series: pre-built scenarios, which require the player to work under certain conditions and achieve specific goals with cities that have already been developed and already have problems, such as dealing with high crime in Detroit, or flooding in Rio de Janeiro. The series has always eschewed a traditional level structure, favoring a more open-ended approach to game play.

In general, the series does well in teaching basic lessons about energy use, but these issues are a side dish to the main gameplay of building and maintaining a city. The series' approach to teaching is similar to the one used in *SEA*: produce a simulation and let the user play with it. The difference is that where SimCity's approach is broad, *SEA*'s is more tightly focused, and includes a specific campaign mode that will lead the player through pre-planned levels meant to focus the player's attention on certain subjects.

B. Rhetorical Games

Another recent phenomenon in game studies is the rise of "procedural rhetoric." This term was coined by Ian Bogost, author of *Persuasive Games* [11], and co-founder of the similarly named game development studio Persuasive Games LLC. In an article entitled "The Proceduralist Style," he explains:

> I have given the name "procedural rhetoric" to an argument made by means of a computer model. A procedural rhetoric makes a claim about how something works by modeling its processes in the process-native environment of the computer rather than using description (writing) or depiction (images) [12].

In this new mode of argument, the designer does not simply create an interactive simulation for the player, but also specifically infuses it with gameplay rules that form a compelling argument. A few examples of this method are presented below.

1. September 12th

The first is *September 12th*, an online Flash game meant to argue against American-style military intervention as a response to terrorism [13]. In this game, the player is presented with a small Middle Eastern town with many civilians and a few terrorists roaming around (see Figure 4). The player is given a cross-hairs and has the simple choice to shoot, or not. In similar point-and-click "assassin" games on the internet, the player is immediately rewarded with a precise, instantaneous shot to the exact spot she clicked on, allowing players to surgically eliminate "bad guys" with precise head shots without risking harm to "good guys." *September 12th* is markedly different, however, and may even assume that the player expects a precise shot. In this game, when the player clicks on a spot, a short delay counter begins, after which a cruise missile flies on screen and explodes-destroying buildings and killing all nearby people, good or bad. In this system, it is nearly impossible to kill terrorists without leaving collateral damage. In the very rare case that the player should actually manage to kill a terrorist and no one else, the civilians do not mourn his passing, and even ignore the damage done to buildings demolished by the blast. But when the player inevitably kills a civilian, everyone nearby begins to weep, at which point they raise their fists, flicker, and become terrorists themselves. The game's rhetoric thus implies that civilians do not have any sympathy for terrorists, only their fellow civilians, but that when military intervention inevitably destroys their lives, they become terrorists themselves. This game argues that "surgical strikes" are a myth–*September 12th* is a game that cannot be won. The game's argument has been made countless times before but is quite powerful when demonstrated procedurally.

Fig. 4. September 12th

2. Debt Ski

The second is *Debt Ski*, developed by Persuasive Games [14]. Here, the player controls a piggy bank riding a jet ski that first travels through obstacle courses collecting and spending money, and then must pay off debt in between levels. The piggy bank constantly moves forward but can slow down, speed up, or jump to control whether he runs into cash (collecting income) or into merchandise (increasing "happiness," but spending money). This rhetoric of gameplay implies that spending is not entirely under our conscious control, that our impulses and instincts have the better of us, but that through striving and self-control we can adjust this. When the piggy bank reaches the end of a level, his income is compared to his spending, and if it is negative, he accrues debt. If it is positive, he can do several

things with it. First, he can pay off debt from previous levels. If he doesn't pay the minimum amount, the interest rate on this debt increases, leading to even more debt at the end of the next level. Secondly, he can upgrade his jet ski, either by purchasing decals and new paint jobs (a "cosmetic" purchase with no in-game effect), or by upgrading its engines (giving it more jumping power) or its brakes (allowing him to slow down better). This choice demonstrates the difference between practical purchases and frivolous purchases; investing in the jet ski's systems increases the player's ability to collect income and avoid spending, as well as increasing "happiness." In contrast, investing in cosmetic upgrades provides "happiness," but nothing else. Lastly, the player can save any leftover money, which will collect interest and can be used to pay off future debt or upgrade the jet ski. The game ultimately rewards the player with a high score for maximizing both happiness and positive savings at the end of the game. This game not only teaches the player the absolute basics of money management but also demonstrates through its gameplay a procedural argument for why debt seems to just accrue and "happen," by showing the player the relationship between uncontrollable circumstance (the jet ski starts out hard to control), making wise decisions (going after more income than merchandise, saving money and paying off debt between levels), and investing in ways that increase your ability to earn, save, and avoid debt (upgrading the jet ski).

C. Energy Games

Finally, there are games specifically designed to inform the player about energy use and sustainability. Though more are being released every day, five are described herein: *Lose Your Excuse!*, designed for the US Department of Energy, *Kampen om Energien*, produced for a Danish Natural Gas association, *EnergyVille*, commissioned by Chevron, *Oil God*, produced for Shockwave.com, and *Climate Challenge*, produced for the BBC.

1. Kampen om Energien

Kampen om Energien is the closest game to *SEA* in terms of design and structure. It is an online browser-based game (made for Macromedia's Shockwave player) with nice production values – its graphics look quite similar to the original *Age of Empires* in both style and quality (see Figure 5). This real-time strategy game purports to take the player through the development of an entire civilization, researching new energy types and power sources [15]. Despite its incredible promise and great presentation, it has two key flaws. First, it is only available in Danish, which means that although this author can play and understand it, most people cannot. Secondly, it seems to be incomplete, as it features a fatal interface flaw; the player is instructed to right-click on the map in order to move a unit such as a worker, but right-clicking merely brings up the Shockwave context menu, which keeps the player from accomplishing most of the missions. This author was unable to even finish the tutorial levels, leaving the game's potential untapped.

Fig. 5. Kampen om Energien

2. Lose Your Excuse!

Lose Your Excuse! is a simple game that tries to teach children basic tips on how they can save energy at home [3]. In this game, the player controls a character called "Watts" whose goal is to save energy from "excuses." It takes the form of a two-dimensional platform-jumping game, where Watts must collect "energy" and then make his way to an exit while avoiding monsters ("excuses") who occasionally say short phrases like, "Programming my thermostat's a drag," and "CFL[1] bulbs look so weird" (see Figure 6).

The first and foremost critique is that the player's main tasks (moving, jumping, avoiding obstacles) have nothing whatsoever to do with saving energy. Educational "facts" are presented between stages, such as: "DID YOU KNOW? To save energy, you can shut off electronic devices when not in use." The player is thinking almost entirely in terms of solving a geometric problem (avoiding obstacles, traversing space), while the learning content is just thematic dressing. This is a dangerous approach, because video game players have been trained to ignore these themes, as Koster explains: "Games, by the very nature of what they teach, push toward this sort of understanding. Since they are about teaching underlying patterns, they train their players to ignore the fiction that wraps the patterns" [1]. For a game to be a useful vehicle for learning material, the lessons themselves must be the game's underlying patterns, not its superficial flavoring. This phenomenon leads to frustration, even if the game itself is fun; the player just wants to play the game, but the game keeps distracting him with superfluous "facts" and "lessons." The player would actually enjoy learning from the game if the gameplay itself would provide the lesson.

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[1] Compact Fluorescent Light bulbs, which use less energy than incandescents.

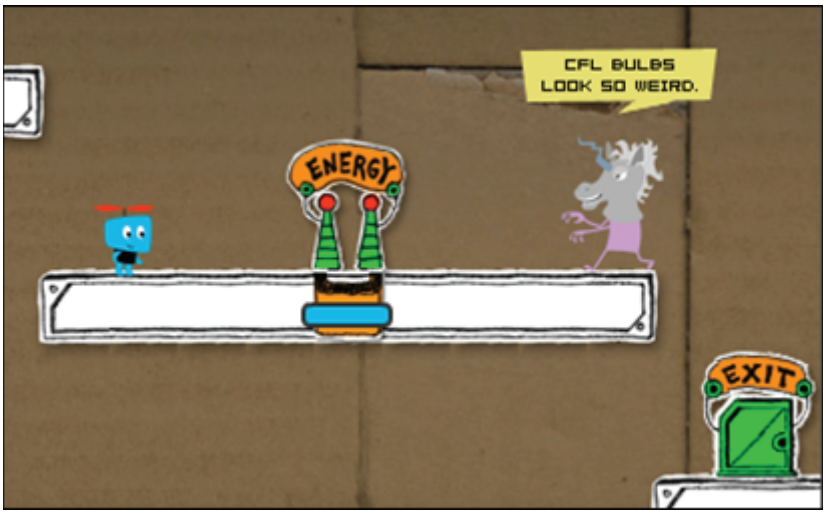

Fig. 6. Lose Your Excuse!

3. EnergyVille

In the next game, *EnergyVille*, the player is in charge of a city and must make choices about energy that will affect how the city grows[16]. The player can select from a wide range of options (coal, gas, petroleum, wind, solar, nuclear, hydro, hydrogen, biomass, etc.), which she can drag and drop into the city to power it (see Figure 7). The player cannot interact with the city in any other way – adding or removing power plants is the only legal action. No in-game currency or resources are tracked. Instead, each power plant choice affects various "impact" meters, broken down into economic, environmental, and security. For instance, nuclear power plants have high economic and security impact, but low environmental impact, while coal plants have high environmental impact but low economic and security impact. After powering the city, the player can advance to the next era and see the results of her choices and how well the city handles certain random events. There is an interesting and deep system being modeled here, but the game is quite short. It takes less than five minutes to play through both of its levels, at which time the player is given a final score card filled with numbers, graphs, and statistics. A more drawn out

level structure, or some scenarios with specific goals, could greatly increase both the fun and learning value of this title.

Fig. 7. EnergyVille

4. Climate Challenge

Climate Challenge, by Red Redemption, is quite similar to *EnergyVille* but has more meat on its bone. The player is cast in the role of the president of the European Union, tasked with the simultaneous goals of staying popular, providing for the needs of citizens, and of course, reducing emissions (see Figure 8). The game is turn-based, and presents the player with various "policy cards" that can be played each turn, divided into several sectors: National, Trade, Industry, Local, and Household, which represent laws or policy that the government can enact in those domains[17]. Four resources are tracked : money, en-

ergy, food, and water, as well as the "negative" resource of emissions. Another resource that is not labeled as such is "approval," which represents the people's satisfaction with the government's policies. Each policy will affect these resources when played. For example, the national "raise retirement age to 70" policy will greatly increase the government's money, but will also come with sharp disapproval from the people. Most policy cards are directly related to energy, such as "promote industrial energy efficiency," "research nuclear fusion" or "promote cooperative windfarms." Others deal with other aspects of the economy – funding a space program or hosting the Olympics will generally be expensive in terms of both resources and pollution, but will be extremely popular with the people. Certain policy cards will unlock new ones later in the game – for instance, researching fusion is costly and has no immediate effect, but allows the player to build nuclear fusion plants later on, which produce lots of energy. Likewise, "support low-intensity farming" unlocks "support organic farming", while supporting high-intensity farming unlocks "produce GM food" and the bizarre futuristic policy choice "Grow meat." Each turn advances the game 10 years, and calculates new demands and stresses on the economy, so things get progressively more difficult. Creating a good foundation of wise choices in the early stages makes things much easier later on, as the cumulative effect of past choices can drain the player's resources as their emissions skyrocket, effectively caging them. At certain milestones, the player is sent to the United Nations where they must convince other world leaders to join with them in setting emissions targets. This is dependent on two factors : first, how well the player has done in lowering emissions in their own country, and second, how much money the player gives to foreign leaders at the meeting to "subsidize" their energy initiatives.

Climate Challenge does a much better job than *EnergyVille* in turning an economic simulation into a game, though the game's appeal is limited. As far as production values, the game has simple and clean graphics, but minimal animation, and no audio to speak of – neither music nor sound effects. Although this spartan affair keeps the focus squarely

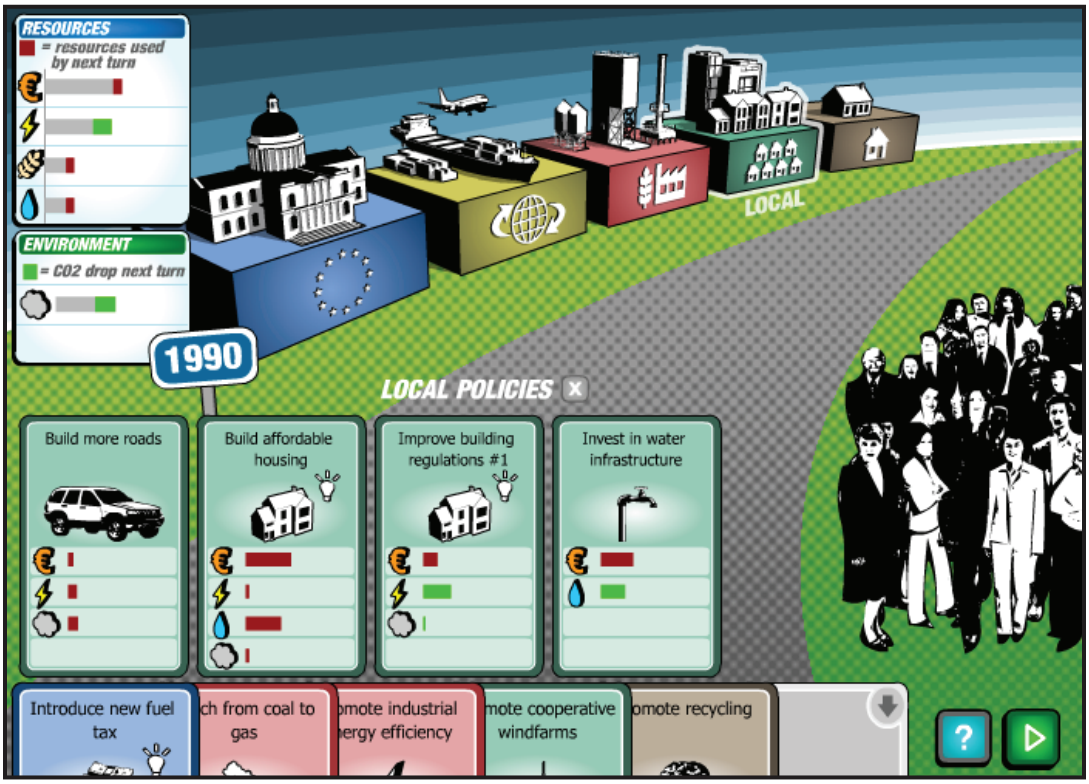

Fig. 8. Climate Challenge

on gameplay, *some* level of multimedia feedback is required to both reward the player and induce fun. And as for the game itself, it features lots of dense reading and requires the player to swap back and forth between dozens of policy cards. Ultimately, the only task the player really has is to balance numbers. Although managing trade-offs is the essential mechanic of many games, more needs to be done to give this a sense of visceral importance, and to make it fun. In *StarCraft* [18], arguably one of the world's most popular RTS games, mismanaging an economy results in being quickly over-run by an opponent's heavily armed troops and blown to visually spectacular bits. In *Climate Challenge*, mismanaging the economy results in bars turning red instead of green and a low score being displayed on the final game summary screen. *Climate Challenge* does the best of all the games reviewed so far in connecting learning material with interesting gameplay, but its appeal is likely

to be limited to academics and people already interested in energy economy. It could be considered successful as a learning game, but falls flat as something the general game-playing audience would connect with. In short, there is too much "serious" and not enough fun in this serious game.

5. Oil God

Next is *Oil God* by Persuasive Games [19]. In *Oil God*, the player is given a rich simulation of a world, with various countries buying and selling oil (see Figure 9). The player takes the role of a malevolent and wrathful "Oil God" tasked with doubling the consumer price of oil as quickly as possible [14]. The game's purpose is to show how the price of oil rises in response to global events. The simulation models all sorts of things-different governments (Democracy, Imperialist, Totalitarian, Theocracy), different economies (Capitalist, Socialist, Communist), the distance oil has to travel, geographical features such as seismic faults and bodies of water that make certain regions more vulnerable to certain disasters than others, and much more. It is clear that some serious research went into this game, and that a very sophisticated algorithm is driving the cost of oil. However, the game suffers from a few flaws. First of all, it is overwhelming, with the complex interactions at play explained all at once through a few densely packed tutorial cards. Secondly, the game itself features a single level, is incredibly fast-paced, and easily short-circuited; all the player has to do to win is click "start war" several times and wait about 45 seconds. In fact, nearly any of the powers available to the Oil God will have a similar effect, be they tornadoes, earthquakes, or civil insurrections. Obviously, "disaster and war causes the price of oil to go up" is a valuable lesson, but the game has so much more to offer, if only the level design was as well planned as the simulation under the hood.

Fig. 9. Oil God

D. Impressions

None of the aforementioned energy games successfully connects fun with learning, with the possible exception of *Climate Challenge*. *Lose Your Excuse!* has mildly fun gameplay which actually distracts from its message, *Kampen om Energien*'s potential is extinguished by game-halting bugs, and only a bit of learning can be teased out of *EnergyVille* and *Oil God* before their gameplay comes to an abrupt end. *Climate Challenge* is on to something, since real-world trade-offs can be a great source for interesting decisions, but has limited appeal given its threadbare multimedia presentation and overly wordy interface. The design of *SEA* builds on these previous attempts, learning from their successes and avoiding their shortcomings. Furthermore, this design is informed by Koster and Bogost's work. When it

comes to applied games, fun is the spark for learning, and procedural rhetoric its tinder.

CHAPTER III

METHODOLOGY

A. Design

The basic idea of *Super Energy Apocalypse* was to create a real-time-strategy game that drew its economic features from real life, with a focus on energy production. This would provide the game with interesting new subject matter and mechanics (fun) as well as useful lessons and facts for the player to absorb (learning).

The process began with a few core principles of design. First, a quick prototype was constructed, after which an engine was built which was iterated upon many times until the game was finished. Rather than laboriously documenting the development of the entire game step-by-step, this section begins by discussing the design's first principles and finishes with a description of the game in its final state, justifying the individual decisions that brought it there[1].

1. First Principles

1. **All aspects of the game's energy economy must be based on research.** Energy numbers may not be "made up," or fudged into obedience, not even for the sake of game balance. Approximations, estimates, etc, are allowed. Conceptual accuracy is desired, not literal precision.

2. **The player is required to produce (and therefore pollute) to some degree.** This forces the player to experience the problem in order to learn how to solve it.

3. **Tasks not directly related to energy economy (such as combat) are allowed** so

[1]See Appendix A for an in-depth description of the game's development, Appendix D for the numbers behind the game, and Appendix E for the game's background research

long as they enhance understanding of energy economy and do not distract from it. Managing an economy should be the central focus. In response to principle 1, aspects of the game not dealing with energy need not be modeled realistically.

4. **Matter may be transformed into energy or another form of matter, but it may not be destroyed.** In many games, an object can be completely and totally removed from the game simply by blowing it up. An explosive animation plays, the object is deleted, and that is all. Veteran game designer Ernest Adams refers to this cliché as "neat, tidy explosions:"

> Look closely at a picture of a place where a bomb went off. It's a mess. A real mess. Things are broken into pieces of all sizes, from chunks that are nearly the whole object, to shrapnel and slivers, down to dust. And they're twisted, shredded, barely recognizable. Things that are blown up by a bomb don't fall neatly apart into four or five little polygons - they're blasted to smithereens.
>
> I suppose for the sake of our stomachs we'll have to preserve the TV and film fiction that people who die violently do so quickly and quietly rather than screaming and rolling around; but I don't see any need to pretend that high explosives are less than apallingly [sic] destructive. Bombs ruin things - lives and buildings. They leave the places theyve been shattered and unattractive. Let's tell the truth about them [20].

In addition to misrepresenting the true nature of violence, "neat, tidy explosions" also violate the physical law of conservation of mass: if a building is demolished or destroyed, it has not been "deleted," it has simply been turned into a heap of rubble that must be cleared before anything else can be built there. The same thing goes for enemies that have been destroyed - their bodies will be left on the battlefield as garbage. The player will not be able to "delete" something he does not want - he will be forced to deal with his garbage, just like in real life.

5. **In-game objects will represent real-world counterparts, but not on a one-to-one ratio.** One game vehicle can represent an entire fleet of 1,000 real vehicles, and one

game day can represent a year of real time. Proportions must be maintained, but both sides of the equation may be multiplied by a constant value.

6. **There should be no dominant strategy.** Each level should require a unique approach, and there should be multiple solutions to any situation. Furthermore, no economic tool should be a "silver bullet" for the player's problems. (This conforms to what has been found through energy research. If there was a silver bullet, we would all be using it). On the other hand, it is perfectly acceptable for a feature to be "useless" or "underpowered" so long as this is the result of implementing real-world research.

7. **Fantasy situations are allowed** so long as they contribute to the game's rhetoric and are clearly understood as fantasy situations.

B. Gameplay Overview

The player finds herself in a hostile, post-apocalyptic world teeming with monsters. At the center of the game map is a fortress which must be protected at all costs. Surrounding the map is wasteland, the home of strange green monsters the survivors have nicknamed "zombies." Many other RTS games require the player to simultaneously juggle exploration, economy, and combat, but this leads to frantic micro-management and multi-tasking. *SEA* instead limits the game to a single, non-scrolling map, eliminating exploration entirely, and splits the game into two phases during which the player focuses exclusively on either economics or combat. During the day, the player will build up her economy and try to minimize her pollution. When night falls, the zombies will march out of the wasteland and try to destroy all of the player's buildings (see Figure 10). If they destroy the fortress, the game is lost and the player must restart the level. The player is thus forced to run an economy to produce enough resources to survive, but the zombies will feed on the player's

Fig. 10. SEA: "Zombies" Invading by Night

waste (principle 2). In this way, the daytime phase lets the player try out an economic strategy, and the night-time phase will test how well it works. If the player produced lots of resources and little pollution, she will have plenty of ammunition to use against weak, easily-destroyed zombies. If the player produced few resources and lots of pollution, she will have little to defend herself against pollution-fueled super zombies.

1. Defense

The player's immediate concern is to protect her fortress from zombies, which come in three different varieties, each with their own strengths and weaknesses. To defend herself, she places automated turrets that attack enemies as soon as they come into range. Each defensive building provides a different attack and consumes a different resource (see Fig-

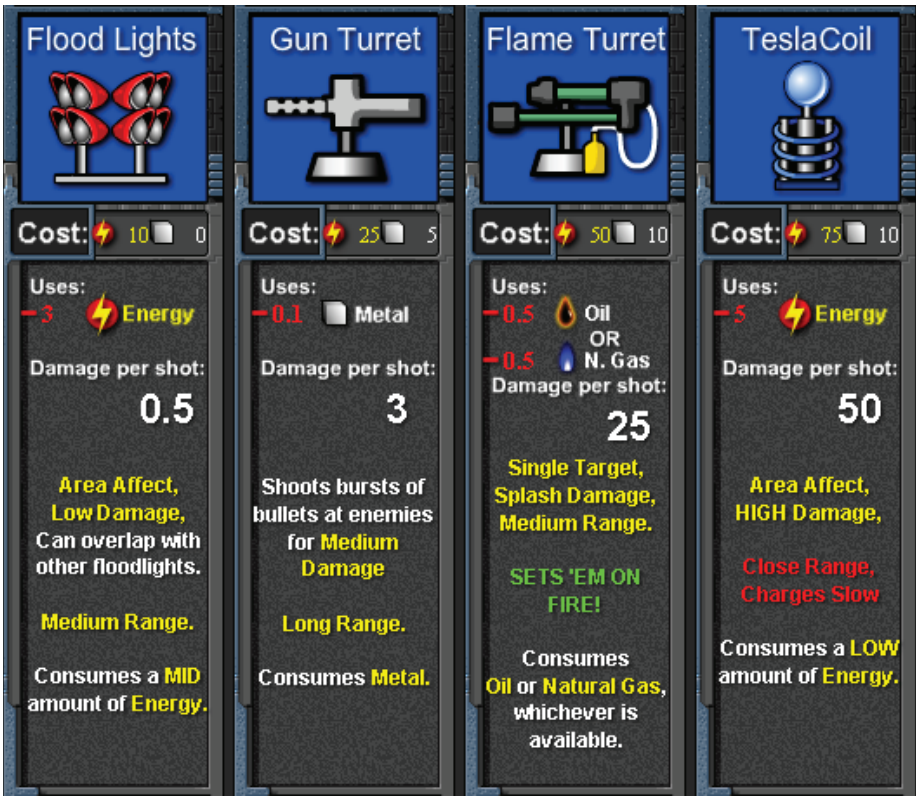

Fig. 11. SEA: The Various Defensive Buildings

ure 11). The basic options are gun turrets, a strong, stable defense that consumes metal, and flood lights, a cheap, simple defense that consumes energy. The advanced defense options are flame turrets, which incinerate enemies but consume valuable natural gas or oil (whichever the player has more of), and Tesla coils, which consume large amounts of energy in a super-powerful electric attack. Since each weapon consumes a different resource and has a different method of attack, no single choice is appropriate for all situations (principle 6).

