A Stirling Adventure

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Desolate Plains

2098.

A rare ray of sun surfaced after long absence, unexpectedly illuminating the ruins that stretch out for miles before his eyes. Boy sat on the cliff, overlooking the crater. The world is a much different place now, haunted by the aftermath of a nuclear holocaust nearly eighty years ago, hope became the only fuel that drives people to hang on for dear life. Eighty years passed in interminable groans of pain and outcry. Hunger, disease, fallout, energy shortage…even an occasional ray of sunshine bestowed upon this barren land seems like a undeserving grace.

The memorial service for the eightieth year anniversary of the nuclear holocaust is held at the town square tonight by the foot of the hill, candles are passed around as people sing the old tunes to mourn their loved ones who were snatched away by the ruthless hands of death. Eyes are lightened up by the flickering candle light, so weak the ravaging wind nearly choked out its life, yet so resilient like the life behind those eyes.

Boy retreated to the cliff, he couldn't bear repeating the same melancholy tunes, reminiscing of days he couldn't image without acid rain and sandstorms, or even days without his girlfriend laying sickly in the hospital bed, battling immense suffering. The cliff is boy's favorite place, there he has a uninterrupted view of the village and miles of nothingness beyond, blurred by heavy smog in the distance. Old buildings once covered in glamour and grandiose are now in shambles, broken down windows fixed up by tarp nailed down on the frame, doors ripped open, and that's where the 300 townspeople call home.

The hospital is a short gray building just half a mile down by the crater, everyday after five in the afternoon all the power in the village goes out due to energy shortage, power has to be rationed. The boy's gaze roams through the bleak, gray wreckage, in what felt like a daze, a sudden surge of impulse rushed in his veins. There it is, the red brick building beyond the village gates, standing out in the smog like a glowing block of hope.

Grainger library.

He knows that he wants life to change, and he also knows that there is enough knowledge hidden in those books to make that happen. It closed down a year ago, the massive lock on its heavy doors barred anyone from seeking wisdom and knowledge from the books that are slowly rotting within. He needs to get inside.

The Library