2. Garbage

The player's next concern is garbage. When zombies die, they turn into garbage (principle 4). Other zombies will eat this garbage, and become stronger. To deal with this threat, the

player must build garbage trucks. Once built, garbage trucks will run automatically with no input from the player, collecting garbage. Once they have a full load, they will seek a landfill to deposit the garbage in. These trucks, like all vehicles in the game, are governed by a model based on real-world fuel usage, with each in-game truck representing an entire fleet of real-world vehicles (principles 1 & 5). Landfill placement is thus a key strategic choice for the player, since placing a landfill far away from garbage sources will result in long trips for their trucks, increasing fuel consumption and leaving garbage on the map for a longer amount of time. However, placing landfills too close to the front lines might make them a target for zombies. If a landfill is destroyed, all the garbage will spill out, creating a feast for the zombies. Should too much garbage pile up on any one spot, it will create polluted sludge similar to the wasteland that borders the map. At night, zombies will spawn directly from this spot, giving them closer access to the player's base. The player should quickly learn that cleaning up waste is essential for survival (principles 1,3 & 7).

3. Power Plants

Having dealt with the immediate concern of surviving against the zombies, night turns to day and the player must think about the future. Almost everything the player does requires energy, which is produced by in-game power plants, all based on real-world data, and intended to reflect the relative cost-to-energy output ratio of each facility (principle 1). Although each facility's ratio of building cost & fuel input to energy generated is accurate, one in-game facility does not correspond to one real world facility (principle 5). If this were done, wind and solar power would only produce fractional amounts of our in-game energy units each turn. To compensate, each in-game wind and solar plant actually represents many real-world facilities, multiplying both the cost and the energy output of their real-world counterparts by a constant factor.

Like the defensive buildings, each of the 6 power plants has different pros and cons

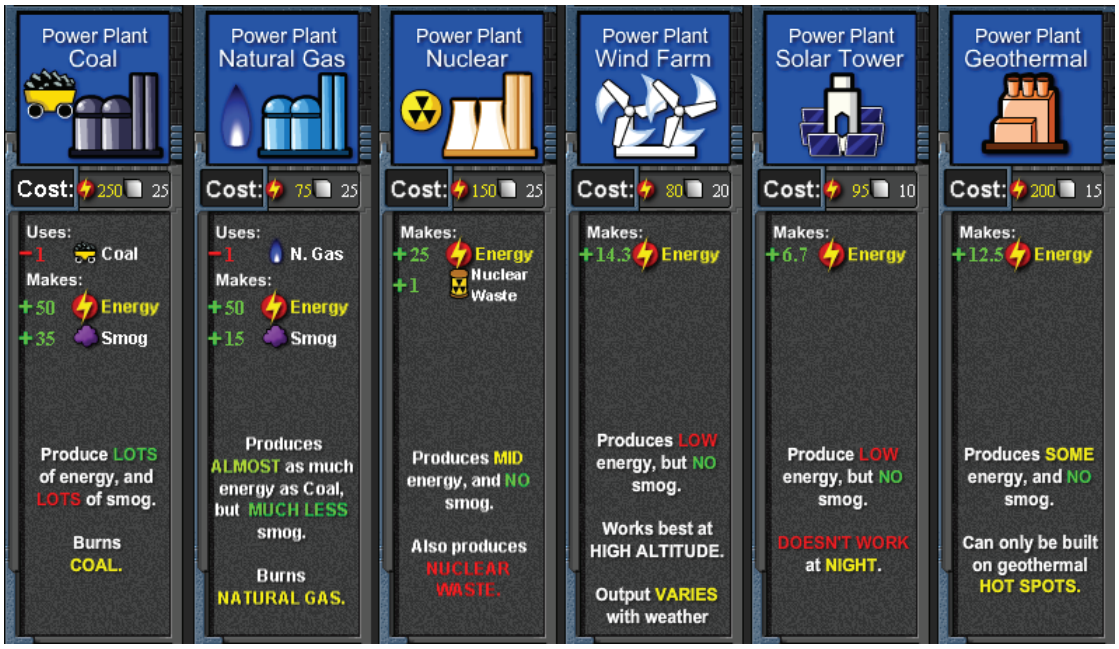

Fig. 12. SEA: The Various Power Plants

(see Figure 12). There are three "conventional" power plants, which have high energy outputs and moderate to severe environmental downsides. First is coal, which pollutes the most, uses the cheapest fuel, and produces the most energy. Next comes natural gas, which ties coal for energy output and has less pollution but is also a scarcer resource. Nuclear power has no smog and about half the energy output as coal but also produces nuclear waste, which causes zombies to become super-sized should they eat it (principles 3 & 7). Nuclear waste must be disposed of properly in a nuclear waste dump, which the player must guard even more carefully than a landfill. The three alternative power plant choices are wind, solar, and geothermal. Wind produces a little less than 1/3 of coal's output, but this is an average rate. The actual output varies depending on the weather, ranging from double the average to nothing at all. Wind plants achieve better speeds at higher altitudes. Solar suffers from a similar problem (varying cloud cover) and has even lower output. Geothermal produces a medium amount of energy and does not depend on weather.

Geothermal is only usable on geothermal hot spots, of which the there are large and small- the larger providing double the output. Geothermal spots are not available on all maps. The diversity in power options should teach the player about the differences in power output, pollution, and geographic suitability of the various power plants (principle 1). If the player wants the best results, he will have to suit his power choices to the varying situations in each level (principle 6).

4. Supplying the Base

On the consumption side, most of the player's buildings consume both energy and food throughout the day. Should the player run out of energy, the buildings will not function, and should the player run out of food, the buildings will become damaged . Furthermore, it always costs energy, and usually metal, to build new things. Metal for construction and fuel for power plants can be produced by mines and wells, which may only be placed on specific resource-rich areas of the map. These spots will produce both resources and garbage, and over the course of time they will run dry. The food problem can be solved by building farms, which consume energy and produce food, as well as smog. This serves to regulate the player's growth: the more buildings he produces, the more food those buildings need. The more food they need, the more farms he builds, which requires more energy to run those farms, which in turn requires more power plants. All of these power plants and farms (and the garbage trucks to deal with the garbage produced by the farms) will eventually lead to smog accumulation.

5. Air Pollution

"Smog" is the other form of pollution in the game, which abstractly represents all air pollutants, including those with global warming potential as well as those that are simply toxic to air quality and human health (the latter often being left out of climate change discussions).

Smog is particularly dangerous because it has an immediate effect on zombies; every 100 units of smog causes all incoming zombies to enter with an extra level of strength. There are no buildings that "reduce" smog- the only way to lower existing smog levels is to produce less and wait for the atmosphere to stabilize. This can be done by disabling high-emission facilities and vehicles, and/or upgrading them through research.

6. Upgrades

Research and technology is the next concern of the game. Should the player be able to deal with the immediate threat of zombies, clean up all his garbage, produce enough energy to keep the lights on, find enough resources to keep the power plants running and the population well-fed, keep smog levels down and still have some resources left over, he can invest in the future by building laboratories. Labs will consume energy and food and produce "research," a resource that can be spent on upgrades. Power plants, landfills, and vehicles can all be upgraded.

Power plants can be upgraded in order to reduce emissions and increase output. There are four levels of upgrade, ranging from 0 (no upgrades) to 3 (the maximum). Although power plants become better as they are upgraded, their relative differences to other power plants at the same level do not change. For instance, a Level 3 coal plant might produce slightly less smog than a Level 0 natural gas plant, but a Level 3 natural gas plant beats it by a mile.

Landfills can be upgraded to include recycling centers. Recycling centers will allow for some of the garbage to be converted back into useful materials. Some of it can be turned into metal, some of it into energy, and some into natural gas. What kinds of resources can be harvested, and how much, depends on the upgrade level of the recycling center.

Finally, the player can research and upgrade the fuel of their vehicles. Initially, only gasoline is available, which consumes oil. Later, the player can unlock natural gas, ethanol,

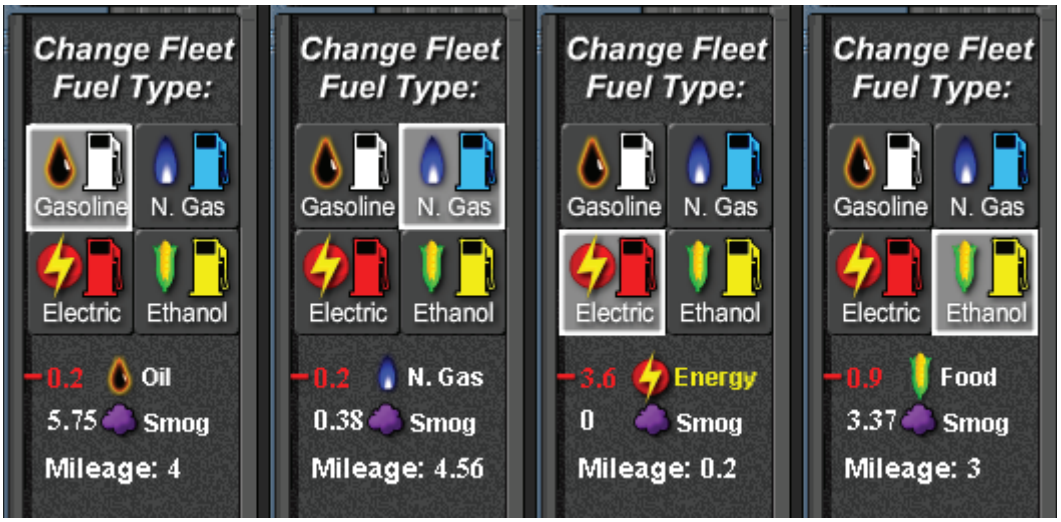

Fig. 13. SEA: The Various Fuel Types

and electric engines. Each of these consumes a different resource (ethanol consumes food and electric consumes energy), produces a different amount of smog, and has a different travel distance per unit of fuel consumed (mileage) (see Figure 13). Upgrading improves emissions and mileage, but, like power plants, the relative differences between fuel types remain the same. Gasoline will always produce some smog, and electric cars will always have to stop to recharge their batteries after comparatively short drives.

7. Game Modes

The game comes with two modes : campaign and sandbox. In campaign mode, the player progresses through 9 increasingly difficult levels with intermittent story sequences that frame the challenges within the tale of a band of post-apocalyptic survivors trying to rebuild a nation. Each level presents the player with a series of objectives to accomplish, as well as tutorials (in the early stages) explaining how the game is played. Campaign mode can also be played in three difficulty levels : easy, normal, and hard, to accommodate different levels of expertise.

Sandbox mode allows the player to design their own challenge by selecting one of several maps and adjusting the amount of starting resources, zombies, daytime, night time, and many other options. Players can even choose to turn zombies off entirely and just enjoy building things. In addition, this mode comes with 5 pre-built scenarios that serve as extra content, as well as an example for the player of how to design interesting scenarios.

8. Summary

In summary, the player's immediate goals are survival against the zombies, which is accomplished by placing defensive turrets. These turrets consume different resources, which the player must conserve wisely or else run out of ammo. Zombies will eat both garbage produced by the player as well as that produced by fallen zombies, so garbage trucks and landfills are essential in order to survive. These trucks will consume fuel and produce smog. Once defense is taken care of, the player must build a sustainable base. This comes first from building power plants for energy and things like farms, mines, and wells to harvest resources. Buildings will constantly produce smog and garbage, as well as vehicles, so the player must manage his expansion or face an onslaught of super-zombies the following night. Once the player has enough to live on, he can invest in laboratories to upgrade his economy and lower pollution. Only by correctly balancing defense, energy, resources, pollution, and research can the player survive the *Super Energy Apocalypse*.

CHAPTER IV

EVALUATION

There were several goals for this game. They were to make a game that was popular, innovative, and fun, and to teach people about energy economy. After the game was released online, a torrent of feedback from users and fans was received, and quite a few statistics were collected.

A. Popularity and Reach

As of November 1st, 2009, *SEA1* and *SEAR* have generated a combined 3 million plays, of which 2.2 million were unique, according to the game's distribution partner, MochiMedia (see Appendix C, Table X). *SEA1* was entered into a casual game design competition at JayisGames.com, where it won second place [21]. Kongregate.com, a popular Flash games portal, features both weekly and monthly contests for the best game uploaded during that time period. *SEA1* was the second place game uploaded the week of April 6-12, 2008 [22]. *SEAR* was the first place game uploaded the week of January 25-31, 2009 [23], and the second place game uploaded in the month of January, 2009 [24]. *SEAR*'s rating on Kongregate as of October 1st, 2009 is (4.12/5.00) [25], which makes it the 126th highest-ranking game out of all 19,303 games on the site (top 0.7% percentile). *Super Energy Apocalypse* succeeded in getting widespread play and visibility in the world of Flash games, a highly competitive environment in which literally thousands of new games are released by amateurs and professionals every day.

B. Critical Reception

Most Flash games do not receive reviews by major game journalism sites like Kotaku, Joystiq, and Gamasutra. There are a few sites that regularly review these types of games more frequently, such as "casual game" community sites like JayIsGames, and "indie game" communities like TIGSource and Indiegames.com, but even then, only a small percentage of the mountain of Flash games released every day make it to these, the review sites most closely associated with the medium. *Super Energy Apocalypse* has received several critical reviews, two from JayisGames.com's Derek Breid (one for *SEA1* and one for *SEAR*), one from TIGSource's Derek Yu, and one at Gamasutra, written by Emily Short, best known for her work in Interactive Fiction.

JayIsGames.com is a website focused primarily on reviewing and analyzing "casual games," a loosely defined category whose defining characteristics include but are not limited to simplicity, usability, shorter play sessions than "hardcore" games, and ease of "pick up and play." Furthermore, "casual games" tend to be played on the PC or mobile devices, rather than a dedicated games console. With over 3 million monthly page views (from 840,000+ unique individuals) [26], JayIsGames are regarded as one of the premier sites for casual game write-ups on the internet. Their reviews are generally targeted towards casual game players looking for fun and interesting new things to try out.

TIGSource.com is more squarely focused on "independent" or "indie" games, another loosely defined category which includes but is not limited to the work of hobbyists who develop games in their spare time, as well as those of small professional game companies whose artistic and gameplay visions go against the grain of traditional mainstream video games. There is often significant overlap between "casual" and "indie" game titles and developers, but the respective subcultures that follow them are fairly distinct. TIGSource.com is perhaps one of the most active scenes for independent games developers, where "indies"

from all over the world gather to share techniques and collaborate. The site is edited by Derek Yu, one of the developers behind Aquaria, the grand prize winner in the 2007 Independent Games Festival.

Finally, Gamasutra.com is the industry trade journal for game developers of all stripes, both indie and mainstream, applied and pure. It features articles ranging from game design, audio, and programming, to business, marketing, legal concerns, and industry news. Gamasutra is published by the United Business Media company, which also owns the print game development magazine Game Developer, and hosts both the Independent Games Festival (IGF) and Game Developers Conference (GDC), the latter of which is to game developers what SIGGRAPH is to visual effects professionals.

1. SEA1 (v1.0-1.2)

The first review the game received was written by JayIsGames.com's Derek Breid as part of the site's coverage of their 5th Casual Game Design competition, for which *SEA1* was produced. He generally praised the game's theme and creativity, cited lack of a save feature, performance issues, and bugs as the game's major downsides, and counted the game's tightly interlocking systems and tower defense mechanics among its strengths. In particular, he noted that "The in-game guide, Dr. Ananastasia Wurstwagen, does an excellent job of stepping you through the game mechanics without making it feel too much like a tutorial." Furthermore, he identified the game's pollution and garbage system as being the key differentiating feature from other tower defense games: "The real twist that sets Super Energy Apocalypse apart is the balance that originates from having to clean up after yourself" [27].

Breid noted that the 1.0 version of the game was a bit rough around the edges, as it had "a bit of unbalance with some resources, a bug here and there, lack of a save feature, and some performance issues for some machines during the heat of battle." A version 1.2

patch was released a few days later to address these issues, which he noted in the review, but which were too late to be considered for final judging. Overall, however, he seemed impressed with *SEA1*, as did the judges, who gave it second place out of 21 games entered:

> Nonetheless, a well-deserved congratulations to Lars for taking Second Place in our 5th Casual Gameplay Design Competition, crafting a quirky, fun, and well-balanced game. His creativity exhibits itself throughout all aspects of the game, from the random bits of humorous dialog to the intricate resource system and the solid inclusion of the Upgrade theme[27].

He suggested that, had the changes in the patch been finished before the deadline, the game could have taken first place[27].

The game's initial reaction from the audience was generally upbeat, but there were a few complaints that consistently appeared both in the designer's email inbox and online message boards. Although many players like Breid specifically cited the game's introduction as one of it's strengths, others felt that the game amounted to a giant tutorial. Many said that the game ran slow on their system, even with the patch. Despite all this, most players liked the game and were interested in its theme, and wanted to see more, offering ideas for improvements. In his initial review, Breid suggested a specific alteration to the game's objective system:

> The only further change I can suggest is to get rid of the infinite time limit for completing certain goals; it's too easy for players to build up their resources, in particular the research points, since the upgrades they are spent on remain through all future levels. Start the countdown as soon as the player receives their first objective, and if they cannot complete all objectives (including survival) by the level's end, then they must replay it.

It was clear that players were interested in a follow-up to the original. Even the complaints seemed to take for granted that a new version was forthcoming which would fix its flaws.

2. SEAR (v1.7)

Although JayIsGames was the only website to formally review *SEA1*, it received widespread play and exposure on online game portals such as Kongregate, OneMoreLevel, NewGrounds, and many others, from which feedback was received. The praise and criticisms were taken to heart and a new, revamped version of the game was created, as described in the methodology section of this thesis and Appendix A. *SEAR* received much more attention than *SEA1* and received three reviews from various sites.

JayIsGames were proud to see that the game had matured and asked Breid to write a follow-up review. The review was overwhelmingly positive, declaring the game "one of the most enjoyable and fun educational games ever created" [28]. Contrasting the polished *SEAR* to the rather crude *SEA1*, he said, "it is now virtually bug-free (at least, I haven't found any)." Furthermore, the editors at JayIsGames were fascinated by the story behind the game's development and subsequent sponsorship by HARC, mentioning it on their site as an inspiration to others:

> Lars discovered that there is a market for games like this, and more importantly that he could turn his "Flash game hobby" into a viable career. So, budding game designers take heart! The casual game field is full of opportunities and still growing, and more opportunities like Lars had are bound to occur.[28]

Some commenters complained it was still a bit difficult and fast-paced, but agreed that *SEAR* was much better than the original. The most popular features were the newly enhanced sandbox mode (complete with challenge scenarios), as well as the revamped storyline, graphics, buildings, and enemy types. All in all, the JayIsGames community loved the game and were proud of its success, giving it their stamp of approval.

TIGSource.com, as the foremost site for the "indie gaming" community, has a sharper focus on mechanics and systems when it comes to evaluating a game. Derek Yu gave *Super Energy Apocalypse : RECYCLED* a mixed review, finding it fun to play and praising its high concept, but sharply pointing out its implementation flaws. Yu found the game's

fundamental approach -using zombies to teach the player about energy use- interesting, but in need of more hard facts about energy use:

> Unfortunately, while the message is certainly worthwhile, it gets slightly lost in the post-apocalyptic narrative, in my opinion. From an educational standpoint, more real-life facts about the world's energy consumption and its consequences would have been great. As it was, I was thinking more about killing zombie mutants than conservation while playing the game.[29]

Nonetheless, he still found the game fun and engaging, giving general approval and encouraging more work to be done:

> None of the aforementioned problems really prevented me from having fun with the game. As with most tower defense games, it's enjoyable just to lay down weapons and watch things die. But I think more could have been done to develop the game's strategy and overall theme (more educational games, please!).[29]

Yu's review suggests that merely "baking" real-world information into a simulation is not enough to make the topic clear to all players. Furthermore, not giving the player an easy-to-use interface to compare power and fuel choices side-by-side probably made it hard to make an informed choice about the in-game technologies, a criticism repeated in Ms. Short's review, as well as emails and comments from fans. Although the game's approach fell flat for some, however, a rather lengthy comment left on Yu's review by a TIGSource reader demonstrates that others were getting the message:

> Despite the flaws mentioned above, I think this game does a great job in illustrating the problems inherent in trying to switch to more energy-efficient fuels. Coal and oil powered based [sic] are cheaper and faster to get up and running, and when you're operating within tight constraints, that's important, because if you're halfway through building a perfectly carbon-neutral base and the zombies come and you don't have any defences [sic] up yet you're stuffed. On the other hand, if you just ignore the pollution that comes from burning coal with blithe abandon, then in the long run, you're even more stuffed, because the zombies feed on that pollution.[29]

Although TIGSource is a tougher crowd to please, they still seemed to like the game as it was delivered, and, again, expected to see future endeavors.

One critical mention of the game came from an unexpected venue. At the Casual Connect 2009 conference, two Kongregate employees, CEO Jim Greer and Community & Developer Relations Manager Greg McClanahan, specifically mentioned *SEAR*'s tutorial system as an example for other developers to follow. Their presentation was entitled "Finding Fatal Flaws - Lessons from Kongregate," discussing common mistakes in Flash games. Among other topics, they discussed a common problem among developers - getting frustrated with players who don't read instructions. "I just want to make it clear - players do not read instructions." said McClanahan, then had this to say:

> If your game has instructions and they're sort of tucked away on the title screen and they're crucial to the game, and you start the game without reading the instructions and you have to go back to the main screen, the player is already frustrated.[30]

The next slide in his presentation showed a screen shot from *SEAR*.

> So this is a game I have featured here, it's called Super Energy Apocalypse : Recycled. And I really like this game a lot, and it's definitely the most complicated and confusing game on the entire site, probably...But, it got 4.11 rating and 650,000 game plays on Kongregate. And people really love this game, and the reason is because literally about two-thirds of the game is essentially a tutorial, it really walks the player through everything, which a lot of games can sometimes be really shy about. Like, they don't - they don't want to feel like they're forcing players to play through a tutorial, but really if you can make it fun and you can make it enjoyable, and you sort of like gradually introduce new mechanics, it's definitely a much, much better strategy than just sort of just dropping the player in and being like, "well I hope you read the instructions on the title screen."[30]

To be singled out at an industry conference as an example for other developers to follow is a tremendous honor, and further illustrates the reach and success of this title.

Lastly, the game was reviewed at Gamasutra.com by Emily Short, who works with Interactive Fiction and writes a column called "Homer in Silicon" syndicated at GameSetWatch and Gamasutra, focusing on the narrative aspects of games. In "Analysis: The Super Energy Apocalypse Approach" she began with a curious fascination with the game's eclectic mix of themes and genres, describing it as "part persuasive game, part resource

management toy, part tower defense sequence, and part zombie survival horror story."[31] She pointed out that the game's unusual origin as a contest entry, later polished under HARC's employment, set the game apart, putting it "in the unusual position of having been optimized once from the perspective of player entertainment and once from the perspective of education about energy issues." She called the result "mixed but curiously compelling." She played both the campaign and sandbox modes, noting: "I think the campaign could have been better balanced in a few places to allow the gameplay better to reinforce the emotional weight of the story, but overall it works." Contrasting it with other games, she praised the game's sandbox mode in particular:

> But the story is really only the beginning of the experience, and this is where *SEAR* diverges from many of the story-oriented games I have looked at here in the past. Its ten levels pass quickly, and are fairly easy to defeat ... The really challenging decisions come when you start in on sandbox mode and try to meet various challenges[31].

She pointed out that sandbox mode was better at letting her directly compare the various energy and fuel sources:

> This is where the game's educational aspect comes to the fore, as well. During the campaign, it's easy to be too focused on the level goals to have time to study the tradeoffs in going with one form of energy over another. In sandbox mode, there's more opportunity to compare and contrast the values of different energy cycles[31].

However, she noted that it was difficult to directly access the data at the heart of the game's simulation, echoing what was learned from Yu's review:

> The result is somewhat instructive, though at times the interface made it a little unclear how much energy different options consume (and how often), or how much pollution they produce how often; so it was not always easy to know what to make of this process[31].

She summed up her final ideas in a series of paragraphs that only quoting in full can do justice to:

> In trying to do so many different things at once, SEAR falls short of doing any of them perfectly. Its campaign narrative is fun and engaging, but could in spots be better integrated with game play. The weapon placement aspect of play lacks the sophistication of most dedicated tower-defense scenarios. The resource-management is occasionally a little hard to follow from the interface.
>
> And yet it's oddly compelling. It's neither pure pedagogy nor pure propaganda. The blend of fiction and simulation, goofy fantasy and grounded research somehow convey the muddled ways we talk and think about climate change. We want science to provide a solution – ideally one that doesn't require too great a lifestyle sacrifice – but we respond to dire threat with our lizard brains.
>
> That's a switch I found myself making over and over during the day/night cycle of SEAR: I started each day laying out resources with the best planning I could, but as the sunlight waned, I stopped building research labs and started placing guns [31].

The underlying theme that played out in all of the feedback was that people loved the idea, liked the execution, had legitimate gripes about how it could be done better, and were waiting eagerly for the next one to come out.

C. Learning

A lot of people played the game, and it was received fairly well by the critical community, with a few mixed reviews pointing out what was lacking. It even won a few contests. So, it can be said that the game was successful critically and popularly. However, the real evaluation question is, "was the game successful as a learning tool?" Forum posts, emails, and official reviews give a decent (if anecdotal) picture of what people thought, but little insight into what people actually learned by playing the game. To that end, a special evaluation was designed to test the game's effect on learning for a small group of players.

1. Designing the Study

To begin, an evaluation question was formulated: "Does playing the game demonstrably affect people's knowledge of and/or opinions about energy economy and pollution?" A mixed methods approach was used, combining a quantitative test of knowledge and facts

with qualitative responses from the participants. First, a questionnaire was created for the players to take before and after playing the game (*SEAR*) that would test their knowledge about certain energy economy facts. This would allow for a simple comparison in knowledge before and after playing the game. This was a useful approach, but had some downsides. First, this was a small sample size and any measured changes might not be statistically significant. Second, there was a risk that the questions themselves could obscure the meaning of the data. Lastly, players could learn all sorts of things by playing the game, but the only learning this study could measure would be that directly related to the specific questions asked. To mitigate these problems, qualitative data would also be collected to fill in the gaps of the numerical analysis. This was done in two ways: first, the players were given several free response questions in addition to the numerical test, and second, participants were given the opportunity to participate in a focus group style interview after playing the game, where they could be probed for deeper understanding.

The selection pool for participants was limited to people aged 18 years and up who lived in Bryan/College Station. The age limit was chosen for two reasons - first, *SEA* is a fairly complex strategy game which was designed for an older audience, and secondly, the IRB approval process for minors is more involved than that for persons 18 years old and over. As for the geographic constraint, every participant was a potential interviewee, so it was essential that they live locally in order to meet up for the focus groups. These participants were recruited through an email sent to the Texas A&M University departments of Computer Science and Architecture mailing lists. This email explained the study, asked for volunteers, and provided no incentive other than the chance to play a fun game. In addition to this, Dr. Vinod Srinivasan offered his students the chance to participate in the study as an optional extra credit assignment for his video game design class. In all, 21 participants willing to complete the entire study were recruited. Had there been a larger group of participants, a separate control group could have been set up where players played

a game unrelated to energy economy, such as *Tetris*, while keeping all other aspects of the study the same. This would control for the effect that the framing of the study itself (answer some questions, think about them for at least an hour while playing a video game, and then answer them a second time) had on player knowledge. However, given the scope of the study and the tiny size of the participant pool, it was decided not to divide up the group, relying on qualitative results to verify the numerical findings.

a. Quantitative Study

A special website was set up where participants could sign up for an account, provide some demographic information, fill out a questionnaire about energy economy, play the game for at least 60 minutes, and finish the study by re-taking the energy questionnaire. No stipulations were given as to which game mode or difficulty the player should pick, so long as it was played for at least an hour. Most players picked campaign mode over sandbox, and played on the "normal" difficulty level, advancing through the levels one by one.

A few basic demographic questions were asked, such as the player's gender and age, as well as how many hours they spent playing video games in a typical week, what their favorite types of games were, and what periodicals and websites they depended on for information about games. This data was used to construct a "gamer profile," in order to determine which players were the most experienced in various dimensions of gaming. This would help determine if the game appealed to certain kinds of players more than others, or if a player's gaming background had any affect on how much they learned.

Then, players were asked to fill out a questionnaire to test their baseline knowledge about energy economy. They were instructed to rate the air pollution levels of the six types of power plants represented in-game as either "none," "some," or "high." Then, they were asked to rate the energy production levels of these same power plants as "low", "medium", or "high." Lastly, they were asked for their opinion on what they thought was the best

alternative to gasoline (or if they thought gasoline was still the best), out of the four fuel types represented in the game. After playing the game, they would be asked these questions again, with the before and after results compared for the final study.

After finishing the initial study, the players were asked to play the game for at least 60 minutes. The game was integrated with an online database which recorded the players' activity, noting every time the player logged in and out of the system, as well as capturing detailed reports of the player's performance in-game. After the players were finished playing, they were asked to re-take the energy questions, as well as give basic feedback on the game itself, such as explaining their strategy for winning, what they learned (if anything), and whether they would play the game again. The answers to these latter questions would be used for qualitative analysis.

b. Qualitative Study

Since the game's lessons included hard facts as well as nuanced situations, a simple test would be insufficient to demonstrate the game's effect on learning. To that end, a qualitative study was designed in which certain participants from the quantitative study would be selected for in-person focus-group interviews. The players who had the most to say in post-game feedback were contacted, with the hope that they would be equally loquacious when interviewed. Of those contacted, 5 were willing to participate. They were split up into two focus-group interviews, one on October 9, 2008 with 3 people, and the other on October 16 with 2 people, in the same conference room at Texas A&M University's Visualization Laboratory. The interviewer was given the same five questions to ask both groups,, with instructions to let the conversation flow organically. The questions were:

- What was the most interesting or most fun part of the game?
- What was the least fun part of the game, or what did you find the least interesting?

- If you could change one thing about the game, what would it be?
- What were some things you learned from playing the game, if anything? (Consider prodding them with these topics if they stall: power sources, fuels, energy, pollution)
- If you were talking to someone who had never played the game, and they asked you how to win, what would you tell them?

2. Results

The study's results were both encouraging and revealing . It was demonstrated that players did in fact learn things from playing the game, that it piqued their interest in sustainable energy use, and that they found the game interesting and fun. Also, further cues as to how the game could be improved were received (see Appendix B for detailed study data).

a. Quantitative Results

The answers from the questionnaires were used to calculate test scores for each participant prior to and after having played the game. Comparing their original scores to their final ones, the average change for all players was an increase of 1 point out of a 13-point test, or 7.7% (see Appendix B, Table IV). Of the 21 participants, 7 had strong improvements ranging from 2-6 points (15-45%), 5 participants increased by 1 point (7.7%), 6 showed no change (0%), and 3 players actually decreased between 1-5 points (7-38%).

These results were put through a paired t-test, giving a p value of .0626, indicating a 93.74% certainty that the changes in score were not due to random chance (see Appendix B, Table V). This is just barely short of the standard for a statistically significant p value of .05, representing a 95% certainty. Based on these results alone, it's likely the game increased the player's knowledge, but needs corroboration from the qualitative data. To be absolutely certain, the study could be repeated with a larger sample and compared to a

control group.

This study was also designed to determine whether the game changed players' opinions about alternative fuels. Out of 21 players, 11 made different choices after playing the game than they did beforehand, 52% of the group. Of these, 8 changed their choice to natural gas as the best alternative fuel, 2 chose electric cars, 1 chose ethanol, and no one changed their choice to gasoline. Of the 10 who didn't change their opinion about the best fuel source, 7 chose electric, 1 chose natural gas, 1 chose ethanol, and 1 maintained that gasoline was still the best. At final count, electric cars and natural gas tied for the most popular final choice with 9 votes each, with 2 votes for ethanol and only 1 for gasoline.

Next, the individual questions from the test were examined. There were 21 participants, and the test had 13 questions, resulting in 213 final responses. Collectively, the participants changed 76 of their answers in the final test (see Appendix B, Tables II,III,& VI). Of these, 45 changed an incorrect choice to a correct one (positive change), 23 changed a correct choice to incorrect (negative change), and 8 changed an incorrect choice to another incorrect choice (neutral change). These changes were not distributed evenly across questions - some questions had almost all positive changes, whereas others had similar amounts of all three (see Appendix B, Table VI). The changes for a given test question shall be listed in parenthesis with "+" for positive, "-" for negative, and "n" for neutral. For example, a question in which 4 players showed positive change, 2 showed negative change, and 1 showed neutral change would be expressed as (4+,2-,1n), leaving 14 players who did not change their answers.

Players came in with the most prior knowledge of coal, wind, and solar plants, showing mostly correct answers for both the air pollution and energy production of these facilities on the initial test. After playing the game, players showed the most improvement in correctly rating the air pollution of natural gas plants (8+,2-,0n) and geothermal plants (7+,1-,0n). However, they seemed to have trouble with the question about the air pollution

produced by nuclear power plants (3+,5-,3n), which suggests there was a problem with its depiction in game or the framing of the question itself. Perhaps players did not notice that the questionnaire was asking for the air pollution rating of the facilities, rather than their pollution in general. It is also possible that players who gave nuclear power plants a higher air pollution rating after playing the game thought they were assigning a generic pollution rating, noting that nuclear power plants produce hazardous nuclear waste.

With few exceptions, players were more able to correctly rate the relative energy output of power plants after playing the game. Nuclear power saw the most improvement (7+, 2-, 0n), followed by solar (4+,0-,0n), coal (4+,2-,0n), and wind(3+,1-,0n). The exceptions were natural gas (0+,4-,2n) and geothermal (4+,3-,3n). In the case of natural gas, it seems the problem lies with the game - all the players who changed their answer incorrectly went from "high" to "mid" (the correct answer was "high," as natural gas produces comparable energy output to coal). There is no easy way to compare power plants side-by-side in the game, so players probably never noticed that natural gas plants produce as much as coal in game. This was not the case, however, with geothermal power. 4 players changed their answer after playing the game, and correctly rated its power output as "mid." However, what is interesting is the quality of the 3 neutral choices, who all changed from "low" to "high." Even though these last 4 got the answer wrong, they moved in the right direction, demonstrating that the game showed them that geothermal produced more energy than they initially thought. They overshot the right answer; perhaps it was easier to correctly rate facilities such as coal and wind whose power and air pollution ratings were on the low or high end of the scale than to correctly peg a facility in the middle.

Across the board, players made improvements in their score, but were confused by certain specific questions. Clearing up both the presentation of the study and the presentation of the information in the game itself would likely improve the quantitative results. Furthermore, players came in with very high scores on the pre-test as every single par-

ticipant was an undergraduate or graduate student at Texas A&M University. This highly educated group already knew things such as the fact that coal produces lots of energy and smog, and that solar power is clean but has low output. It would be interesting to see if changes would be greater in a group that was equally experienced with games, but had less formal education.

b. Qualitative Results

It was clear from the start that many of the lessons that players learned from the game are hard to quantify. Certain players had no increase in score between the two tests, but this does not necessarily mean they learned nothing. The results from the free responses and interviews bore out this hypothesis, demonstrating that not only did players learn things not measured in the test, but also that it piqued their interest in a subject they had not cared about before. See Appendix B, Tables VII-IX for the players' free responses, and Appendix F for the full interviews.

When asked what they liked best, players responded that they enjoyed the game's blending of classic tower defense and real time strategy elements with a resource management game based off of the real world. One participant (player 61) said, "for me it was just the critical thinking...when you had to treat it as a real-time-strategy resource game, but you had to keep in mind the information he [the game's designer] brings to the table about the energy resources." Another participant (player 28), a fan of classic RTS games like Age of Empires, said:

> It was pretty much like the real world...nothing was left for granted, you had to think about your trash and those things and then you had to think about creating a dump for that, you had to think about the pollution that was being created, so it was not just about creating more and more oil wells, for example, or more and more oil stations, you had to think about the fumes that were coming out of it.

Players said that the game was a lot of fun, and they enjoyed the way it mixed inter-

esting fantasy elements with valuable learning content.

When asked what they didn't like, players in the interviews mentioned performance issues, as well as lack of variety in the defense portion of the game. Players said that most of the strategic options were exhausted after a single play through of the game's campaign, and that they'd like to see more depth in their choices. Player 77 mentioned he didn't like the story very much, though several others said they enjoyed it. Player 43 mentioned being annoyed by the objective system, which would "interrupt" him with the next objective while he was focusing on something else that he wanted to do. He also mentioned in particular that the game's build cycle bothered him, because all the power plants of a single type would "tick" at once, limiting the maximum amount of energy you could get from a single source. "And so you're basically relying on that 900 energy for the next minute and there's no source of additional energy in between at the end of the game that's just not feasible at all," he said. He thought for a moment and then said, "well I guess maybe that's the point, that you had to diversify all your different energy sources and stuff instead of just relying on one, that way they would all tick at different times," but maintained that this was an artificial and annoying way to do things. Player 43 agreed with him. Finally, almost all the players mentioned that the final level of the campaign on normal mode was too sudden a jump in difficulty, a complaint repeated in countless emails.

When asked what things they learned, players consistenly mentioned subtle and nuanced points about energy use that were built into the game, but not measured on the quantitative tests. One student (player 63) responded that he learned about how optimal energy choices vary by region, as he explained what he learned about Geothermal energy:

> I knew a few things about the certain power sources, but a lot of things which I kind of knew ... I didn't really think about, like that Geothermal power ... is going to work better in certain spots, because the Earth is not at one temperature underground, it's got certain areas that are used for that stuff

He continued, with what he learned about wind power, noting that wind power is

variable as it depends on the weather:

> Then, like wind power, it'll work less at night 'cause the wind doesn't blow- I don't know - that happened in the game, I don't know...what's up with what the wind does through the day and night cycle, but if it does that'd be something to think about.

Then, he mentioned solar power:

> The fact that solar power doesn't work at night, I mean that's obvious, but I never really thought about that...You think, "I'll just make solar power," but uh, there's no batteries when you're generating that much power, you just send that right out to the grid, so what if people need a lot of electricity at night? Cause a solar power plant would be useless, cause you can't power things at night.

Later in the interview he mentioned that he learned some new things about fossil fuels:

> I didn't really think about the difference between oil and natural gas until I was playing this game. It's like, two different things. Even though people kind of confuse them a lot of the time.

What is most fascinating about player 63's above interview responses is that he was one of the players whose change in score on the quantitative section was 0%. His score on the initial and final tests were exactly the same, 12 out of 13 points. This clearly demonstrates that there were interesting lessons that players learned, even if the test didn't capture it in the form of an increased score. It also shows that even players who came in with significant prior knowledge left with hard-toq facts that they likely did not know before playing the game. Similar to player 63, Player 61 also had a change in score of 0%, but mentioned how the game opened his eyes to the entire topic of energy use and pollution:

> You know, I never really cared about the resources...you hear about it in economics...but this thing about the resources that we use every day...I guess just learning that we need to advance in our resources for us, I guess for us to survive...and it's just advancing in resources, and what we have to adapt to these new resources, and that's just what it made me think about it.

By presenting the situation in the familiar context of a game, this player was made aware of the seriousness of energy use and became more interested in the topic, even though his test score didn't improve after playing.

Players 77 and 43 (with score improvements of 30% and 46%, respectively) also had interesting things to say about what they learned. Player 77 mentions that he learned about the various energy and pollution outputs of power plants, but suggests that the game could have told him more about the underlying processes, and that he was not sure when he started playing whether the lessons from the game were meant to be taken as fact:

> I learned, I believe this is true, I'm not very sure if it's true or not, from the game what I understood is, the different amount of pollution that is created by the different kinds of mining, or nuclear, or waste that is generated by nuclear power reactors. The scale of how much it can create, a coal power plant will create a lot. I used to think that a geothermal power plant might create pollution, but from the game, what I understand is that it does not create pollution at all, and it does give you a lot of energy. I can't imagine how that works, I mean, how it could give you a lot of energy at all. And these things, - stuff about the environment, that I learned.

Player 43 said that he learned quite a bit, but qualified that by saying he wouldn't have paid as close attention if he hadn't been told at the outset that the game was for educational purposes:

> The thing I came out with learning was kind of the smog levels that you get from each of those things, and then the amount of energy produced by those things as well, but I gotta say though, I mean, I only say that I learned those things because I was told going into this that this was an academic research project that's designed to teach people things. So if I had gotten into this just playing the game, not knowing that this was supposed to be an educational game, I probably wouldn't have gotten that out of it. I would have just assumed that it was a game where some people just made up arbitrary numbers to represent these different things as opposed to being maybe, scaled to real-life values.

He mentioned that the things that surprised him the most were smog levels for vehicles, as well as the fact that farms produced toxic emissions. He specifically pointed out being disappointed by the output of solar and wind power:

> ...and then you realize that you really do need like an entire wind farm, and basically, one turbine is not going to do you any good, basically, so. It's a good supplemental power source maybe, but it's not at the end of the game, not unless you build like a hundred of them or something.

This is a particularly interesting quote because it demonstrates two things. First, it shows that the player understood the concept that alternative power sources like wind and solar in general have lower output than fossil fuels. However, it also looks like the player was confused by the game's representation of plants - whereas an in-game coal power plant is more or less a 1-to-1 representation of a real-world facility, 1 in-game "wind plant" is not just a single turbine, but in fact an entire wind farm in and of itself. However, the graphic used for wind plants is a pair of wind turbines, which implies that it represents not hundreds of turbines, but two. So although the message got across, the sheer magnitude of the reality was a bit muddled by the choice of icons. It seems player 43's misconception also held true for solar plants. He said, "so then even like one solar panel in the game doesn't really do you any good at all." He went on to conclude for solar to really be successful, one would have to build solar plants on an enormous scale. The choice of icons didn't make it clear that each in-game solar and wind plant *already* represented many of these large-scale facilities. This suggests that players took cues from the graphic design and assumed that one icon represented one building in real life. Even with this confusion of scale, however, they still learned about the limitations of solar and wind power.

Going further, player 43 demonstrated a clear grasp of an educational nugget built into the game, that coal-based energy produces not only air pollution from burning the fuel, but also solid waste by mining it:

> Oh! And that was the other thing. Pollution levels from the - the mines and stuff like that. I was always surprised whenever I would pop up a mine and then I didn't have garbage trucks and stuff ready for it, and it would start pumping out pollution like crazy, and you gotta get someone over there before something bad happens, that always caught me off guard, a couple of times - [laughter from all] - it caught me off guard a lot.

Testing whether the player was aware of this fact would be difficult without asking a leading question, so it was left out of the energy questionnaire. It's good to see that this player picked up on it and freely mentioned it without being specifically prompted.

The next question the players were asked is what they would tell someone who had never played before what to do if they were asked how to win the game. Player 61 gave an interesting response: "if you just choose to look up power sources ... that's the key to winning, is knowing those power sources." This player, who mentioned earlier that he'd never thought about sustainable energy use before playing this game, suggests that a new player's best course of action is to hit the books and do some research. Player 28 had more direct in-game advice for new players, urging a balanced approach to construction, defense, waste management, and research:

> Balance like you said, you have to focus on every section of the game, like you just can not keep on building guns everywhere, you have to worry about energy generation, you have to think about research, you have to think about farms at some point in time, and I guess if you want to really win you have to make a balanced profile and at the same time keep on upgrading your profile as you get a chance.

Player 68 was a bit of a power-gamer, and suggested the following strategy:

> ...you build one of everything always, 'cause you need power for different guns, good in different situations, and if you have different sources of power, if one goes out for whatever reason you've got a backup. Getting the research as early as possible... I couldn't really tell what effects the upgrades had, but I went for the upgrades right away, and just maxed everything out [Laughter].

Player 43 also mentioned going for a "power gamer" strategy of trying to push the game to its limits, which had the side effect of making strategic choices peter out before the end of the campaign. When the interviewer asked a follow-up question about fuel sources, many of the players responded with comments about power plants instead. This suggests that players didn't spend as much time playing with and thinking about alternative fuels as with power plants, and probably learned less about them. Player 77 suggested a balanced approach, to be careful early on not to overbuild early on and only build a basic defense in order to keep smog levels and garbage low.

When asked what they would change or like to see improved, many of them suggested that the game needed more strategic depth as a game, as well as more educational content.

"More of everything" was the common theme. Player 68 thought the energy simulation could have been deeper, especially regarding Nuclear Power:

> I thought that the pros and cons on some of the power sources were kind of simplistic. Especially with nuclear power, I mean the pollution stuff for coal and the other burning fossil fuels, that makes sense, that you get more power versus the, uh, versus clean fuels like solar and wind, but with Nuclear it was kind of just, "well it's dangerous and expensive," but a lot of the problems with Nuclear power are sort of rooted in the real world... it's kind of hard to translate a complicated issue like that into a game where you're fighting zombies. So making the Nuclear power make the zombies super-powered, I guess that's, that's a compromise and it works in the game but I guess it kind of defeats the point of teaching people about the pros and cons of power.

When asked how he would have designed the system, he laughed and said:

> I - I don't know. I'm trying to think...how it would work. I mean, in a game like SimCity the risk is that it can blow up and destroy half the city, but uh, that might be too harsh in a game like this where you just have to restart the level, and I mean all the issues are even more subtler than that, it's you've got terrorism to deal with, but also costs, and what kind of nuclear power to go with, it's like light water versus heavy water, and storing your waste back in [unintelligible] your deal, depending on the kind of reactor you use? I don't know how I'd do it. Depends on how much you want to make the game educational versus how much you want to make it fun.

Many players suggested that a sequel to the game be set in a city with people moving around, so the player could better relate to the game and see the effect of their actions on human beings. Player 28 had this to say:

> That's one of the things that kind of makes me feel like it might have been better in a city like setup where you could see the affect on the humans. When we talk about humans, all the humans that were there, whether driving trucks or garbage, or the engineers in the cars, I would have loved to see some more humans.

Overall, players used coal power only as an initial "bootstrap" power source and then transitioned to cleaner sources as soon as possible. Otherwise, there was no consistent strategy - players each had a distinct mix of natural gas, nuclear, and/or geothermal, supplemented by solar and wind. No players reported relying solely on wind or solar. All four fuel sources were used, with natural gas and electric being the most popular. In terms

of defense, players reported a wide range of strategies, with some building dense, energy intensive bunkers or perimeters(usually running off of massive, heavily defended nuclear power grids), and others building light, strategic defenses in small clusters, counting on low smog and waste to keep them safe. Most players considered coal and gasoline as being far too dirty to be used safely, even when upgraded.

3. Study Limitations

There are several limitations to consider in evaluating the results of the study. First of all, it was a small pilot study consisting mostly of college students, a highly educated and fairly mature group, largely consisting of tech-savvy computer and visualization science majors. Secondly, the participants were only asked to play the game for a minimum of 60 minutes, and overwhelmingly chose to play campaign mode alone, which the qualitative feedback suggests was less useful for comparing energy choices. It is possible their learning would have increased even more had they played sandbox mode, which merits further study. Participants could have been required to play both campaign and sandbox mode, but this was not done for fear that setting too many requirements would keep them from finishing the study. The participants were mostly male, which also skews the results somewhat. Furthermore, there was no control group to measure results against. Had there been the time and budget to do a full scientific test, a similar test would have been set up in which the same number of people who took the real evaluation were given a completely unrelated energy game, such as Tetris, to play for 60 minutes in the place of *Super Energy Apocalypse*, but still asked to take the initial and final tests. Currently, the rise in scores is assumed to be from playing *SEA*, but a second group could help control for things such as the effect of merely taking the test and thinking about the responses for an hour, including the fact that the test is unsupervised and students may very well be looking up the information online. The control group could account for this change, and compare it with the experimental

group to verify to what degree the change in learning is indeed the result of playing *SEA*. Also, players could be given different versions of *SEA* to play, such as one that only has campaign mode, one that only has sandbox mode, and one that requires both to be played, to determine the effect of level design and play style on learning, as well.

Finally, the ability to do interviews was limited. Of the 10 participants contacted, only 5 were available for interviews, all of whom had test score increases of 0% or better, and most of whom indicated that they had enjoyed the game, skewing the interview results towards those who generally had positive things to say. Of those contacted who said they did not enjoy the game, none wanted to be interviewed. The interviews were time-consuming and difficult to set up, and any more focus groups would be beyond the scope of this thesis' simple pilot study.

CHAPTER V

CONCLUSION AND FUTURE WORK

A. What Went Right

The game was a success in many ways, both at being fun, and helping players learn about energy economy. Based on user feedback, the study results, and original analysis, the following decisions are highlighted as helping to make the game great.

1. Flash Was the Right Platform

There is no doubt the game owes it's popularity and wide reach to the Flash platform. Since Flash runs on all three operating systems and has an install rate of 98.9% on internet-enabled PC's throughout the world, this equates to hundreds of millions of computers capable of running the game without installing any additional software [32]. Compare that to 32 million XBOX 360's sold [33], and the decision to choose Flash over a technology like XNA becomes clear. Writing the game in OpenGL with C++ would have allowed for a fairly broad compatibility base, but would have limited the ability to distribute. Internet users are less likely to play a game that asks them to download and install a program, rather than simply running in a browser window.

2. Zombies Were a Good Theme

At first, there was some reluctance to the idea of putting zombies in an educational game, since it has nothing to do with the real world. However, Raph Koster asserts that players are less affected by theme than underlying mechanics in terms of what they learn, so it was decided to keep them in. This way, players would be drawn to the game by the interesting theme of zombies, but get the message about smog, garbage, and energy as they tried to

survive. It is clear from the results that this approach was generally successful.

There were a few instances in which the zombies made the players focus more on defense than energy economy, but the solution to that is to simply expand the role of energy efficiency rather than cutting the zombies out. Without the zombies, there is less reason to play this game. It should be noted that a major difference between this game and other educational/serious game titles is that *SEA* does not rely on a captive classroom audience and competes directly with other games online. An overt "educational" theme would have hindered its ability to connect with players. For the best results, applied games with educational messages should be able to stand on their own by being as much fun to play as any other game.

3. Two Game Modes Provided Flexibility

With a few detractors, most players enjoyed the story's quirky blend of humor and melodrama. Also, the campaign mode helped players learn the ropes in a guided play session that introduced all of the features one by one. It was known from email feedback that many players enjoyed sandbox mode, and used it to directly compare energy sources after they were finished with the campaign. It is quite possible that test scores would have been even higher had players been asked to play sandbox mode for an hour in addition to playing through the campaign. Including a test of sandbox mode in future studies is strongly encouraged.

Having two game modes increased the game's appeal, since players who didn't particularly care for the story were more than welcome to just play around by themselves in sandbox mode and explore the game's system to its fullest.

4. Real World Topics Provided Fresh Game Ideas

The most frequent question the designer received from people when he told them about the game's premise was, "How will you make the game balanced?" This question concerns whether all the strategic options available to the player will be equally viable in some way. The designer discovered that nature and the real world are excellent sources for new ideas, as well as balance. Since there is no "silver bullet" in real-world energy economy, it stands to reason that there would not be one in an in-game model of the same thing. They key is that most real world systems have natural feedback mechanisms, as well as pros and cons. Coal is incredibly powerful, but it pollutes terribly. Wind is clean, but has low output and varies with the weather. Those are just facts, and easy to implement in a game. Aside from a few tweaks here and there, the energy economy section of the game practically designed itself.

Other games, both in and out of the educational sphere, could do well to take their inspiration from natural systems. After all, many gameplay topics such as war and resource management are based on unsolved problems from real life.

B. What Needs Work

A few things consistently cropped up as problems with the game. These included everything from performance issues and minor bugs to fundamental flaws in the game's design and implementation. These are the following choices made in *SEA* that will be revisited in future titles.

1. Game Runs Slow

The game was written in Flash Actionscript 2.0, which is rather slow. It took a long time to optimize the game to the point where most people could play it comfortably on most

machines, and even then it tends to chug when the screen is swarming with zombies. This was due to an unfortunate side effect of a design decision that zombies would only increase in size and strength, but not number, as pollution increased. However, zombies would slowly increase in number the further the player progressed in the campaign. This caused problems with the game's performance as frame rates plummeted when on-screen zombie counts peaked in the later levels. Difficulty could have been increased without killing performance by simply presenting the player with a small number of stronger zombies, but this would have confused the relationship between pollution and zombie strength. This especially caused problems for players using Macs, since the Mac version of the Flash Player continues to be slow.

Future games could get around this problem while still using Flash in several ways : first, optimizing the game's engine from the very start to show lots of on-screen enemies, second, by adding new and different enemy types that only show up in later levels, which can be used to increase difficulty without increasing the number of on-screen enemies or confusing the player, and lastly, by taking advantage of the performance increases in Flash Actionscript 3.0, which the designer did not have access to when the game was first produced.

2. Combat Distracts from Economics

The second problem the game faced was that the defense game and the economic game, though tightly linked, directly competed with one another for attention. The day/night cycle helped the player to focus on one task at a time, but the game's frantic pacing and sudden transitions between them still divided the player's focus to some degree.

This could be solved in several ways. First, combat could be eliminated entirely, catering to those more interested in building than fighting. This currently exists as an optional feature in sandbox mode, which allows the player to disable zombies entirely. However,

the zombies are a big selling point for the game, and a useful mechanic for making pollution sting. A better alternative would be giving the player more time between defense and building modes without having to constantly switch back and forth. The zombies might only come every few nights, for instance. Also, the defense portion of the game could be more carefully balanced so that the defensive options either have environmental downsides as well, or put strain on the economy in different ways. Lastly, the player could be given economic goals to work towards above and beyond having enough resources to power his defenses for the coming night.

3. Hard to Directly Compare Energy Sources

This is another issue that kept coming up. The game made it difficult for the player to easily compare power and fuel sources side-by-side in an objective manner. In order for certain power plants like wind and solar to produce more than fractional amounts of in-game energy units, those facilities had to be changed to represent hundreds of real-world installations, though players still thought of them as "one" power plant. Secondly, the resource report interface was mentioned nowhere in the tutorial and required the player to discover it by mousing over the resource bar and clicking. Lastly, the player's ability to selectively upgrade some facilities but not others made it easy to present misleading comparisons between power and fuel sources at different upgrade levels - a player could easily get confused comparing a level 4 coal power plant with a level 1 nuclear plant, for instance.

4. Tutorial is Clumsy

The tutorial was a success in introducing a complex game to players one step at a time, but it was an inelegant solution. Some players felt that the entire game felt like a tutorial, and resented being spoon-fed. This tutorial system could easily be modified to present the

player with non-linear, discovery-based objectives, where the game only interrupts them when they find something new, rather than forcing them down a static, linear path. This could make the player feel like she is learning at her own pace, rather than being told to follow one set of school-like instructions after another.

5. Limited Replay Value

Another problem with the game was that there wasn't much to do after the campaign was finished. There were several ways *SEAR*'s design sought to mitigate this, including an expanded sandbox mode with additional pre-made challenge scenarios. However, the game still ran out of juice after a few hours of play since there were eventually no new features or situations to offer. By making upgrades universal for all buildings of that type, and making them carry over from level to level, the player could easily reach a point where there was nothing left to upgrade. Since research was the only thing to invest in besides extra defense once a stable economy had been set up, there was little else for players to do besides place extra guns, which got boring fast. In all fairness, *SEA*'s play time is actually pretty long for a Flash game. But much more could still be done to make this a game that players and students will keep coming back to and learning from. For instance, a full-featured scenario and map editor was the single most requested feature for the game, which will be included in any future titles in this series.

C. The Bottom Line

Super Energy Apocalypse has been clearly shown to be a fun, popular, and innovative game in its own right that succeeded in garnering both critical acclaim and widespread attention in the world of online Flash games. Furthermore, it has been shown to be useful as a learning tool among this small sample of college-aged players, demonstrating increased

knowledge of certain facts, as well as increased interest in the topic of energy economy and producing stimulating conversation and dialogue amongst them. The game's execution could definitely be improved in many ways, but the foundation it is built on - using fun as the fuel for the learning process - is solid. This game serves as a useful model for designing and developing an applied game about important educational topics, or a pure game that draws inspiration from real-life systems.

D. Future Work

There are many directions for future work. First of all, new games could be informed by the lessons learned in this thesis. Secondly, a more thorough evaluation of this or other games could be done to reveal new data this small-scale pilot study was unable to uncover. Lastly, a deeper study into how games affect learning could be conducted, by producing a full scientific experiment in which multiple versions of this or other games are produced to test if certain features or game modes are more conducive to learning than others.

1. New Games

There are many different kinds of games that could be built that draw from the discoveries of this thesis. The most obvious would be a a direct sequel to the game, addressing its shortcomings and expanding the educational topics covered. Other ideas include using *SEA*'s real time format with other educational topics. Outside of applied games, pure game designers could start looking to real life topics for fresh sources of inspiration, both in terms of themes and game mechanics. Instead of another game about space marines and warlocks, concepts like architecture, engineering, biology, rocket science, surgery, living with a disability, breeding animals, horticulture, and more could be explored through the lens of game design.

2. Super Energy Metropolis

An eventual sequel for the *Super Energy Apocalypse* is already planned, with the working title, *Super Energy Metropolis*. The key changes in this title would be moving the game's focus from building up temporary bases to carefully planning and constructing a working city. The zombie mechanic would still remain, but the periods between zombie attacks would be longer, and there would be more to do than simply defend your city. The game's primary focus would be an efficient transportation system, crucial both to the city's economic health as well as its ability to rapidly deploy defensive units at a moment's notice. The game will feature human beings as well as vehicles as in-game actors, and the pollution model would be expanded to not only attract zombies, but also affect the health of the player's citizens.

3. New Studies

An expanded study could be done on *Super Energy Apocalypse* or similar games. First, the game could be compared to other energy games to learn which is better at getting players to learn about the topic. Secondly, the evaluation system which tracks player behavior could be deployed online to the general public to collect more data. Lastly, multiple versions of the game could be created to test whether various additional systems, such as an in-game encyclopedia, produce any change in the game's effect on learning.

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APPENDIX A

DEVELOPMENT DETAILS

SEA's engine consists of two key systems feeding into each other - defense and economy, each with their own sub-systems. All of these are tightly interwoven into an overall game system that rewards efficiency and cleanliness and punishes waste and pollution. The design for these changed throughout the development process, as problems were discovered and solutions that flowed from first principles were applied. This section discusses the purpose of each game mechanic, how it contributes to both fun and learning, and how it evolved from initial design to final implementation.

A. Defense

The defensive component of the game was designed to be the fun that gives the player a reason to learn about energy economy. This required a system that was complex enough to provide real strategy and interest, while at the same time relating directly back to energy economy. These goals are accomplished through careful design and balance of the player's defensive buildings and the different kinds of monsters in the zombie horde. Each defensive building differs in both the resource used as ammunition and the way it attacks, allowing for varying strategies from a tactical standpoint (which weapon is best for taking out groups?), as well as an economic standpoint (how do we defend ourselves when we are low on oil and gas?). There are 3 different types of zombies in the game, each with a different way of attacking the player and exploiting his pollution, keeping the player from coming up with a simple solution that only works against one type of enemy.

Defense is confined only to the night-time phase of the game. Zombies can't stand the sunlight and will die instantly at the break of dawn. This way, even if the player is

completely overwhelmed she will live another day if she can hold out just long enough for the sun to rise. This mechanic allows excitement to build to the highest possible levels before giving the player a breather, while still giving her a reasonable chance of survival. Furthermore, the day/night cycle allows the player to dedicate each respective period to economy and defense, without having to do both at once, as is commonly done in real-time strategy games. The player starts building at dawn, and the resources and pollution she's produced by sunset will determine how difficult it will be to live through the coming night.

1. Defensive Buildings

There are four kinds of defensive buildings - gun turrets, floodlights, flame turrets, and Tesla coils, all of which are suited to a particular task, and consume a different resource. The player must use them in balance in order to survive without putting too much strain on their resource base.

Gun turrets have a good range, fire quickly and do steady damage. They suffer from two limitations: first, they are single-target only, which means that a gun turret has a maximum efficiency cap (each unit of metal spent can damage one and only one zombie). Secondly, they are inherently inefficient-a gun turret will continue to fire on an enemy even after it is dead, not stopping until the enemy's death animation has finished and its object is removed from the game, though this might not be immediately obvious to the player. Furthermore, this inefficiency only increases as more guns are placed. When two gun turrets fire on a single enemy, they waste twice as many bullets after the enemy is killed. The largest downside to gun turrets is that metal is one of the most precious resources in the game as it is needed for building most structures and has no substitute. Since conservation is one of the game's lessons, it allows the player to completely run out of metal by overusing gun turrets. Running out of metal will quickly hamper a player's growth and might even spell defeat. However, metal is also very easy to recycle in real life. In accordance

with first principle 4 (conservation of matter & energy), it was decided that 75% of the metal spent to create a bullet would be preserved in the enemy's body upon being shot. Upon its death, this metal would become part of its garbage, which could be reclaimed when deposited at a landfill with a recycling center. Thus, a player with a strong metal recycling program will have greatly reduced mining needs. A final consideration when placing gun turrets is the metal cost of the turret itself. Most defense structures cost metal to build, but since gun turrets use metal as ammunition, it is important for the player not to build too many in the middle of a fight, increasing his firearms but depriving himself of bullets.

Floodlights are the cheapest form of defense. The only defensive option requiring no metal to build (a gameplay concession to allow the player a fighting chance should they run out of metal), floodlights have an area affect over which they do low damage. Floodlights do significantly less damage than all other forms of defense but have the benefit of no efficiency cap: each additional enemy that wanders into the floodlight's circle of light costs no extra energy to damage. Furthermore, the damage radius of several floodlights can overlap, multiplying the damage done to enemies caught in the intersection. Although floodlights are fairly cheap, they have a low energy-to-damage dealt ratio when compared with Tesla coils . Although effective against low-level zombies, floodlights barely scratch stronger zombies. For this reason, many players find floodlights to be a poor defense option when resources are plentiful. But when metal is scarce and energy is low, they will always have the option of throwing up a few floodlights in a last-ditch effort to survive.

Flame turrets are one of the most powerful weapons in the game but also have the largest down-sides. First and foremost, they use the most valuable resources in the game : oil and natural gas, which are non-renewable and scarce on many levels. Secondly, they are difficult to use efficiently. Lighting several enemies on fire at once will get the most bang for the player's buck, but if flame turrets are placed too close to one another they

will wastefully fire on the same group of enemies. Lastly, flame turrets cause incinerated enemies to turn into smog instead of garbage, which can quickly raise pollution levels if the player relies solely on flame turrets.

Tesla coils are the last and most powerful weapon, but, like flame turrets, are balanced by being tricky to use. A Tesla coil has the longest delay between detecting an enemy and firing, during which the original enemy might escape the attack radius, leaving the coil to waste energy firing at nothing. However, this allows a skilled player to set up "traps" for a group of enemies. In this case, the delay is beneficial as it allows the first enemy in a group to start the countdown to the energy blast, which, when timed correctly, fires just as the rest of the group comes into range. The Tesla coil consumes a large amount of energy but deals a heavy amount of damage, so its net efficiency is greater than that of a floodlight (assuming it actually hits something). The danger, however, is that the Tesla coil consumes energy must faster than a floodlight, and an unwary player can quickly deprive themselves of all their energy if too many Tesla coils fire at once. Tesla coils require both energy and metal to build.

In most tower defense games, the player spends resources to construct buildings that automatically fire upon enemies with no ammunition cost. In contrast to this, the main cost incurred by defensive buildings in *SEA* is not constructing the turrets but keeping them stocked with ammunition. A player who relies entirely on one kind of defense will find himself completely undermined when he runs out of the proper resource and all his weapons shut down. This not only balances the weapons against one another so that each has a situation in which it is useful and valuable, but also keeps the defensive game tightly linked to lessons about resource conservation and energy economy.

2. Zombies

The zombies are not intended to directly represent anything from real life. Their primary purpose is to provide the fun that will motivate the player to learn about energy economy and pollution. Although energy sustainability is an important issue, it comes across to many players as a dull topic, and nothing motivates players quite like fighting zombies. Furthermore, the zombies are designed to provide immediate feedback as to how well the player performed on the previous day. Although the various energy and pollution sources are based on real life research, this game does not intend to make literal statements about the effects of pollution, just to make the player learn where it comes from and how to deal with it.

There are three different kinds of zombies in the game, each with different properties and behavior. The first looks like a giant eyeball with four green legs. This enemy, the simplest and most mindless of the zombies, is referred to in the source code as an "Edderkopp," the Norwegian word for "Spider." The next is a strange tentacle monster riding a Humvee, known as a "Raider." Raiders appear when the player is rich in resources and will attempt to steal them. Finally, there is a large cluster of eyes and tentacles riding a blue truck, known as a "Monster Truck." Monster trucks are similar to Raiders but target landfills and nuclear waste.

All zombie types share certain features: they all spawn from the wasteland, turn into garbage upon being destroyed, and are instantly killed by sunlight. Zombies will only ever target the player's buildings, never his vehicles. This was a concession to both gameplay and performance. Having the enemies attack the player's vehicles would have unnecessarily expanded the defense portion of the game and greatly increased difficulty and frustration, as the player has no control over where his vehicles go. Furthermore, it would have opened up a whole new AI problem to solve if the zombies were given both static and mov-

ing targets to choose between. All of this would have distracted, not added to, the game's focus on energy economy. The decision to make zombies ignore vehicles came with the risk that players would assume their vehicles were targets (as they are in most other strategy games) and become confused when the zombies passed them over. This could have been solved by having vehicles rush to a "safe" location at night and thus not be available as targets. However, this would deprive the player of the ability to clean up waste at night while the zombies are out. Ultimately, no plausible story reason was ever devised for vehicles passing under the zombies' radar, but most players did not seem to notice or care.

SEA1 featured the Edderkopp as the sole enemy type, which spawns from the bordering wasteland, as well as polluted sludge created by garbage overflows. Its behavior is to seek out nearby garbage to eat or buildings to attack. It is the only enemy that eats garbage, but since it appears on all levels and forms the backbone of the zombie horde, garbage management is always a concern for the player. Once an Edderkopp targets a building, it will fire on it until the building is destroyed or the Edderkopp is killed. Since a destroyed building turns into garbage, this creature can grow quite strong if it destroys a few buildings in a row and eats all the resulting garbage. Low-level Edderkopps take less than a second to be killed by the simplest defenses, but at maximum level it can take several minutes, even under heavy fire, to take one down. At this level, they are practically invincible and can take down a building in a single shot . The original version of the game only featured this single type of enemy, which worked fairly well in providing the proper incentives to manage a clean and efficient energy economy. Originally, it was decided to have only one enemy type to keep the game's focus squarely on energy economy. However, players complained that the defense game was too easy with only one enemy type, making efficient energy management less important. Furthermore, Edderkopps were so simple-minded that they could be defeated with easy tricks that either short-circuited the defense game or let the player get away with being dirty and inefficient.

Two of the most common tricks were “death perimeters” and “bait mines.” The “death perimeter” strategy consisted mostly of building large walls of guns, floodlights, and Tesla coils all around the base so that no economic buildings were exposed to enemy attack. Strictly speaking, this was not an exploitative strategy on the part of the player - it was balanced by the downside of being wasteful and expensive. However, if the player was resource-rich, it made the game boring. A skilled player with plenty of energy could simply surround herself with Tesla coils, walk away from the keyboard, and watch the zombies throw themselves uselessly against her death perimeter. High level Edderkopps would eventually become immune to this strategy should the player pollute enough to produce them, but most low and medium-level Edderkopps were decimated. The intention was for the player to notice the difference in just a single level of enemy growth, and Edderkopps alone simply were not clever enough.

The “bait mine” strategy was also quite popular and consisted of placing unprotected mines close to the wasteland for zombies to attack. Mines are practically free to build , their main cost coming from the energy needed to run them and the garbage they produce. However, mines, like most economic buildings, don’t run during the night, which means that for only 1 energy unit, the player can buy themselves at least 15 seconds of safety from an Edderkopp intent on taking down the closest building, whatever it is. On a map with enough spots to place mines, a player hardly had to build defense buildings at all. This, along with the “death perimeter” strategy, suggested that Edderkopps alone were not enough of a challenge.

The second type of enemy , the Raider, was designed specifically to defeat the “death perimeter” strategy and to keep resource-rich players on their toes. Raiders appear when the player amasses resource surpluses, and appear in direct proportion to how rich the player is. Unlike Edderkopps, Raiders do not seek out and eat garbage while slowly marching towards a target. Instead, they drive quickly and directly to a source of wealth (a building

associated with the resource type the player has a surplus of) and attack it. When they attack it, they fire a single heavy-damage shot, steal some resources, and then retreat to the wasteland. Should the Raider make it off-screen successfully, they will recover their health and return again to another target. Raiders thus provide a challenge and a balancing factor for players for whom the game has become too easy, without unfairly punishing players who are resource-poor and barely clinging to survival. Although Raiders do not eat garbage, they do level up with smog. In *SEAR*, a resource-rich player trying to get away with high pollution levels will find their death perimeter penetrated by a Raider fast enough to outrun Tesla coil blasts, tough enough to survive a flame turret, and strong enough to level a power plant in a single shot. Should the player dot the map with "bait mines," she runs the risk of a Raider targeting one of them and stealing her precious metal.

The third type of enemy, the Monster Truck, was designed specifically to illustrate the danger posed by solid and nuclear waste. The purpose was to acknowledge the environmental hazard of having a landfill in one's backyard by making these facilities pose more of a security risk in game terms. This was part of *SEA1*-if a landfill was destroyed, all the zombie-attracting garbage would pour out-but they were easily guarded behind simple perimeters. Even worse, players often placed them right next to important buildings like power plants and the fortress, a choice that *SEAR* sought to discourage . Next, nuclear waste needed greater negative consequences. Originally, it was treated as another form of garbage, albeit more potent at leveling up zombies. However, Edderkopps were so slow and simple-minded that a nuclear dump full of nuclear waste rarely posed a security risk. If zombies were never plausibly able to capture the waste, nuclear plants would, in game terms, be completely innocuous and have no downside. Monster trucks were designed to exploit both of these waste streams in *SEAR*.

Monster trucks, like Raiders, ride on fast vehicles that can penetrate perimeter defenses, come in for a quick potshot, retreat, recover, and do it again. Unlike Raiders, they

target landfills, nuclear dumps, and exposed nuclear waste. Targeting landfills makes them a real threat. A ruined landfill will have all its garbage pile right up on that spot, instantly polluting the ground. This will then spawn Edderkopps in a few seconds, who will have enough tasty garbage to catapult them to the highest levels of strength. This produces several incentives for the player : first, to be careful not to place landfills too close to important buildings or to the wasteland, second, to space out their landfills and not dump all their garbage into a single site, and last, to simply reduce the amount of garbage they produce.

Next, if a monster truck is able to capture exposed nuclear waste (waste not stored in a nuclear waste dump), they will instantly spawn several high-level Edderkopps right on that spot, potentially in the middle of the player's base. Should the monster truck attack a nuclear waste dump, it will carry off some of the nuclear waste stored inside with it. Should it get to the wasteland, it will share the waste with its friends, creating several high-level edderkopps who will wander in from off-screen. If the player kills a monster truck that has already stolen nuclear waste, the waste will be dropped along with the monster truck's normal death garbage, giving the player a chance of picking it back up with an engineer. It is therefore always a good idea to store the waste in a dump since exposed waste could instantly create a problem. This provides several incentives for the player - first of all, to instantly secure any nuclear waste, to defend her nuclear waste dumps, and to keep them away from important buildings and the wasteland, and second, to limit the amount of nuclear waste she produces by diversifying her power sources.

B. Economics

Economics is the other half of the game. This consists of extracting resources from the environment, processing some of those into energy, and using these resources to build,

maintain, and run the player's base. The primary resources are energy and food, produced respectively by power plants and farms. Buildings require both - they cannot function without energy, and without food they will suffer damage from starvation. Energy is the game's primary currency - almost every action the player takes costs energy, including construction, repair, upgrades, and supplying buildings with the power they need to run. Furthermore, energy can also be used as ammunition for floodlights and Tesla coils, as well as a fuel source for electric vehicles. Food's primary use is to keep the player's base alive, but may also be used as fuel for vehicles with ethanol-based engines.

The game's secondary resources are metal, coal, oil, natural gas, and research. Metal is used as a construction material, as well as ammunition. Coal, oil, and natural gas represent the three different fossil fuels available in the game. Coal is used solely as a source of energy, whereas natural gas can be burned for energy as well as placed directly in a vehicle's fuel tank. Oil is not used as a power source in this game, but can be used as gasoline fuel for vehicles. In addition, natural gas and oil may be used as ammunition for flame turrets. Research, the final "resource," abstractly represents the labor and insight of the player's scientific community. Research can be used to purchase upgrades for power plants, fuel types, and recycling centers.

1. The Game Cycle

The main idea for the economic section of the game was to clearly demonstrate how energy and resources were consumed, produced, and transformed. The idea was to depict this visually - for instance, coal would be seen entering a coal plant, and then energy and smog would be seen exiting it. In early builds this would happen continuously: every second, every building would consume its inputs and produce its outputs, playing the accompanying animations (See Figure 14).

When more than a few buildings were placed on the map, however, this became pure

Fig. 14. SEA: Energy Production Visualized

visual cacophony - icons were everywhere, and it was impossible to follow what was going on. Therefore, the production cycle was stretched out, with each type of building waiting until its designated turn to run. This would let the player follow the process of his economy one step at a time. This is called the "game cycle," which lasts for 15 seconds of game time (see Figure 15).

Putting the economy on a timed schedule like this helped tone down the visual clutter while still providing important information to the player. The cycle continues throughout the day and into the night, when most buildings shut down. Farms, mines, wells, and labs will only produce at daytime, but power plants and factories will continue to run after dark. This forces the player to plan ahead during the day and limits what the player can do during the night, to keep daytime's focus on economy and nighttime's on defense.

It should be noted that game time is one area where the design has taken some lib-

Fig. 15. SEA: Buildings Producing in Turn

erties with the simulation. For the numerical model driving the economy, 1 game cycle corresponds to 1 year of real time, but is not meant to depict that amount of time in the game's world. For instance, it is quite unrealistic to build several power plants, farms, and factories in a single day, but for the sake of simplicity this is allowed in 1 game day of *Super Energy Apocalypse*. Furthermore, if every cycle were depicted as a full year's time the characters would all grow old and die before the first level was finished. All the numbers that drive the game's simulation are intended to demonstrate the relative ratios of power, pollution, production, and consumption rates of the various buildings, and nothing else. The numbers for the game cycle are based on an annual model because that was the easiest time frame to collect and normalize data for, but do not take this to mean that the game's depiction of time is intended to be literal or realistic.

2. Energy

Energy is the central focus of this game. Money was intentionally omitted as a resource, using energy as the main currency instead. Energy is used in order to build new buildings, repair damaged ones, and build vehicles. It is also consumed by farms, mines, wells, and recycling centers whenever they produce their regular outputs. Lastly, energy is used by floodlights and Tesla coils as ammunition, and as fuel for vehicles when using the "electric" fuel type. If enough energy is not available when a building attempts to produce, it will skip its turn that cycle and a speech bubble with an energy icon in it will appear to alert the player of brownouts.

Since energy is so important, it is given a prominent location in the resource bar, and color-coded to represent how much is left (red for low amounts, yellow for medium, and green for high). Furthermore, since the amount of energy fluctuates so often and so rapidly, the player needs to know not only how much energy he currently has, but also the rate at which it is increasing or decreasing. For this reason, a net gain/loss is depicted next to the main energy readout at all times. By mousing over this value, the player sees how much is being consumed and produced each cycle to produce that net value (see Figure 16).

Fig. 16. SEA: Energy Breakdown on Mouseover

When mousing over this value, the player is prompted to click to see a full report on energy. This takes the player to a breakdown that shows them which facilities, and how many of each, are contributing to energy production and consumption (see Figure 17).

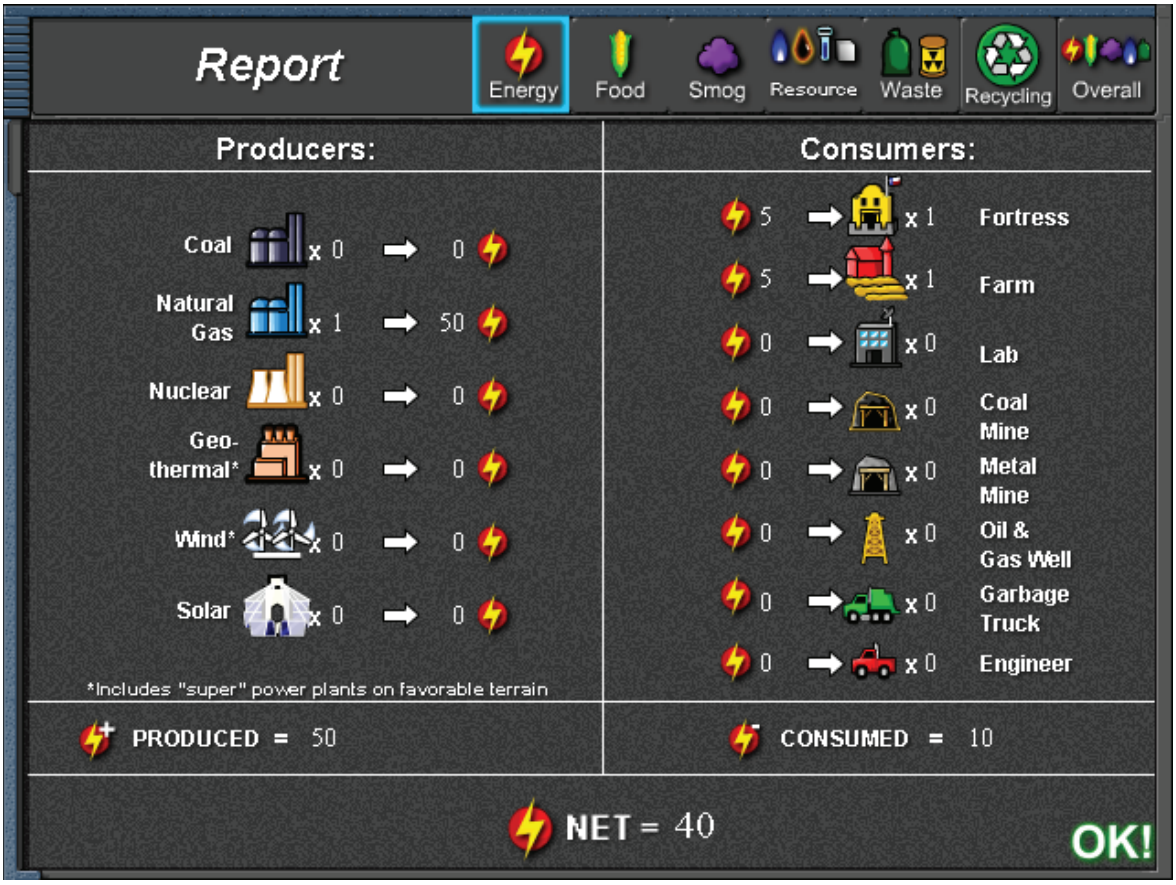

Fig. 17. SEA: Clicking Opens the Full Report

3. Power Plants

Power plants produce energy, and balancing their relative advantages and disadvantages is at the heart of the game. The original goal was to present as broad a range of power plants as possible, but the final design settled on the six power plants presented herein - Coal,

Natural Gas, Nuclear, Wind, Solar, and Geothermal, as they formed a representative slice of traditional and alternative power sources already in use, and were the easiest to model within the game's framework. Other candidates such as Hydroelectric were passed over because of the difficulties in modeling their environmental impacts in the game's limited framework, which tracks pollution in terms of airborne emissions and solid waste. The game's power plants are generally divided into two categories - "traditional" power plants, including coal, natural gas, and nuclear, and "alternative" power plants, comprised of wind, solar, and geothermal. The former group is characterized by high output and high pollution, whereas the latter is characterized by lower outputs, no pollution, and various other setbacks that limit their use or dependability. The positive and negative qualities of these power plants comes directly from their real-world counterparts.

SEA1 featured an oil-fired power plant, but not coal. After discovering that oil-fired power plants are quite rare in the United States, oil being used primarily for gasoline, the oil power plant was replaced with coal for *SEAR*. Coal is considerably cheaper, and according to the the Energy Information Administration of the United States, 48% of America's energy is produced by coal-fired power plants alone [34]. This information was surprising, and thus coal's inclusion in the second version of the game was deemed essential. Although it might have been interesting to keep oil-fired power plants as an extra strategic choice, the pollution and energy output of oil plants was so similar to coal that this might be confusing to players early in the game, so they were removed, leaving oil's primary use as fuel for vehicles.

A key learning objective for the game was the economic concept of negative externalities- the cost of production that is not borne by the manufacturer or the consumer, and thus not accounted for in its selling price. This means that "cheap" materials often have non-money "costs" that are quite large, which are passed on to a vulnerable third party. For the fossil fuel family of power plants, this comes from the toxic emissions they produce, which

have already been described. Coal-fired power plants, however, have the additional "hidden cost" of the waste produced through mining coal. Coal is considered "cheap," in terms of dollars spent to extract it from the ground and deliver it to market, but this does not take into account the negative and costly effects of erosion, toxic leachate, dumping of waste rock, and general despoiling of landscape upon the community that hosts the mine. These decrease the value of that land by reducing its usefulness, beauty, and habitability, as well as increase the cost of restoring it to such a state. Though very cost-effective in terms of energy in vs. energy out, coal mines produce more garbage than any other source in the game (as they do in real life), and require the player to have a steady stream of garbage trucks (all consuming precious fuel) to cart the toxic waste away before it spills over and pollutes the ground. Should it pollute the ground, the player will have to create an engineer to clean up the mess, which costs energy, metal, and fuel. If the player ignores this waste, the cost will be realized in the form of hungry, powerful zombies. The zombies, fantastic though they are, are the game's way of making the player recognize and bear the costs of his economic decisions that are usually externalized to vulnerable third parties in real life. Investing in upgrades can help reduce the emissions of coal plants, but do nothing to help the mining situation. In real life, "Clean Coal" technologies focus almost entirely on power plant emissions, which is laudable, but ignore the larger, non-climate-change related dangers of coal power. In game terms, coal power is a great way to get lots of energy quickly, but must be used sparingly or the environmental downsides will quickly overwhelm the player. In informal observation, most players use Coal as a boot-strapping technology to get their base running, but then quickly switch to an alternative source.

Natural Gas is a fossil fuel often produced alongside petroleum that produces a comparable energy output to coal, but with significantly lower emissions. Although gas is much cleaner than coal, it is also more expensive, and takes longer to harvest a comparable amount. In general, it is not renewable, though landfill gas can be converted to natural gas

by investing in recycling technology. Natural Gas is also valuable because of its many uses - as an energy source, as a fuel source for vehicles, and as ammunition for flame turrets. Since power plants, vehicles, and defense can all potentially compete for the use of Natural Gas, it is important that the player spend it wisely, since it becomes harder to come by in later levels and is sometimes only available in fixed amounts.

A quick note on gas and oil - drilling does have an impact on the environment, but less than that of coal mining. Still, it should be noted that the in-game oil&gas wells do not effectively convey the negative externalities of real-life oil & gas exploration. Since the only environmental hazards modeled in the game are air pollution and solid waste, drilling is presented as "cleaner" than it is in real life, since extraction alone does not produce much garbage or smog. The game also leaves out offshore drilling or oil spills, as the game is entirely land-based. Given the time to create a more robust simulation, these externalities could have been incorporated into the gameplay.

Nuclear plants are the last of the three "traditional" power plants modeled in game. They produce about half the power of Coal or Natural Gas plants, but produce far more than the alternative energy sources. In the real world, nuclear power plants consume uranium as their fuel source, but this resource is not tracked in-game. The reason for this was that the player already had enough resources to deal with, and nuclear plants consume relatively small amounts of uranium (compared to the amount of coal consumed by a coal plant). Although this is somewhat offset by the scarcity of uranium, this was ignored for game purposes, as the main concern with nuclear power is not fuel consumption but nuclear waste. Nuclear waste is dangerous, and remains dangerous for a very long time. Another risk concerning nuclear waste relates to the national security - radioactive material being the perfect ingredient for a dirty bomb should it fall into the hands of terrorists. Rather than modeling any of these literally, zombies simply stand in for all the environmental and security risks involved. In real life, nuclear waste does not make lizards grow into Godzilla,

but it is a real, permanent danger. It is entirely the player's choice to decide whether they are more comfortable with conventional pollution or nuclear waste as the by-product of power generation.

The first of the "alternative" power sources available to the player is the wind plant, which represents an array of wind turbines. These have an average output of 1/5 that of a coal plant, with no emissions. Wind turbines are fairly cheap, and given enough metal, the player can produce quite a bit of power from them. Their major drawback, however, is inconsistency. Wind turbines depend entirely on the weather, which changes randomly each cycle. The game's weather system is very simplistic - it simply varies the wind speed throughout the day, moving up or down one level at the end of each cycle. Certain parts of the map represent high altitude, which increases the wind speed by one level for any turbines built there. This shows the player that wind power is more effective in some regions than others, and cannot be relied upon as the sole source of steady power generation. On higher difficulty levels, there are fewer high altitude spots.

The second alternative power plant is the solar plant, which represents a solar thermal power plant. In real life, there are two main types of solar power, the first being photovoltaic and the second being solar-thermal. Photovoltaic solar power converts the sun's energy directly into electricity through a solar cell. In contrast, solar-thermal power depends on a boiler and steam turbine like most traditional power plants, but concentrates the sun's rays to generate the boiler's heat instead of burning a fuel source. There are several variants of this : some use mirrored parabolic troughs to heat salt, which is then used in the boiler, whereas others use an array of mirrors to concentrate the sun's light on a central tower that houses the boiler. The game's solar plants are based off of solar-thermal technology The main drawbacks of solar power are low output, high cost, inconsistency, and reduced or no output at night. Solar plants are just as sensitive to weather changes as wind plants, so varying cloud cover is incorporated into the game, which changes randomly each game

cycle, just like wind speed. Although some existing solar plants continue to produce energy into the night, most of them do this by burning natural gas. A few, such as those that heat molten salt during the day, are able to store latent heat to keep the boilers running at night, but at diminished output. For *SEA*, solar plant output drops to zero when darkness falls.

The last alternative power source is Geothermal, which has the highest output of the alternative energy sources, but still far less than nuclear, coal, or gas. Geothermal plants, like most other power plants, rely on a steam turbine. Instead of burning fuel, however, a geothermal plant uses the earth's own heat to produce steam. One method involves threading a closed, water-filled loop of pipe through a geothermally active area of the earth. The water goes into the earth, heats up, rises as steam, turns the turbine, condenses, is re-injected, and the process repeats. Other methods involve exploiting a naturally occurring source of geothermal steam, such as a hot spring. In either case, the availability of this power source depends entirely on whether a given location has any areas of geothermal activity. Volcanic islands like Iceland and Hawaii are rich in geothermal power, whereas Iowa is not. This is modeled in-game by making "geothermal spots" available in certain locations throughout the game, but not in every level. Geothermal spots come in two forms: large and small, with the large spots yielding twice the power output. On higher difficulty levels, there are less geothermal spots in general, and large ones become rare.

4. Pollution

As pollution touches each of the other systems, the preceding paragraphs have covered it fairly well, but are summarized here. Pollution comes in four forms - smog, garbage, toxic spills, and nuclear waste.

Smog is produced mainly by burning fossil fuels in power plants and car engines, as well as from some other sources like farms. Smog causes zombies to become stronger, increasing the level of all newly spawned zombies by 1 for each 100 units of smog in the

atmosphere. This applies to all zombie types - edderkopps, raiders, and monster trucks. Smog decreases naturally at the fixed rate of 45 units per game cycle. The player receives a score penalty for each net gain in smog, and a bonus for each net decrease. Smog cannot go above 999 or below 0, but the player still receives the same reward or penalty to their score for their net rate of change each game cycle.

Garbage is produced by most resource extracting buildings such as farms, mines, and wells, as well as from demolished or destroyed buildings, and dead zombies. Edderkopps will seek out garbage and eat it, which causes them to level up, increasing their size and strength (see Appendix D, Table XIV). Garbage consists of 4 parts - organic material, which can be recycled into natural gas, scrap, which can be recycled into metal, "useful" material, which can be recycled into energy, and junk, which is useless and can only be thrown away, though all forms of garbage are equally tasty to zombies. The composition of garbage depends on its source, with gun turrets producing piles of scrap as they fire (spent bullets), mines producing mostly junk, and dead zombies consisting mostly of organic material. When a building is reduced to rubble, its garbage composition depends on how it was leveled. If it was safely demolished by the player, it will contain high amounts of recyclable materials. If it was destroyed by zombies, however, it will be mostly reduced to useless junk. Garbage is conserved, so the more garbage zombies eat, the more they will leave behind when they are killed. If a zombie is incinerated with a flame turret, the garbage in their belly will be converted to smog along with their body. This prevents the player from letting zombies eat garbage and then kill them to "delete" the waste. The player receives a score penalty for each unit of garbage eaten by zombies.

Toxic spills are produced whenever too much garbage piles up in one location for too long. These toxic spills count as extensions of the wasteland, so zombies will spawn from them at night, giving them close access to the player's base. These spills can be cleaned up with an engineer, but will leave a permanent stain on the player's score.

Finally, nuclear waste is produced from nuclear power plants. This waste has no direct environmental threat, but can easily increase the strength of zombies. Players must store it securely in nuclear waste dumps, where it is always vulnerable to capture by monster trucks. Should the zombies get a hold of it, they will instantly spawn high level edderkopps that are incredibly difficult to kill, even under constant fire.

C. Game Modes

Before any code was written to allow for dynamic levels, a single default map was built which had a little bit of everything that was planned for the final game, just to test things out. Many of the game's early testers really enjoyed playing the game like this and found it quite natural. However, when fresh testers were brought in they were immediately frustrated and confused. The players who had been testing from the start had the advantage of being introduced to the features one at a time as they were coded, whereas the new players were being overwhelmed by the game's tightly interlocking systems. The complex state of a typical game level was just too much for newcomers. To this end, a campaign mode was created to guide the player through a series of pre-planned levels that introduced them to one feature at a time and showed them step by step how to play the game. After playing campaign mode, players would be more than ready to enter sandbox mode, where all the features of the game would be exposed, and they could direct their own play by tweaking all of the game's settings and choosing from a wide selection of maps.

1. Campaign Mode

The purpose of campaign mode is to let the player jump in with no understanding of the game's rules and provide them with a steadily increasing challenge that teaches them how to play the game. Each level is based around a series of objectives - such as building a

certain kind of power plant, producing X amount of a given resource, and so on. These are all presented in the framework of a story of post-apocalyptic survivors trying to rebuild the "Republic of New Texas."

The main challenges to overcome were player confusion and skepticism over the game's theme. There was a great risk of losing the player in the first 30 seconds of play, in which the game had to compel her with its premise, show the player that she could handle what was being thrown her way, and convince her that a game about energy use was indeed fun. To handle these problems, the game starts with something exciting, simple, and familiar - shooting zombies. The player's first mission, "Taking out the Trash" starts with a shootout between the player and the enemy. The player has a fortress and several guns already placed, with zombies marching in from the right. The main character, Dr. Ananastasia Wurstwagen, sends out a distress callas the troops under her command assure her that their automatic defenses are in place. The zombies march in, the guns fire on them, and the player survives. This informs the player of the primary threat-zombies, the primary way of handling them-defense turrets, and that these structures fire automatically. The player is instantly primed to the sort of game she is playing, all without any risk of losing by not knowing what to do yet. The entire interface is mostly blank, with all of the command buttons and most of the resource bar blacked out to avoid confusion. Energy and metal are the only resources that are visible at this point, generously granted in numbers higher than the player could possibly spend for the first level. After the initial wave of zombies dies, Dr. Wurstwagen mentions the garbage left over from the dead zombies is a food source for the enemy, and that it needs to be cleaned up. A short tutorial graphic showing how to build garbage trucks is shown and at this point, the "factory" button glows and becomes visible. The player is given the objective of building a factory, and then garbage trucks to clean up the mess. Various other objectives follow, including building a landfill, setting up additional defenses, etc, until night falls and the player must faces the zombies once more.

This ends the level on a high note, and as the last zombie hits the ground the player has successfully learned how to "Take out the trash" in more than one sense.

The levels that follow use this objective/tutorial system to unveil further defensive options, all of the power plants, research, upgrades, and more, in a way that builds on the player's accomplishments from the previous level. The campaign mode thus serves as a structured lesson plan for learning how to play *Super Energy Apocalypse*, as well as the vehicle for an interesting story. The story features some twists and turns, as well as a climactic final sequence which requires the player to master both defense and extreme energy penny-pinching to survive. The reward for finishing the whole game is a short ending sequence followed by a rousing theme song written and performed by one of the game's first testers, Scott Johnsgard.

The levels and story both went through countless revisions to provide a smooth experience for the player. This was especially difficult because so many players were at different levels - some found the game incredibly easy, while others were struggling, and it was impossible to please both at once. To account for this, three difficulty modes were created: easy, normal, and hard, so players could pick the amount of challenge they wanted. However, it was important not to compromise the essentials of the game's engine in designing these different modes. For instance, making coal pollute less on "easy" mode would make that mode more accessible, but undermine the game's educational message. To that end, the simulation is exactly the same in across difficulties, but the level design varies. So instead of having zombies do less damage on easy mode, there are simply less of them in the "easy" version of level 3 than in "normal" mode. Buildings still produce the same amount of pollution and waste in easy mode, but resources are more abundant. Likewise, hard mode has more zombies and less resources, forcing the player to rely on alternatives and conserve every drop of fuel. Although there is a risk that players will not learn the same things in different difficulty modes, there is a greater risk of them quitting the game

entirely if it is too easy or too hard for them.

2. Sandbox Mode

Sandbox mode grew from the original "walled garden" the game was tested in. *SEA1*'s version of sandbox mode merely allowed the player to choose between several pre-designed maps. The player would then be given a default amount of starting resources and zombies would appear at a standard rate which increased over time. There were no objectives, and therefore no way to win. The game would keep going until the player chose to quit, or was overwhelmed by zombies.

Most players were unsatisfied with this. They wanted the ability not only to play around with settings and experiment, but also to set goals for themselves to give the game some basic direction. In *SEAR*, the player can modify not only their starting resources, but also the length of the day and night, the number of zombies that appear, the rate at which zombies increase, and more. Furthermore, the player can choose which areas of the map are bordered with wasteland, and can also choose to turn off zombies entirely. Lastly, players can set goals for themselves by setting how many days must be survived in order to win the mission, instead of simply playing forever.

These changes were met with greater satisfaction among players, although some still complained that sandbox mode didn't provide enough variety after campaign mode had been finished. As a bonus, five "challenge" maps were added, specific hard-coded scenarios playable from sandbox mode to provide players with a bit of extra content after campaign mode was over. These also served as examples of scenarios players could build for themselves using sandbox mode. The most frequent request by far was for a fully featured map/scenario editor, which was not possible to provide due to time constraints.

APPENDIX B

STUDY DATA

Table I. Participants

User ID	sex	sea_exposure	hours	age	gscore	genres	t_genres	minutes	difficulty	maxlevel	enjoy
37	male	never_played	20+	20	8	21	8	140	1	9	2
38	male	never_heard	1-5	23	3	5	3	90	1	9	1
42	female	never_heard	6-10	18	5	13	5	162	1	9	0
43	male	never_heard	20+	25	10	17	6	84	1	9	1
44	male	never_heard	1-5	18	2	17	6	112	1	6	0
54	male	never_heard	11-20	18	6	12	4	100	0	9	1
61	male	never_heard	11-20	18	10	16	5	160	1	4	2
62	male	never_heard	11-20	18	8	9	3	212	1	9	2
63	male	never_heard	1-5	18	5	18	6	96	1	9	1
69	male	never_heard	1-5	18	2	5	2	78	0	5	1
70	male	never_heard	<1	23	1	14	6	106	1	7	2
72	male	never_heard	6-10	18	4	6	3	76	1	6	2
77	male	never_heard	<1	23	2	9	4	494	1	7	0
78	male	never_heard	<1	27	1	8	5	94	1	7	2
28	male	never_heard	<1	25	1	7	4	88	0	3	1
83	female	never_heard	<1	21	0	5	2	166	0	9	2
84	female	never_heard	<1	21	2	19	8	312	1	9	1
85	male	never_heard	6-10	20	4	6	0	142	0	9	2
86	male	never_heard	1-5	20	2	16	7	360	1	7	2
89	female	never_played	6-10	26	8	21	10	230	1	7	2
90	female	never_heard	1-5	21	2	12	4	132	0	9	1

Table II. Pre-test Scores

User Id	Score	Percent	Nuke air	Farm air	Ngas air	Coal air	Wind air	Geo air	Solar air	Nuke power	Ngas power	Coal power	Wind power	Geo power	Solar power	Best fuel
37	8	61.54%	no	**no**	some	high	no	no	no	**high**	**mid**	**mid**	**mid**	mid	low	electric
38	10	76.92%	no	some	some	high	no	no	no	**high**	high	high	low	**low**	**mid**	**gasoline**
42	5	38.46%	**some**	**no**	some	high	no	**some**	no	**high**	**mid**	**mid**	**mid**	mid	**mid**	electric
43	7	53.85%	**some**	some	**high**	high	no	**some**	no	**high**	**mid**	high	low	**low**	low	**ngas**
44	7	53.85%	no	**no**	some	high	no	**some**	no	**high**	**mid**	high	**mid**	**low**	low	electric
54	7	53.85%	**some**	**no**	some	high	no	no	no	**high**	**mid**	high	**mid**	mid	**mid**	ethanol
61	8	61.54%	**some**	some	**high**	high	no	no	no	**high**	high	high	**mid**	mid	**high**	**ngas**
62	7	53.85%	**some**	some	**high**	high	no	no	no	**high**	**mid**	**mid**	low	**low**	low	**ethanol**
63	12	92.31%	no	some	some	high	no	no	no	**high**	high	high	low	mid	low	gasoline
69	9	69.23%	**some**	some	some	**some**	no	no	no	**high**	high	high	low	**low**	low	**gasoline**
70	10	76.92%	no	some	some	high	no	no	no	**high**	**mid**	high	low	**low**	low	**gasoline**
72	7	53.85%	no	**no**	**high**	high	no	no	no	**high**	**mid**	**mid**	low	**low**	low	**ethanol**
77	5	38.46%	no	some	**high**	high	no	**some**	no	**high**	**mid**	**mid**	**mid**	**low**	**mid**	electric
78	10	76.92%	no	some	some	high	no	no	no	**high**	high	high	**mid**	mid	**mid**	electric
28	8	61.54%	no	**no**	some	high	no	**some**	no	mid	high	high	**mid**	**low**	**mid**	**electric**
83	8	61.54%	**some**	some	**high**	high	no	**some**	no	**high**	high	**mid**	low	mid	low	electric
84	13	100.00%	no	some	some	high	no	no	no	mid	high	high	low	mid	low	**electric**
85	10	76.92%	no	**no**	some	high	no	no	no	mid	**mid**	high	low	**low**	low	**gasoline**
86	6	46.15%	**high**	**no**	**high**	high	no	no	no	**high**	**mid**	**mid**	low	**low**	low	electric
89	10	76.92%	no	some	some	high	no	**high**	no	**high**	high	**mid**	low	mid	low	**ngas**
90	6	46.15%	**high**	some	**high**	high	no	**some**	no	**high**	high	**mid**	low	**low**	**mid**	**gasoline**
KEY	**13**	**100%%**	**no**	**some**	**some**	**high**	**no**	**no**	**no**	**mid**	**high**	**high**	**low**	**mid**	**low**	**n/a**

wrong right

Table III. Post-test Scores

User ID	Score	Percent	Nuke air	Farm air	Ngas air	Coal air	Wind air	Geo air	Solar air	Nuke power	Ngas power	Coal power	Wind power	Geo power	Solar power	Best fuel
37	9	69.23%	no	some	some	high	no	no	no	**high**	**low**	high	**mid**	**low**	low	electric
38	**9**	**69.23%**	**some**	**no**	some	high	no	no	no	**high**	**mid**	high	low	mid	low	**electric**
42	6	46.15%	**high**	**no**	some	high	no	no	no	**high**	**low**	high	**mid**	**high**	**mid**	electric
43	13	100.00%	no	some	some	high	no	no	no	**mid**	high	high	low	mid	low	ngas
44	8	61.54%	no	**no**	some	high	no	**some**	no	**high**	**mid**	high	low	**high**	low	electric
54	7	53.85%	no	**no**	**no**	high	no	no	no	**high**	**mid**	high	**mid**	mid	**mid**	ethanol
61	8	61.54%	**high**	**no**	some	high	no	no	no	**high**	**mid**	high	low	mid	**high**	**ethanol**
62	7	53.85%	**high**	**no**	some	high	no	no	no	**high**	**mid**	**mid**	low	**low**	low	**ngas**
63	12	92.31%	no	some	some	high	no	no	no	**high**	high	high	low	mid	low	gasoline
69	9	69.23%	no	some	some	**some**	no	no	no	**high**	high	**mid**	low	**low**	low	**ngas**
70	11	84.62%	no	some	some	high	no	no	no	mid	**mid**	high	low	**low**	low	**ngas**
72	11	84.62%	no	**no**	some	high	no	no	no	mid	**mid**	high	low	mid	low	**ngas**
77	9	69.23%	no	some	some	high	no	no	no	mid	**mid**	**mid**	**mid**	**high**	low	electric
78	13	100.00%	no	some	some	high	no	no	no	mid	high	high	low	mid	low	electric
28	9	69.23%	**some**	some	some	high	no	no	no	**high**	high	high	**mid**	mid	**mid**	**ngas**
83	8	61.54%	**some**	some	some	high	no	no	no	**high**	**mid**	**mid**	low	mid	**mid**	electric
84	**8**	**61.54%**	**some**	**no**	some	high	no	**some**	no	mid	**mid**	high	low	**low**	low	**ngas**
85	**8**	**61.54%**	no	some	**high**	high	no	no	no	**high**	**mid**	**mid**	low	**high**	low	**ngas**
86	8	61.54%	no	**no**	some	high	no	no	no	**high**	**mid**	**mid**	low	**low**	low	electric
89	13	100.00%	no	some	some	high	no	no	no	mid	high	high	low	mid	low	**electric**
90	8	61.54%	no	**no**	some	high	no	no	no	**high**	high	**mid**	**mid**	**low**	low	**ngas**
KEY	**13**	**100%%**	**no**	**some**	**some**	**high**	**no**	**no**	**no**	**mid**	**high**	**high**	**low**	**mid**	**low**	**n/a**

wrong right

Table IV. Final Scores

User Id	Initial score	Final score	Change	Change (%)
37	8	9	1	7.69%
38	10	9	**-1**	**-7.69%**
42	5	6	1	7.69%
43	7	13	6	46.15%
44	7	8	1	7.69%
54	7	7	0	0.00%
61	8	8	0	0.00%
62	7	7	0	0.00%
63	12	12	0	0.00%
69	9	9	0	0.00%
70	10	11	1	7.69%
72	7	11	4	30.77%
77	5	9	4	30.77%
78	10	13	3	23.08%
28	8	9	1	7.69%
83	8	8	0	0.00%
84	13	8	**-5**	**-38.46%**
85	10	8	**-2**	**-15.38%**
86	6	8	2	15.38%
89	10	13	3	23.08%
90	6	8	2	15.38%

Table V. Paired T-test Results

	N	Mean	SD	t	DF	p
Initial scores	21	8.24	2.14	1.9720	20	0.0626
Final scores	21	9.24	2.1			

Table VI. Answer Change Analysis

User id	Nuke air	Farm air	Ngas air	Coal air	Wind air	Geo air	Solar air	Nuke power	Ngas power	Coal power	Wind power	Geo power	Solar power
37	no	some	some	high	no	no	no	high	low	high	mid	**low**	low
38	**some**	**no**	some	high	no	no	no	high	**mid**	high	low	mid	low
42	high	no	some	high	no	no	no	high	low	high	mid	**high**	mid
43	no	some	some	high	no	no	no	mid	high	high	low	mid	low
44	no	no	some	high	no	some	no	high	mid	high	low	high	low
54	no	no	**no**	high	no	no	no	high	mid	high	mid	mid	mid
61	high	**no**	some	high	no	no	no	high	**mid**	high	low	mid	high
62	high	**no**	some	high	no	no	no	high	mid	mid	low	low	low
63	no	some	some	high	no	no	no	high	high	high	low	mid	low
69	no	some	some	some	no	no	no	high	high	**mid**	low	low	low
70	no	some	some	high	no	no	no	mid	mid	high	low	low	low
72	no	no	some	high	no	no	no	mid	mid	high	low	mid	low
77	no	some	some	high	no	no	no	mid	mid	mid	mid	high	low
78	no	some	some	high	no	no	no	mid	high	high	low	mid	low
28	**some**	some	some	high	no	no	no	**high**	high	high	mid	mid	mid
83	some	some	some	high	no	no	no	high	**mid**	mid	low	mid	mid
84	**some**	**no**	some	high	no	**some**	no	mid	**mid**	high	low	**low**	low
85	no	some	**high**	high	no	no	no	**high**	mid	**mid**	low	high	low
86	no	no	some	high	no	no	no	high	mid	mid	low	low	low
89	no	some	some	high	no	no	no	mid	high	high	low	mid	low
90	no	**no**	some	high	no	no	no	high	high	mid	**mid**	low	low
KEY	**no**	**some**	**some**	**high**	**no**	**no**	**no**	**mid**	**high**	**high**	**low**	**mid**	**low**

Changed?	Description		3	5	2	0	0	1	0	2	4	2	1	3	0	Totals
Yes	Right to Wrong															23
Yes	Wrong to Wrong		3	0	0	0	0	0	0	0	2	0	0	3	0	8
Yes	Wrong to Right		5	3	8	0	0	7	0	7	0	4	3	4	4	45
	Any Change		11	8	10	0	0	8	0	9	6	6	4	10	4	76
No	Wrong		1	5	0	1	0	1	0	12	8	5	5	4	5	47
No	Right		9	8	11	20	21	12	21	0	7	10	12	7	12	150

Table VII. Free Response : Learning

User ID	enjoy	What did you learn from playing this game, if anything?
37	2	Wind energy is not reliable if you can't store infinite amounts of energy from the spikes it gives.
38	1	Each energy source has its own drawbacks and limitations.
42	0	more depth about energy conservation
43	1	The relationship between the amount of power generated by the various different forms of power plants. For instance, I'm used to hearing about large solar installations in real life, so I thought that they might be more useful in the long run. Instead, I found out why I had only ever heard about the large installations: because small ones just aren't that useful. I also didn't realize that geo-thermal was that practical in terms of energy production.
44	0	Nothing really in particular.
54	1	I didn't really learn anything from this game.
61	2	That our imnportant resources are gifts and curses. The essential resources are vital to human life but has its consequences like the smog and pollution.
62	2	Natural gas is the best as a fuel source
63	1	The relative pros / cons of energy production in America today. Although they were dumbed down quite a bit, and the danger of zombie production isn't why nuclear power is not widely used in the US.
69	1	Everything is connected, and to be successful you need a balance of energy, waste management, protection, technology, and resources. Everything has advantages, disadvantages, requirements, and vices to using, so choosing the right combination of facilities is essential for maximum efficiency. Efficieny and speed is necessary to survive.
70	2	Everything is a trade off. We could use all smog free energy, but then we might not have enough to fend off zombies...
72	2	Smog pollution makes zombies alot stronger :)
78	0	None.
77	2	Learned bout what kind of power production produces what all kinds of wastes, that farms do produce smog, etc (I hope these are actually true, and not just the imagination of the developer)..
28	1	About energy inefficiency of coal plants, disadvantages of garbage and smog and benefits of clean energy.
83	2	I knew some about the benefits of alternative resources, but in this game you really have to weigh the pros and cons of the resources as a strategy. It is an interesting way to inform people about it (and fun)
84	1	You need a lot more weapons than I thought to kill those zombies. I also learned a little bit about different energy uses.
85	2	Zombies love waste
86	2	I learned that if we are ever attacked by garbage eating zombies, the human race is doomed
89	2	- Nuclear plants do NOT produce the most amount of energy - Coal plants produce toxic levels of smog - zombies are way more evil than i first thought =s
90	1	The amount of emissions put off by different energies.

Table VIII. Free Response : Enjoyment

User ID	enjoy	Would you play this game again? Why?
37	2	Heck yea I would! It's educational, thought provoking, and complicated enough to keep me entertained. For harder difficulties I might try only using coal!
38	1	It was pretty fun, reminds me of Command & Conquer. I probably wouldn't play again just because browser games aren't my thing.
42	0	ehhh It gets kind of repetitive and the script isn't that great.
43	1	Yes. The game was fun to play, had enough depth to keep it interesting, and was somewhat challenging. That said, Flash support on the Mac, which is my preferred platform, is lackluster, since Flash hasn't been optimized for Mac since back in the Macromedia days. Given that my computer is a bit old (3-4 years old), and that Flash hasn't been optimized, some of those "30 second" nights literally took upwards of 5 minutes to complete.
44	0	No, I think it's a little complicated, and the storyline isn't interesting enough to overcome that.
54	1	Probably not. It was fun, but doesn't hold a high replay value for me. Maybe if I tried sandbox mode I would play some more, but that's about it.
61	2	I would definitely play this game more because not only is it informational but it is addictive.
62	2	yes, it was entertaining
63	1	Sure, but only if new elements were added, if there were more upgrades or abilities, and / or if the player could build military units as well.
69	1	I would maybe, it started boring and I failed a few times, but got a little better as the campaign went on.
70	2	Yeah, good game. I like RTSs anyhow.
72	2	Yes, it was creative and fun.
78	0	No.
77	2	I played it for 3 days to finish it off.. I don't know if 'll play it again, maybe when I'm bored.. I generally don't play a game after I finish it (Age of Empires & Max Payne were exceptions :D)..
28	1	Yes but I would like it to be a bit more easy.
83	2	I had a good time with it, might send it to my friends. I would play again to see if I can score higher in some levels, but the end really made me want more. I got addicted pretty fast, but I beat it all in one sitting, was very fun! Heh heh Flame turrets rocked, I ended up using a lot of those.
84	1	Yea, only wish it was longer. I liked the story line as well. The only other complaint I have is that some of the objectives were a little too easy.
85	2	ya, it was entertaining
86	2	yes, because i haven't beaten it yet
89	2	Yeah, beacause Still haven't been able beat the whole game on supernormal mode yet Feel like some of times i just passed a level by fluke, so wanna figure out the best way to beat some of the levels
90	1	yes, but I wish it were more mentally challenging than just creating a central defense.

Table IX. Free Response : Player Strategy

User ID	enjoy	What was your strategy to win?
37	2	Build an economy first, worry about protecting it later.
38	1	Geothermal plants, metal mines, and lots of guns.
42	0	energy=good
43	1	Basically, use coal and geothermal to kick-start my energy economy, then switch over to a predominately nuclear/geothermal approach. At that point, focus heavily on tesla coils and then another defensive tower that is appropriate for whichever resources were abundant on that chapter. Unfortunately, the strategy didn't work out so well on the very last chapter. Since energy caps at 999, ALL power plants of a specific type produce their energy at the exact same time (rather than producing it relative to when they were built), and mass numbers of tesla coils drain energy remarkably fast, I basically was left with a situation where I'd get one "tick" of energy production and would then have to live off of that tick until the next one, which simply wasn't feasible.
44	0	To first make sure I had a lot of incoming energy, counterbalance any ill effects of this energy, and then create effective defenses matching the available resources.
54	1	I tried to build floodlights around buildings and surround major buildings with as much defense as I could. I also focused on getting energy and food up as soon as possible.
61	2	Produce essential resources was key to everything but defenses are also important.
62	2	Lots of geothermal energy and metal
63	1	get max power and build Tesla coils.
69	1	Building many power plants and grouping defenses together heavily in vital areas to protect the base.
70	2	try to make sure I have enough energy to build defenses
72	2	Lots of natural gas, geothermal energy, and energy stockpiles.
78	0	Build.
77	2	In most episodes, I was clinging on to life till I had low smog count, so that the aliens were weaker that way. For that I almost always had to shut down the coal plant and use others like the Solar, geothermal and Wind energy plants. I made a lot of turrets instead of the flame throwers because natural gas and petrol were running out fast. Used very little tesla coils coz they were taking time to charge and weren't killing as well as I initially expected they would. And the flood lights weren't helping much, other than for draining the energy reserves I had. For turrets, I had to mind metal extensively.
28	1	Create as environmentally friendly things as possible, invest more in research.
83	2	I went crazy with my defenses on some levels, but learned you only really need a little bit to survive. I failed the first New Thermopoly level 3 times before i got a decent strategy.
84	1	Try to remove all the zombies before they got close to my buildings and to do all the objectives as quickly as possible.
85	2	to build defense, then resources, then more defense
86	2	build a lot of wind plants, geo-thermals, and tesla coils and upgrade as much as possible
89	2	in order of precedence: - build defenses - build alternatives to coal plants - build garbage trucks and recycling units - disable coal plants and build labs to upgrade everything else asap - build farms - build more defenses
90	1	keep things central and then surround myself with defenses. also keep trash low.

APPENDIX C

GAME PLAY STATISTICS

Table X. Summary

Game	Plays	Uniques	Play/Unique
SEAR	1,372,663	862,928	1.59
SEA1	1,667,922	1,369,071	1.3
Grand Total	**3,040,585**	**2,231,999**	**1.36**

Table XI. SEAR Plays

Date	Plays	Uniques	Play/Unique
Jan 09	466,644	259,203	1.8
Feb 09	236,880	157,089	1.51
Mar 09	113,192	78,882	1.43
Apr 09	61,960	41,529	1.49
May 09	81,345	53,865	1.51
Jun 09	80,750	55,206	1.46
Jul 09	93,624	62,077	1.51
Aug 09	93,973	59,851	1.58
Sep 09	73,606	45,700	1.61
Oct 09	70,689	49,796	1.42
Total	**1,372,663**	**862,928**	**1.59**

Table XII. SEA1 Plays

Date	Plays	Uniques	Play/Unique
Mar 08	139,515	173,018[1]	0.81[1]
Apr 08	448,745	394,910[1]	1.14[1]
May 08	178,766	131,727[1]	1.36[1]
Jun 08	114,061	81,748	1.4
Jul 08	83,540	60,309	1.39
Aug 08	81,379	57,471	1.42
Sep 08	58,955	43,444	1.36
Oct 08	65,596	49,336	1.33
Nov 08	56,056	42,405	1.32
Dec 08	57,087	43,298	1.32
Jan 09	58,079	43,922	1.32
Feb 09	41,375	31,736	1.3
Mar 09	46,764	35,876	1.3
Apr 09	37,783	28,492	1.33
May 09	33,042	25,505	1.3
Jun 09	31,796	24,886	1.28
Jul 09	33,974	26,254	1.29
Aug 09	39,332	26,957	1.46
Sep 09	29,515	23,163	1.27
Oct 09	32,562	24,614	1.32
Total	**1,667,922**	**1,369,071**	**1.3**

[1]Estimate. MochiAds did not start providing this data until June 2008. These were calculated by estimating the ratio of plays/unique for that month and dividing the number of plays by that. Those ratios, in turn, were calculated by taking the play/unique ratio from the first three months of SEAR's release, and multiplying those by the difference between the two game's average play/unique ratios spanning the 4^{th}-10^{th} months of release.

APPENDIX D

GAME NUMBERS

Table XIII. Weapon Table

Type	Dmg/ Shot	Shots/ Second	Dmg/ Second	Ammo/ Second	Ammo type	Damage type
Gun turret	3	10	30	0.1	Metal	Single target
Flood light	0.5	10	5	3	Energy	Area
Flame turret	25	1.25	31.25	0.5	Oil/N.Gas	Single target(25) + Area burn(60/second)
Tesla coil	50	0.67	33.5	5	Energy	Area

Table XIV. Zombie Level-Up Schedule

Level	Garbage needed	Hit points	Attack damage	Size in pixels^2
0	0	25	1	625
1	10	75	3	900
2	30	225	9	1296
3	90	675	27	1866
4	270	2025	81	2687
5	810	6075	243	3870

Table XV. In-game Unit Table

Resource	**Amount per 1 game unit**	**Real-world unit**
Energy	10	MwH (MegaWatt-Hour)
Food	1000	metric tons (mt) corn
Metal	0.1	metric tons various metals
Coal	75000	metric tons coal[1]
Oil	40000	metric tons crude oil
N. Gas	40000	metric tons[2] natural gas[3]
Garbage	1	metric tons solid waste
Smog	1000	mtce[4]
Nuclear Waste	see footnote[5]	none
Research	see footnote[6]	none

[1]Approximation of 74,840 mt coal

[2]Natural gas is usually measured in Mcf, or 1000 ft^3 @ standard temp. and pressure. STP density was used to convert to mt for cross-comparison

[3]Approximation of 37,670 mt natural gas

[4]Metric Tons Carbon Equivalent. The mtce of 1 mt of methane gas, for instance, is $\tilde{2}1$, which means it is equivalent to 21 mt of CO^2

[5]Nuclear waste is tracked as a unitless number in SEA. It does not directly correspond to an amount of spent uranium.

[6]Research is tracked as a unitless number in SEA. It does not represent any amount of researcher-hours, published papers, or test tubes filled with interesting blue fluids

APPENDIX E

POWER PLANT NUMBERS

Table XVI. In-game Power Plant Table

Type	**Cost**		**Energy Out**	**Uses**	**Amt. Used**	**Smog**	**Notes**
	energy	**metal**					
Coal	250	25	50	Coal	1	35	
N.Gas	75	25	50	N. Gas	1	15	
Wind	80	20	10	—	—	0	Weather changes output
Solar	95	10	4.67	—	—	0	Weather changes output
Geoth-ermal	200	15	12.5	—	—	0	Only on hotspot
Nuclear	150	25	25	—	—	0	Makes nuclear waste

Getting data on specific power plants was quite difficult. For most facilities, all that could be found was the MwH output of each plant. In most cases, this was either posted on the company's website or found by contacting the power plant by phone [35][36][37][38][39][40][41][42][43][44][45][46][47][48][49][50][51][52][53]. Oftentimes, power plant representatives were reluctant to help the researcher collect data for what he described as a "school research project." Although some were able to supply MwH output, none were able to supply data for the annual emissions of their plant. Luckily, the EPA's 2002 NEI (National Emissions Inventory) had emissions data many facilities. The game's air pollution focus was on all pollutants rather than just carbon dioxide emissions, so all chemicals tracked by the NEI were combined into one emissions value for each facility. The cost to build or purchase each plant was the hardest information to find, and was only publically available for a few facilities. The following data was found for certain power plants, focusing specifically on ones in Texas (??? means no data was available)

Table XVII. Power Plant Research Table

Facility Name	Power Plant Type	Cost (USD)	USD/ MwH	Output (MwH)	Emissions/ MwH (tons)	Emissions (tons)
Martin Lake	Coal	???	???	2250	66.24	149049
Welsh	Coal	???	???	1650	56.45	93141
Alcoa Sandow	Coal	???	???	1000	91.29	91291
Fayette	Coal	???	???	1641	34.57	56726
Harrington	Coal	???	???	1066	41.98	44752
Tolk	Coal	???	???	1080	37.6	40605
Coleto Creek	Coal	1,140 M	1.80 M	632	30.39	19209
Coal Avg				1,331	51	70682
W A Parish	N. Gas/Coal	???	???	3565	25.61	91291
Lost Pines 1	N. Gas	???	???	545	1.18	641
TC Ferguson	N. Gas	???	???	420	1.84	773
Jones	N. Gas	???	???	486	4.72	2292
Nichols	N. Gas	???	???	457	2.34	1068
Plant X	N. Gas	???	???	442	2.53	1118
Hobbs (Planned)	N. Gas	300 M	0.55 M	550	???	???
N. Gas Avg				470	2.52	1178
Nevada Solar One	Parab.Trough	220 M	3.44 M	64	0	0
Nellis Air Force Base	Photovoltaic	100 M	7.14 M	14	0	0
White Deer Wind Park	Wind	104 M	1.31 M	80	0	0

This provided basic numbers for the cost of certain power plants. $1,800,000/MwH was arrived at for the coal plants, and $500,000/MwH for the natural gas plants. Wind was pegged at about $1,300,000/MwH and Solar Photovoltaics at $7,000,000/MwH. This left Nuclear and Geothermal plants. Direct power plant profiles were not found, but two numbers were discovered through research: $3,000,000/MwH for Geothermal[54] and $2,200,000/MwH for Nuclear [55]. This was definitely a small sample size, but gave good enough data for a "back-of-the-envelope" calculation. These were used as starting points, with a little bit of liberty given to balancing the game, so long as the ratios were kept in tact. The relative cost to build in dollars was used merely as an indicator of ratios. From this were derived arbitrary costs in energy and metal that more or less reflected that ratio.

Normalizing units proved difficult. The original plan was to have all physical materials be directly comparable (ie, each "1 metal" and "1 coal" both represent X metric tons of those resources). Unfortunately, if this were done resources like metal would simply drop off the scale when compared to resources like coal, since the amount of metal mined and consumed annually in the United States is many orders of magnitude smaller than that of coal. Therefore, it was decided to let each unit represent a fixed "convenient" amount, unique for each resource type, which fulfilled several goals:

- Allow for meaningful amounts of the resource numerated from 0-999.
- Minimize the need to track fractional amounts of a unit.
- Allow for the main power plants to consume "1" unit of their resource as an easy point of comparison to other uses of that resource in the game.

APPENDIX F

INTERVIEWS

Interview #1

Time: Friday October 9th, 2009 @ 7:30 PM

Place: Texas A&M University, Langford Room C429

Participants:

A = Player 61

B = Player 63

C = Player 28

INTERVIEWER: If I could just get everyone to introduce themselves and give your name or your made-up name and then whatever screen name you used to play the game

B: I don't remember my screen name...

A: I'll start off, I'm [name], Computer Science Engineering major here at A&M, and uh, I believe I used [user id].

C: I'm [name], you can call me [nick name], I must have used my ID, [user id], (spells it).

B: I'm [name]. I'm also a computer science major here at A&M, and I totally forget what I registered myself as for this game [Laughter].

C: Oh, by the way I'm a computer engineering major.

A: Nice

INTERVIEWER: I'm an English major, I'm completely out of my element here (laughter from all)

B: I'm not one of those people who is like an engineering elitist, I'm probably going to go to law school, gonna be a traitor.

INTERVIEWER: So, to you guys what did you think was the most interesting or most fun part of the game, what did you enjoy the most when you were playing?

C: The whole gameplay was kind of interesting, it was kind of hooked on to you, like you

had to build different kinds of guns and energy, energy-producing stations and then you had to build some different kinds of defenses, I guess that was kind of interesting, the gameplay.

INTERVIEWER: So, just the relationship between everything that you were making?

C: Mmm-hmm. Yes

B: Yeah, I really liked the gameplay and stuff, you know that's fun, you had the upgrade mechanics, sort of a tower defense thing, but also, little bit of real-time-strategy sort of stuff, managing your resources, I like all of that stuff, and then some [unintelligible] were decent, I liked that part of it.

A: You know, for me it was just the critical thinking, where, um, when you had to treat it as a real-time-strategy resource game, but you had to keep in mind the information he brings to the table about the energy resources, and you have to use real-life experiences, real-life information in this game, and if you didn't know the background, well I guess, (laugh) the better things you know about these resources, the better the game will play. Whether you're a beginner at RTS or an expert on [unintelligible], I guess just the knowledge of these resources is what, um, is what makes this game. And it brings that challenge of just knowing, and the more you know about it, I guess the easier the game would be, but it's still the challenge, probably, in setting up the difference of all how you say with the garbage trucks, how they drop off the trash...

B: Yeah, you gotta manage a few things

A: Yeah, you got to manage the small dudes as well-

B: You have to defend yourself, you have to build up your, I guess your economy of trash-collectors-

C: It was pretty much like the real world, it was not like, nothing was left for granted, you had to think about your trash and those things and then you had to think about creating a dump for that, you had to think about the pollution that was being created, so it was not just about creating more and more oil wells, for example, or more and more oil stations, you had to think about the fumes that were coming out of it.

B: Like a cartoony-real world, I would call it a realistic game, it's a, uh, definitely like a tower-defense, but they put a skin I guess over it, but, but now you're using energy to defend yourself you gotta think about that and maybe learn something, kind of like SimCity except you have guns. [Laughter from all]

B: the way the graphics look.

INTERVIEWER: So have you all played a lot of games like this before?

A: Definite. Command & Conquer, played a lot of that. [Unintelligible]. I guess while it would be easiest for me to set up shop, it was just um, you know teaching me these resources, so I could know what was really going on.

B: Yeah, it's kind of like an RTS, but you don't really command units, so I guess I compare it to a lot of the older city-building sort of games, like SimCity, uh, like Sierra Games where

you were like a Pharaoh or Caesar, those games, kind of like that, yeah, you build a little city, yeah ... Civilization - kind of - in terms of view, but the gameplay's a lot different. Advance Wars, there's this game for the GameBoy Advance where you control military guys and move them around and, that was a great game and, I don't know, the gameplay was different, but I kinda got the same sort of feel from it with the grid map and stuff.

INTERVIEWER: That was actually one of the things Lars said really inspired him for this project.

B: was Advance Wars?

INTERVIEWER: Yeah. [Unintelligible] [Laughter]

A: He's got good taste. Good taste.

C: Yeah, I am off and on the PC player, I kind of never had a station gaming had to really play any game, but I would definitely place that, I mean in terms of the genre, if I were to, were to think about it, I would place it around Age of Empires, Age of Empires, Age of Emperors?... Age of Empires, right? (Seems to be asking if the game he's thinking of is called "Age of Empires")

INTERVIEWER: Yeah.

C: I would definitely place it around Age of Empires, or there was this other game called Commandos or Call of Duty? The one in which you had commandos, the one in which you have

B: I think it was "Commandos" or "Commando?"

C: Pretty much... place it, where basically you have a different frame of view and you're viewing things from a 3rd person perspective, and you are like, I mean you are sort of looking with just controlling the spawns and making sure that the game turns out to be good for your side.

A: okay, I guess

B: In terms of themes, I think there's a whole bunch of games that have sort of made it... I think in gameplay, like you could actually could count it as, "Tower Defense," it's like Desktop Tower Defense, if you've played that or uh,

A: is that the iPhone, anyone?

B: Of course it's over like everything, I think it started in Warcraft III actually, not sure though, someone made that game mode where you build towers and someone made a flash game of that, and a million people just copied it and put any kind of theme to it, kind of tower defense, and uh you just build towers to stop wave after wave of enemies. So this game looks at that and says, said... [interviewer's phone rings] "Let's call you on the phone!" [Laughter]

INTERVIEWER: It's a text message, I'll read it later [switches off phone].

B: But, uh, they took that and put it in with SimCity, where it's like, "Let's have an economy. Let's build farms, and stuff like that."

INTERVIEWER: So was there anything that you guys really disliked about the game? Like, what was the least fun moment for you?

B: I'll start it I guess. Uh, when I found out that you couldn't upgrade it any further, cause I looked and saw the upgrades carried over between the levels and I thought that was cool but I eventually maxed out all the upgrades and could just spam everything and that sort of broke the difficulty, I guess? I kind of wish there was a little more depth in what you can do, just uh, more things you can do to build, and change up your strategy after a while.

A: I guess for me, um like, well I guess it's part of the action of any game, but as the enemies increase the frame rate, the frame rate of the game, it began more lagging a little bit, glitching, [unintelligible] I guess that was just the most disappointing part for me, but I guess it can happen to any game, it can happen in any game.

C: I guess the most frustrating part of it was zombies that would just coming and didn't seem to have any life of their own. [chuckle] But yeah, uh, I mean, I think that there was just a certain limit after which you could upgrade and that was kind of the sad part of it, and then there was also the fact that once you had done certain things wrong, it might be very difficult for you to reverse the direction of the game and then you're back to your side so for example, if you have already produced too many, too much smog you would almost always have to restart the game...

B: Oh yeah?

C: ...to actually end up on the winning side. I mean, I guess it actually could have fit in with the theme of the game, which is kind of trying to model the real world in terms of the environment and just kind of in a sense imagine that once you have a problem you can not really reverse it, but I guess when you play it in a game maybe you would only expect that, maybe no matter how badly you had performed in the past if you perform good in the future you might have a chance of winning back again, kind of something you just expect.

B: I forget which mission, I totally screwed up, I didn't have enough farms and I couldn't build any more farms because I didn't have enough power, sort of destroyed yourself - I kind of wish you could upgrade the towers, uh the towers? But yeah, I'm used to playing tower defense and you could always upgrade the towers, so I was clicking on the guns, and it just said, "gun." I was sad. [Laughter]

INTERVIEWER: So if you could change one thing about the game, just any one facet of it, what would you do?

A: I think I would go with you, it just uh, needs more customization with the guns, I guess, or just, it's not that there was nothing wrong with the guns or any of that, cause they did defend, they did do their job, which was to defend, but um, but for the guns to really be effective, you had to have too many of them, and with the uh, flash, the floodlights, the flashlights, for them to be effective, you had to put up a good 3 or 4 of them in the area. If you could upgrade like the, the width of the lights, or the power of the lights, um, I guess it would have been better I guess just customization of the guns.

B: I thought it was pretty fun to have a whole bunch of em, I didn't mind that, but uh, to upgrade them at certain critical points, where you want to use more power, would get some more tactical flexibility, something like that?

C: I would personally want some, um, uh, what's the word, some variety in the zombies, maybe? That's something that would naturally after a point it was kind of boring to see the same things coming up again and again, of course, granted that the situation was different and you were in a different position every time and again and perhaps like previously you were thinking about building a farm and those kinds of things and later on you were thinking about upgrades, but this thing was kind of stuck throughout the game, that the zombies were always the same.

B: Zombies, and zombies with cars [chuckle]. Special zombies that are only weak to certain things, or...

C: Maybe it would be good to see, maybe different zombies for example, just in terms of appearance and their susceptibility, and maybe some zombies who should perhaps die from a certain type of energy...

B: Like in Left 4 Dead, if anyone here has played that?

INTERVIEWER: Oh yeah

B: [Unintelligible] zombies, and then the cool zombies who'll mess up your game by doing special things to try to separate your group, and uh, drag you out to die. I dunno. I guess just to be, might improve it for the game would be just to put in more stuff, more kinds of zombies, more things you can do, more depth to the strategy. But that's a whole bunch of changes, if it was just one thing, I'd go with the tower upgrades.

INTERVIEWER: So, were there any things you learned from the game, like what were some things that you thought you knew more about when you finished?

A: The point of the game, energy. You know, I never really cared about the resources, you know, you hear about it in economics, you know um, special topics and whatnot, but this thing about the resources that we use every day, and uh, the ones that are up and coming, like, even with the cars, probably over 90% of the cars we use right now run off of gasoline, which is all, it's polluting our city with, I come from Houston and with- Houston is growing, it's growing at a ridiculous rate right now- every street is packed, every you know, freeway is packed, and you have multiple cars that it's creating all of like [unintelligible] garbage, creating gunk, and smog, and now we're moving all to electrical cars, and I guess just um, I guess just learning that we need to advance in our resources for us, I guess for us to survive and everything about it and all, and it's just advancing in resources, and what we have to adapt to these new resources, and that's just what it made me think about it.

B: I knew a few things about the certain power sources, but a lot of things which I kind of knew in the back of my head I didn't really think about, like that Geothermal power work- is going to work better in certain spots, because the Earth is not at one temperature underground, it's got certain areas that are used for that stuff, so that's interesting to think about. Then, like wind power, it'll work less at night cause the wind doesn't blow- I don't know - that happened in the game, I don't know...what's up with what the wind does through the day and night cycle, but if it does that'd be something to think about. The fact

that solar power doesn't work at night, I mean that's obvious, but I never really thought about that. [Laughter from all]

You think, "I'll just make solar power," but uh, there's no batteries when you're generating that much power, you just send that right out to the grid, so what if people need a lot of electricity at night? Cause a solar power plant would be useless, cause you can't power things at night.

C: Yeah, I think delivering the message was sometimes, the game was very much right on. Of course as B said, I um...What were you saying, just now?

B: The wind power, working less at night, and solar power and not working at night, or...?

C: No, I completely forgot...

B: Sorry

C: I don't remember now...

B: It'll come back?

INTERVIEWER: Something about pollution, or energy?

C: No...

INTERVIEWER: What did you guys think of the fuel sources?

C: Wait, it was just, as [B] said, we kind of been used to most of us having, how much 12? 12 years? 20 years of education of hearing this? But I mean definitely for somebody with new intelligence, maybe, maybe somebody would enhance this for them, this might be very much educational. You think so?

A: [Unintelligible] definitely.

INTERVIEWER: So if you were talking to someone who had never played this game, what would you tell them if they asked you how to win?

B: Build Nuclear power plants [chuckles], and then cover the map, and then just build Tesla coils in every other square of the map. [Laughter from all]

B: And then you just get so much power that you can power the Tesla coils, just put a few guns just in case. But uh, as long as the zombies don't get to your Nuclear Power plants they'll be good.

A: Tell em, just listen to what the game is telling you, teaching you, once you get to the, it's just the basics fundamentals of learning, just um, understanding of background, it's understanding what they're telling you to do, and paying attention, you know - if you just choose to look up power sources if you choose, it'll be, that's the key to winning is knowing those power sources, and um, it's knowing those power sources.

C: Balance like you said, you have to focus on every section of the game, like you just

can not keep on building guns everywhere, you have to worry about energy generation, you have to think about research, you have to think about farms at some point in time, and I guess if you want to really win you have to make a balanced profile and at the same time keep on upgrading your profile as you get a chance.

B: The game sort of learns, you build one of everything always, cause you need power for different guns, good in different situations, and if you have different sources of power, if one goes out for whatever reason you've got a backup.

B: Getting the research as early as possible, I don't know, I couldn't really tell what effects the upgrades had, but I went for the upgrades right away, and just maxed everything out [Laughter]. I made all my cars electric, because I usually had a lot more power than I could use.

A: Yeah, me too.

INTERVIEWER: What did you guys think of the various fuels available for your fleets?

A: It just opened my eyes, [unintelligible] like Ethanol, it really depends, I guess electricity now. I guess I just compared it to the vehicles of modern day, about the fuel I could just um, ethanol just, um, is dominant, basically the dominant fuel right now...energy resources, with the expansion. I kind of makes you think of which one is the best to use at what time? To get the more effective outcome.

C: You know I would agree with [A]. Even for me it was the things visually. Because I could see that wind could get away with lesser pollution but at the same time I had to pay a cost in terms of efficiency, for example, like how fast they would run, I mean how much energy would they generate, for example. For example in case of solar energy it's clean but the fact that you don't have any energy at night. Those were the factors that I had to consider and that's what I would think about for the fuel resource.

B: It was interesting how it depended on the map, what fuel you think is the best. Because if you had a whole bunch of coal, you could make power with that, and keep it on electricity, I kept it on electricity the whole time, because I was always going for a lot of power, but if you had a lot of gas, you could refine, or you had a lot of oil, it actually might be a better fuel even though it polluted because then you could use your power for other stuff. This is kind of related, I didn't really think about the difference between oil and natural gas until I was playing this game. It's like, two different things. Even though people kind of confuse them a lot of the time.

A: Mmmm-hmmm.

INTERVIEWER: Was there anything that wasn't in the game that you guys thought that should have been there?

B: I thought that the pros and cons on some of the power sources were kind of simplistic. Especially with nuclear power, I mean the pollution stuff for coal and the other burning fossil fuels, that makes sense, that you get more power versus the, uh, versus clean fuels like solar and wind, but with Nuclear it was kind of just, "well it's dangerous and expensive," but a lot of the problems with Nuclear power are sort of rooted in the real world, and with government and stuff like that, and it's kind of hard to translate a complicated issue

like that into a game where you're fighting zombies. So making the Nuclear power make the zombies super-powered, I guess that's, that's a compromise and it works in the game but I guess it kind of defeats the point of teaching people about the pros and cons of power.

INTERVIEWER: How would you have handled that?

B: I - I don't know. I'm trying to think, [laughter], how it would work. I mean, in a game like SimCity the risk is that it can blow up and destroy half the city, but uh, that might be too harsh in a game like this where you just have to restart the level, and I mean all the issues are even more subtler than that, it's you've got terrorism to deal with, but also costs, and what kind of nuclear power to go with, it's like light water versus heavy water, and storing your waste back in (unintelligible) your deal, depending on the kind of reactor you use?I don't know how I'd do it. Depends on how much you want to make the game educational versus how much you want to make it fun.

C: I don't know, I would have loved to have played a game, I guess it's beyond the scope of the game, but I would have liked to play a game in which I'm kind of an eco-lord of a city, and then I mean the industrial base kind of thing, so perhaps that might have been interesting for me, trying to interact with, stuff like making buildings and having to base decisions on what kind of materials to use in my buildings, like more from the point of view of a city than from this setting?.

A: I don't really know how to answer this, cause um, I guess this genre got [unintelligible], not really something I play, it's more like a FPS or RPG. I guess just uh, just to really see how it affects us, adding humans counterparts, adding humans for -like how you control the garbage trucks and engineers, you know - put humans out there with the zombies, and see how that affects us directly, I guess. That's what I'm saying, all I can think of.

C: That's one of the things that kind of makes me feel like it might have been better in a city like setup where you could see the affect on the humans. When we talk about humans, all the humans that were there, whether driving trucks or garbage, or the engineers in the cars, I would have loved to see some more humans.

B: So... you ever played SimCity? Sounds like you wanna play a game like that, where you actually you sort of build a city. where you pick what kind of power plants you want?

C: Oh yeah, I think I was really interested in how you were describing SimCity like that, I don't know.

B: Yeah, it was a great game. 4, 5, a whole bunch of 'em. But uh, I don't know. A game like this with a flash game, if you're building the city, that could work then, but then I guess it's what would hook people in the game would make it really fun? Because I like the zombies, super energy...that's the name of whatever? Where, you had this game, but you sort of learned a few things on the side, but it didn't feel like you were learning them, so there was a lot of voices you know, and, like, "Oh, yeah of course, you don't...Solar Power doesn't work at night." and learned things like that. If you make it into a city, you definitely could learn a lot more, the game could present a lot more stuff, but then it'd be the risk of being too preachy, a little bit, sort of, [mock preachy voice] "This is what power is good, you're gonna listen to me..." [Laughter]

INTERVIEWER: Did you guys feel that it was a good balance between, like, fun and

educational, or was there any point at which you thought it was too much of one?

A: Um, definitely. I'm thinking definitely balanced. Because as you get more into the game, the uses of the energies become more challenging, and you have to think about how to, I guess it depends on how you play the game, the end is the same, you know, you couldn't stop making enough energy, but what if you can't stop making enough ethanol, or just natural gas, you know it makes you think, "Well how can I, I have so much of this, how can I, kind of spread it around to where it compensates for the other energies." And with that knowledge it kind of makes the game more challenging, and for me more challenging is more fun. And I guess for people who are seeking that challenge, it'll make it more fun for them. That's how the balance comes through for me, with the use of the energy.

B: I had a lot fun playing the game, it was great. And I felt there was enough stuff in there that you actually learn a little bit about energy production and pollution. I mean, I guess you could expand on both, like you could put in more gameplay to keep people playing, you could put in more content. But I think, it was definitely balanced, the way you've got, you've got a little bit of units and it kept the ratio perfect.

C: Yeah, I also went away thinking the game was very much balanced. I remember the first time I started the game, somehow I was kind of surprised by the initial email I got about the game, it was kind of somebody wanting me to test a homegrown game which is not so interesting, and I remember playing it for the first time for maybe just, 5, 10 minutes and then I was out of it, and after I quit I got a reminder for that and then I played the game again, and the next time that I played it, by the time that it was over, I realized that I had already exceeded the time I was supposed to play it [Laughter by all]

C:... I was just saying that I actually might have to play it a bit more, and then I realized I had already exceeded the time. [unintelligible] I think it was definitely a good balance.

NOTE: This is the end of the formal interview. At this point the interviewer just started chatting with the respondents informally.

INTERVIEWER: Interesting that y'all bring up the idea of having the setting in a city, because that's actually the sequel he's working on right now, it's called "Super Energy Metropolis." [Laughter] You're still going to have to fight off waves of zombies, but you'll have to manage like roads, and how people get to defense points. [Laughter]

B: Advance wars was the inspiration, you'd have to have little soldiers you could control, upgrade their little guns.

B: Roads you could put in, all that public transport you could put, deal with that problem.

C: Think they could put in a super hero. [Laughter]

B: Yeah, and he's powered by something. [Laughter]

INTERVIEWER: Well, I think that's pretty much all the questions I had. If you guys have any questions feel free to ask anything you want, I mean I don't know anything, but I can answer what I can.

C: What's the future of the game? Because it seems like it's already available online on separate game, because I was trying to search for "Super Energy Ap - Apocalypse, right?" I was searching for it and I actually found it on a different website...

INTERVIEWER: Yeah, it's available a lot of places online, and there's actually two separate versions, you guys got to play the souped-up version. Because he was actually creating it for a contest, and so in order to get it in for the deadline, he had to cut a lot of corners and it was kind of buggy, and all the research wasn't quite there. So the new version was called "RECYCLED" underneath, that one had, I think he re-did all the resources, so all, like, the balance between the energy powers and stuff was all based on actual numbers, and fixed a whole lot of bugs and added some features and stuff.

B: I guess that was my question. Why was this game made? I remember it says in the email, but I did want to know, "why was this game made, what's it supposed to do, who's this for?"

INTERVIEWER: It was a online contest for a website called, "Jayisgames", which sponsors like Flash games,

C: Yes, I believe that was the website that I was at...

INTERVIEWER: Yeah, it probably had both versions on there. And they were having this contest where the theme was "upgrade," so it was pretty open-ended for a lot of things, and that's what he came up with.

C: Sine we're quit already on the minds of flash, he should approach some education department, or some maybe some such place maybe inside Texas A&M itself, he might get a contract to actually make a game for, that could be used for education department.

INTERVIEWER: He's actually looking into that quite a bit. He um, this game was actually sponsored partially by the Houston Advanced Research Center, which works with all kinds of things like that. So, yeah. That's a very good point.

B: They should definitely...public thing to put out for. Putting out for people to play. I definitely think he should try and get some funding from somebody.

B: So, um, why are we here being interviewed? What's, I mean...

INTERVIEWER: He's actually writing his thesis on this. So, he's very interested in educational games, he thought he would put it out there, the most interesting responses he got, he wanted to see what you'll had learned, what you thought of it.

B: I thought it was pretty fun! [Laughter]

C: I would have given him an "A."

B: Yeah, should get an "A" on that.

A: Definite, I'd give him an A.

B: Definitely really hard to try and teach people something, while also getting them to

have fun doing it.

A: Mmm-hmmm. Yeah, cause I have a really short attention span, my mind constantly wanders...

B: Yeah, especially with um, video games.

A: Definitely. I was, I was like [C], I was way over the hour, I think I played for like 2 hours, 3 - my roommate played for 3 - and he's a [non-computing engineering major], he plays games every once in a while, but he thought it was good.

INTERVIEWER: Well thank you so much for your time, it was a huge help.

A: Any time, any time.

C: Hats of to you, man.

INTERVIEWER; I'll pass it all along

B: Let us know when the second one's coming out.

A: Keep me updated if you can.

INTERVIEWER: Well, if you're interested, his website is called BrainJuiceGames.com, so any updates and stuff'll be up there.

–End of Interview–

Interview #2

Time: Friday October 16th, 2009 @ 4:00 PM

Place: Texas A&M University, Langford Room C429

Participants:

D = Player 77

E = Player 43

INTERVIEWER: ...start this up, and if you guys could just introduce yourselves using whatever fake or real name you want, and if you can remember the screen name that you used while playing the game, if you could do that too.

D: Hi, I'm [name], my screen name was actually [user id], spelled [he spells it], I am from [foreign country], I am in the computer science department here. I got the mail, and I just tried it out.

E: And I'm E (unintelligible), or just E, and I used the screen name [redacted], but that's spelled [redacted]. And, uh, anyway I'm computer science department as well. Just got an email, and decided to help out.

INTERVIEWER: And I'm [name], I'll be doing the interviews. Just in case he doesn't know who I am. [Laughter]

INTERVIEWER: Okay, so, you guys, what was the best or most interesting, most fun part of the game, when you were playing...

E: I always like being just overpowered in games, so um, (laughter) building up a massive kinda powered-up energy economy very quickly and very early on in the game, um, just so that I could basically dominate the zombie invasion starting each night, was always a lot of fun. And then also, building a lot of research points early on. Um, and then basically knocking out the research as soon as you possibly could early on in the game, so you had all the upgrades available immediately. You know, that basically made building defenses very easy and maintaining them really easy, and things like that. And I kind of like doing that sort of thing in games.

INTERVIEWER: So, kind of the initial scramble to get everything set up.

E: Basically, so when you try and get it all sort of as quickly as possible, and upgrade as far as possible, I'm kind of a , whenever I play games, like a - turtle, you know? Kinda, build my defenses, hunker down, and then just kind of able to do my own thing, and just completely... build like crazy. Um, and micromanage and whatnot.

D: I like strategy games, and I play Age of Empires a lot,some like, you know. I wanted to try it out, and when I started out, it looked a little similar to what I used to play. So, initially as I tried it out, I probably played about 2 or 3 stages and then stop. But after that, it got me a little focused. I mean, I couldn't survive for - I mean, whatever I do, the zombies would

come and kill me. So, then I wanted to win. That happens, and then you keep on playing. (laughter) So, I like that. I mean, I tried to, somehow, find some technique to keep out the zombies and win. That's what I liked about it.

INTERVIEWER: So you enjoyed the challenge there?

D: Yes, I did.

INTERVIEWER: Interesting. So, playing the game, what was the thing you guys liked the least, or just wasn't fun at all.

D: Except for the difficulty, the storyline was pretty [unintelligible]. It was like a movie, you go from one place to another, you come back, the zombies are attacking this place, then you go back together to the other place, zombies have attacked that place, I mean it's like, it was plain worked out. And this was something, you go to one side of the board, you come back to this side, you go back. That was pretty much what was happening. So, there wasn't the very best storyline. I think the main intention of the game was to give you an idea of the different energy sources and pollution and all those things, it might be an environmental based project or something. I don't know. I believe it is so. It gets a little boring, though, when it gets tougher, I just keep on playing, though, so it's okay. But there wasn't a lot of story. It isn't a big game, I guess, so it's okay.

INTERVIEWER: So would you have liked to see more story, to that?

D: Yes..., no, I thought you know but, then there's kind of , something, I don't know. If you have played strategy games, as in that is basically, because it's related to history and stuff, then you go to the other place, they capture the place, they lose the place, they lose someone, so they fight, to kill the, villains or else.

E: I was going to say, I was actually okay with the story, but, um, I was some of the different options that would occur some time, so there would be like an objective to accumulate X amount of energy or something like that, and you were in the middle of doing something else, and it instantly pops up and interrupts whatever you doing, and says, "hey, you're getting this much energy" and all of a sudden it's telling me the next part of the tutorial. That was always kind of annoying the way they interrupted you constantly like that, it's once you just, I don't know how you would fix that, but that got a little annoying, but I did actually like the story in between the missions and stuff, and the way they kind of set up, and back and forth and whatnot, and the way the zombies kind of advanced throughout the stages. The thing bugged me the most, was I guess you'd call it the "energy tick," when the next tick would occur with energy sources. I noticed that it really became a huge gripe, for me, at the end of the game, was that each different energy source would tick at a different time to give you your next amount of energy. And, by the end of the game, if say you build lots of tesla coils type things, tesla towers, build a lot of them - that's going to be draining your energy constantly, and that's going to be your source of defense basically, and then if you build, say, all Nuclear stuff so you have like 900-plus income coming in constantly, they'll all tick at once, giving you 999 energy, and they won't tick again for another minute or something. And so you're basically relying on that 900 energy for the next minute and there's no source of additional energy in between, and um, at the end of the game that's just not feasible at all. I mean, you could build way more nuclear power plants, but there's just no point because they're not constantly ticking. And so, it became a really big issue, on the last level basically is what it came down to. I could try everything

else before that just fine, but on that last level, there was absolutely nothing you could do, unless you completely - well I guess maybe that's the point, that you had to diversify all your different energy sources and stuff instead of just relying on one, that way they would all tick at different times. But, but,

D: But even then there was a limit on what, how many times you have.

E: Yeah

D: So, all of the, numbers in a particular type was synchronized, they would all pop up together.

E: Exactly. I would prefer it, if they all ticked or popped or whatever you want to call it, like relative to the time that you built them, as opposed to all be synchronized and ticking at the same time. Then you kind of have a constant income of energy, instead of having just a oh, "here's the next 900 for ya"- that just - it basically ruined any gameplay you could come up with, or any strategy that were working before that, it basically stopped working on the last level. (mmmm) So it was kind of disappointing to have something that was working all the way along and was fun and enjoyable, suddenly stopped working at all. So.

INTERVIEWER: Yeah, I can see that. So, if you could change one thing about the game, what would it be?

D: That.

E: That. [Laughter from all]. If you could change that, that would make the game a lot more enjoyable. It seems like you probably could also scale up the difficulty of the game, maybe, if you did something like that, because it would make similar strategies more feasible since you'd have a constant source of income, as opposed to, it comes in once, and then you have to wait a couple of minutes, and then you have it again, and then you have to wait a couple of minutes. It seems like that might work a little bit better. Also, like I was mentioning before, just kind of diversifying. There really wasn't much incentive to diversify much. In your energy sources. I'm not sure if that's something you want to incentivize or not. But, um, you know, early on in each level, it's kind of like you know, heavy up with coal and once you get coal to kind of um, get enough energy to kind of be able to start your economy running, then you can switch out to nuclear pretty quickly and you go from there or whatnot. But um, I don't know. Maybe just to encourage diversifying, if that's a goal of the project, then if not, the energy tick, definitely. That's the thing I would change.

D: I would personally like to have more weapons,or something, defenses, since there was like 3 of them, 1 gun turret, 1 flame turret, [unintelligible] and a tesla coil. But I thought, what happens is, 3 of them uses 3 different things, but I mean, there should always be more options than what you could create. If you run out of all three elements you're pretty much screwed. You can't do anything, that happened to me, a lot of times. I think there are four things you can use

E: The spotlight.

D: Huh?

E: The Spotlight.

D: Yeah, but even that uses energy. I was thinking of the kind of

E: Oh, the resources

D: Resources, I think there was one more resource you could use. If there was some sort of weapon which could, you know, work on that kind of resource, that would be better. I was wondering why they would just have 3 kinds of defenses, 3 or 4. I would have liked to have more.

INTERVIEWER: So, just more structures, and then more -

D: Yeah, just make it a little more complicated - I mean, have little more, elements, it'll make it more fun.

E: I agree, that would be more fun.

INTERVIEWER: So, what were some things you learned from playing the game, if anything?

D: I learned, I believe this is true, I'm not very sure if it's true or not, from the game what I understood is, the different amount of pollution that is created by the different kinds of mining, or nuclear, or waste that is generated by nuclear power reactors. The scale of how much it can create, a coal power plant will create a lot. I used to think that a geothermal power plant might create pollution, but from the game, what I understand is that it does not create pollution at all, and it does give you a lot of energy. I can't imagine how that works, I mean, how it could give you a lot of energy at all. And these things, - stuff about the environment, that I learned. And, okay I also learned how to use my resources properly, dividing the resources between, you know, kind of defenses, and all those things, I learned that, yes.

INTERVIEWER: Okay.

D: Managing resources, basically if you want to put that.

E: I want to say for me, yeah the thing I came out with learning was kind of the smog levels that you get from each of those things, and then the amount of energy produced by those things as well, but I gotta say though I mean, I only say that I learned those things because I was told going into this that this was an academic research project that's designed to teach people things. So if I had gotten into this just played the game, not knowing that this was supposed to be an educational game, I probably wouldn't have gotten that out of it. I would have just assumed that it was a game where some people just made up arbitrary numbers to represent these different things as opposed to being maybe, scaled to real-life values.

INTERVIEWER: Okay.

E: And so that wasn't ever really broached in the scope of the game, and so if I hadn't been told in advance that this is for educational purposes, I wouldn't have assumed that those were meant for educational purposes. [Laughter]. Let's see, yeah, I was surprised at a couple of the different smog levels, sometimes, those became the thing I found myself

having to manage the most often, was smog, which is why I kind of went with nuclear so often with so many of my things. You know, it uh, like farms for instance, I didn't know that farms were producing that much, or the amount

D: Yeah!

E: Yeah, farms really surprised me. The amount the cars were producing really surprised me sometimes, so I found myself micro-managing, switching back and forth between different energy sources, day I would be using the gasoline power, at night I would switch to electric and use my flame throwers like crazy. Things like that, but uh. Yeah, the smog levels really surprised me to a large extent. I wasn't expecting that. Geothermal didn't surprise me, I knew that those, I knew didn't actually produce too much smog.

D: I didn't know that it could create so much energy

E: Neither did I, really, I didn't know it would create that much energy

D: almost as much as coal [this is inaccurate]

E: Yeah, but um, Solar power disappointed me, I guess, gas produced a lot more, but I guess kind of all of the technology in this game stuff, you always hear about these super large solar farms they're producing, and how they're going to power an entire state or something by putting some solar panels in the middle of Arizona or something.

D:And so, um, yeah, I'm always used to hearing about these large scale projects, so then even like one solar panel in the game doesn't really do you any good at all , yeah I guess so, I guess it shouldn't really surprised me, but I guess it's based on what you always say to do, how solar panels are going to save the world and stuff, it kind of did surprise me. Same thing with the wind farms, those were the same kind of issue there, you hear about the Boon T. Picker, or Boon Pickens, the one who wanted to put the giant wind farm in Texas, and

INTERVIEWER: Oh yeah

E: And so you think that's going to be another power source going to have potential to change things and stuff, and then you realize that you really do need like an entire wind farm, and basically, one turbine is not going to do you any good, basically, so. It's a good supplemental power source maybe, but it's not at the end of the game, not unless you build like a hundred of them or something. So yeah, I guess I was surprised at the different relationship of the energy levels and the smog levels and the different pollution levels and whatnot. Oh! And that was the other thing. Pollution levels from the - the mines and stuff like that. I was always surprised whenever I would pop up a mine and then I didn't have garbage trucks and stuff ready for it, and it would start pumping out pollution like crazy, and you gotta get someone over there before something bad happens, that always caught me off guard, a couple of times - (laughter from all) - it caught me off guard a lot. So yeah, I guess pollution, smog, um, energy production.

INTERVIEWER: So do you guys feel like you had learned anything about alternate fuel sources, or different fuel sources.

D: Yeah, I mean, it's like, there were some things that I believed were better, but the game

says that it's not as good. Like he said, solar power, and wind power. I was believing, I was hoping rather, that these things would maybe in a couple of years come up and they wouldn't need any coal or petroleum energy any more. So those things I learned I guess

E: Yeah, the, I just mentioned em and he did too, solar power or wind turbines, I expected those to kinda be more profitable in terms of energy production, um, but yeah unless you just put them up in a massive scale, they're basically going to be worthless for you in the scope of the game, and you could pop up one nuclear energy plant, and be able to produce 10 times as much, or whatever, um, then you had to be able to wait, but you know.

D: Maybe we can put them on the moon or something [all laugh]

E: Yeah, it definitely gave me a different idea about just the scale of some these things, in relation to how they're produced. I just didn't really have an idea of HOW MUCH more powerful some of these things were than others. So.

INTERVIEWER: So, if you were talking to someone, who had never played the game, and they asked you how to win, what would you tell them?

D: It's basically a strategy I use in most of the strategies, build your resources first, build a basic defense that you need initially, because in most of the stages the initial level of the zombies that are coming, are pretty small, excepting maybe like 2 stages in which, when huge zombies come, but you can't do anything and you have to build your own proper defenses. Otherwise don't waste much of your resources by building a lot of defense, just build basic defense, and when the zombies are gone, build up your resources, and manage them properly, so that you know, in the next wave you will have everything ready. That's what I'd tell them.

E: Um, put your back to one of the walls where the zombies are not going to be coming from, and then, um, build a cluster immediately, and then get to nuclear energy as fast as possible on each level, at least on each level that you can build nuclear. And then at that point, surround the perimeter of your immediate cluster with all the different defenses you need. And then, on later days, a couple days, you have to start building massive amounts of defenses out around the perimeter of the stage, that way you can get to them before they get to you. Especially I found by the later parts of the game, where the zombies have these massive vehicles they're coming in, you have to destroy them between the time they enter the level and the time they leave the base, or else you'll have no chance to destroy them in time. Otherwise, cluster up, defend your cluster, and that way you don't have to build massive amounts of defenses, and um, try to avoid things that produce lots of smog, basically. Usually I would try to have a negative smog level during the day. And then the flame throwers would get busy at night, assuming I could fund them. That way I could kind of keep things in check, dissipate the smog during the day, and be able to use them at night. Between flame throwers and Tesla coils you can pretty much keep most things at bay. The spotlights were worthless.

D: Yeah, spotlights were worthless.

E: Even clustered they were worthless. And then the machine guns were okay in the early game but they were worthless in the late game.

D: Actually I used a lot of machine guns towards the later stages also. Thing was, I used a

lot iron resource, and the thing that's not creating smog at all, so I really liked having layers of machine guns around, like, one layer after, after one point, there'd be one more left, and five six left, no one passes through. Maybe you know, a few flame throwers or something after that, so that whoever comes in to kill me, I was doing that too.

E: I don't recall - do the machine guns stop the zombies from walking off at night?

D: They don't stop them, but you know, they keep on firing, and they have a bigger range than the flame throwers. They just keep on shooting, the only problem is you need a lot of iron ore.

E: Yeah, that's true.

D: Mostly mining a lot of iron. Coal, I never, I actually never used coal because I was scared of the smog. Most of the levels are then lost to us, because the zombies are huge, and then what I tried was, reducing the smog levels to, it was an okay tactic, the reduction of smog. If I had an extra vehicle or something, I would make it stop, make it not work anymore. That's the strategy I used.

E: In terms of coal, the only time I would use coal is to jump start things. So if I started with a low amount of energy I needed to get enough to get nuclear up and running, I would use coal to kind of just bridge that gap then, and as soon as I got it up in running I'd just destroy the coal plant, or disable it or whatever.

D: I'd disable it.

E: Because the smog levels, even fully upgraded, the smog levels were too high to manage on a sustainable level.

D: Is there some way of you know, reducing the smog? The only smog dissipation is I think, natural, right? I don't remember that, I mean, does the only way in which, the negative smog is because of nature, but if you can, you know - I don't know if there's anything that works, any human man-made thing that can reduce the smog, or if that is there you could include that in the game and make it easier for people [laughs].

INTERVIEWER: So you were saying you play a lot of strategy games?

D: Yeah, Age of Empires, specifically, mostly. I'll try it and then stop it.

INTERVIEWER: So, have you ever played anything similar to this game before?

D: Hmmm, good question. Yes, I have. I don't remember the name of it. I think it was some 3,000 AD or something. It was pretty similar, I remember. It was pretty similar, I mean it was, it's a pretty old game, it's a 2D game, you get a view from the top and there is no zooming or anything, but you can create your own vehicles or fighters and all this. It was something, some 10 years back, they imagined how it will be in 1000 years from now and then. It was pretty similar, it had a similar theme basically. So I have played that fully. Maybe 2 or 3 days. It was okay, it was a decent game. Wasn't like addictive, but I played it, something like this.

INTERVIEWER: Interesting.

E: Yeah, I've played a lot of RTS's. Not so much in recent years, but some older, like I used to play them a lot. Nothing that dealt with like pollution and stuff, or smog, really. I did have some of the kind of energy production and managing a couple different resources things, I mean, all rts's deal with managing resources, but - managing them more in terms of like, income levels, and things like that as opposed to managing in terms of "do we need more workers in the mine." When I was playing the game, it kind of reminded me of Total Annihilation, which was, came out in '97 I guess, but it kinda dealt with energy production levels and it had an income level, and had a rate of income for the kind of resources you were dealing with, so that one had less resources than this game did, kind of reminded me in the same regard, and how the rate of income and whatnot as a constant rate as opposed to something dissipated or whatnot, depending on whether you had like workers allocated to it or something. But nothing quite like this where you get penalized for, you know, exceeding certain boundaries and things like that.

D: Yeah, that is true. Nothing to do with pollution have I every played.

E: But certainly not pollution. I can't think of anything else either, like if you have [unintelligible] I can't think of any games that have done things like that. It seems pretty unique to me in terms of how it plays.

INTERVIEWER: Now, did y'all feel that it balanced the fun and the education well, or was it too much on one side or too much on the other?

D: I don't know, I felt like it was balanced.

E: Yeah, I did too.

INTERVIEWER: So it was still fun to play, and you felt like you learned something?

E: Well yeah I mean, like I said, I wouldn't have come out thinking I'd learned something if I hadn't known it was educational to begin with. But, I mean, I had a good degree of fun while I was playing. I mean,

D: I wouldn't have played that, if there was no fun I would have stopped in between levels.

E: Yeah, but, same deal. I mean I was planning to play for about maybe 1-2, 3 stages or so, and next thing I know it was like, "well, now I want to keep going," once you've got to the end, I know I mentioned it in the write-up I submitted afterwards, the survey or whatever, but uh I was playing on a mac, and an old mac, and flash hasn't been optimized for macs in years and years and years, so I mean, it took me 5 or 6 hours to play through, and that was without losing. It was really unoptimized to say the least, by the time I got to the last level, and I lost on the last level, I was like, ok, forget it. The last level comes and takes like 20 minutes to play, pretty unbearable when the zombies attack you en masse. But, no, it was a lot of fun otherwise, aside from the performance factor with the mac.

NOTE: This is the end of the formal interview. At this point the interviewer just started chatting with the respondents informally.

INTERVIEWER: Allright. Well, I think that's just about every question I had. Are there any questions that you guys have, I can answer to the best of my abilities.

D: Will he release it as a mainstream game or something?

INTERVIEWER: Right now it's just available free on the internet. He's actually working on a sequel right now, but that's distant future.

D: Yeah, that's what he probably wants out of the interviews.

E: So what's the sequel based on?

INTERVIEWER: It's gonna be called, "Super Energy Metropolis," and the idea is that it's going to be a slightly smaller focus so your focused on one city instead of a huge base, and then you're just trying to manage, not only the pollution and everything, but also like the roadways, and commuting throughout the city and getting your defenders to where they need to be. And factory workers and so forth.

D: Make it harder.

E: Basically, more micro-managing.

D: Yeah! Sounds fun, actually.

INTERVIEWER: So he's hoping to be able to model more, like, the effects of smog and everything, on your people as well, so you're actually going to have little workers walking around, getting sick from smog and stuff like that. Might be a while before we see that.

E: Um, well, I was gonna say I mean, I didn't really have any more questions, in general I would like you mentioned earlier, more research would have been fun. Especially in terms of the cars. I mean like, the vehicles, kind of had, there really weren't very many viable choices. Just because with the electric they were having to stop like every 2 steps to recharge, and with the gasoline they were producing so much smog when you had a fleet of trucks you couldn't do anything with them, so where's the algae or something, like, you know? Can't we use farms to produce bio-algae or whatever, or biofuels? Not ethanol, but um, algae and stuff I was curious about how that would be affect things, basically.

D: There are electric sports cars now.[Laughter]

INTERVIEWER: Really? Wow.

E: They have some really awesome sports cars.

INTERVIEWER: Wow.

D: What are the called, Tesla?

E: Tesla, yeah. They have some really, sweet-

D: And they are actually much faster, maybe not much faster maybe, but as fast as a racing car, and many more are coming, MANY more, and I kind of get mails from here, and some of them are really sweet- beautiful - much better than what you might have seen until late- some of them are awesome. And they give you 0-60 in like, 3.5 seconds.

E: The new Tesla cars are really slick, and they look good, and the prices are actually not bad for a sports car

E: I think the new one is like 80 grand, 90 grand, and it looks good, and like it should be more than that.

INTERVIEWER: Wow.

D: They're trying to make family cars for 20 grand, that'd be like perfect

E: The only problem is the range you'd still have on those things, which the game kind of reflects - [Laughter from all]

D: In the game, you move like a centimeter and you just have to stop, it got unbearable

E: Yeah, it got pretty unbearable. Yeah, if they could just fix the the range on those cars that'd be nice.

D: That'd be better, yeah.

E: 300 miles is kinda frustrating.

E: But no, definitely, I mean, I think it was a good game. It was good, it was fun, I thought it was was educational, but I definitely had a kind of minor grudge here and there, I think the energy tick I mentioned earlier, and then I think I had another grudge I mentioned in the survey afterward, I can't remember what they were now off the top of my head, unfortunately, but uh, no, I did like the fact that it didn't beat you over the head with "this is educational!" You know (laughter from all) and like start to explain the processes between different things and stuff like that, I think that would have been a little bit too much.

D: In that occasion most people who play games won't play it, only people who are attracted to learning might play, it and then...

E: There was another thing that bugged me when I was playing it today when I was about to review it, I was playing it a couple of weeks ago, I played it on some site that you guys linked to, and then it was all fine, but when I was playing today, after every single level it wanted me to submit my high score...

INTERVIEWER: huh

E: It wasn't the same link they sent me in the email, but it took me to some, it ended up forwarding or redirecting me to a different site...

INTERVIEWER: Do you remember the name of the website?

E: The current one? Not off the top of my head. Um I think it was still "fortressofdoom" or something like that, but it linked me with some high scores list or something like that, it prompted me after, it was automatically catching my high score after a level, and then it would show me my high score per level, and then after I clicked okay it would try to show me my high score again, and then I clicked like 2 or 3 times between each thing, and like...

E: Actually, the high scores, they were kind of arbitrary, it seemed like. Like, um, if you completed the game quickly, you didn't seem to get - I don't know - I didn't really pay much attention to the details - it seemed like you could complete the game with like, coming out with perfect smog levels, no pollution levels in the field,everything pristine, and massive amounts of resources, and it'd be like, "1500 points." [Laughter] And you'd be like, "Well, I kinda did well." And on other levels, you thought you did horribly and zombies were all over the place, and you killed a lot of zombies or something , and you got a lot more points. I can't remember how the points broke down, but there seemed like a times where you were like, "I thought I did bad that time, and I got like 8000 points and I thought I did great on that one, you know especially in terms of environmentalism, and I came out with a very a poor score on that one." It didn't quit seem to make sense to me.

INTERVIEWER: Yeah, if I remember correctly, I don't think it's explained in the game, but Lars was telling me, the way it does that, a huge chunk of the points is decided by how many resources you expend, versus zombies killed. So it's like, if you spent a lot of resources for each zombie killed, you're not going to get as many of points.

E: So that's where I was always getting low scores, was, I was overpowering completely, so yeah, It's going to be bad for me probably.

INTERVIEWER: I'm definitely the same way I would have, a thousand resources poured into each kill.

E: Yeah, I was one of those guys that wished the energy meter would go up beyond 1,000. (laughs) , 100,000 or a million.

D: I think that as far as even after reaching those 999, it doesn't go up, it doesn't come down, even if production is going up. So, it reaches 999 and the counter stops. But, if you use it up it doesn't come down. I think, internal counter is going up, not sure.

E: You sure?

D: I think so... because there was some points in which, you know, the turrets will be firing like crazy and my iron ore will be like 999 forever. It will not come down, it will just blink, but it won't come down. I was like, "that's good."

E: Well energy doesn't seem like it does that.... I don't think I ever maxed out my iron, though, maybe I did on a level but I can't remember off the top of my head.

D: That was the thing I was basically trying to max out... butt kicking - turrets from million directions

E: Maybe I should have built more turrets

D: It doesn't cost much, and it doesn't create pollution. I was scared mostly of smog - if it goes up, you're screwed. They come in cars, man. They get zombie cars.

E: That was kind of funny they showed up and it was like, "What are they, are they bandits or are they zombies?" "Yes!" I did like that, I thought it was kind of poking fun at itself, I got a good laugh out of that the first time it came around. [laughter]

E: Then when they came back the other time and you talked to the other zombie and stuff, and you come back to the fort, and they're like, "don't worry there are no zombies." [laughs]

D: [Laughs] "There are no problems, we are absolutely fine," I was like okay. That sounded corny, actually. [Laughter]

E: I liked it, I thought it was funny.

E: But yeah, good game. I enjoyed it.

INTERVIEWER: I'll pass that all along to Lars. So, if you guys have any other questions. Um, other than that, you're free to go.

E: I'm good.

D: I'm good.

E: Can I have a beer? [Laughs]

INTERVIEWER: Sorry, I forgot the ice cream. [Laughs]

–End of Interview–

VITA

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The typist for this thesis was Lars Andreas Doucet.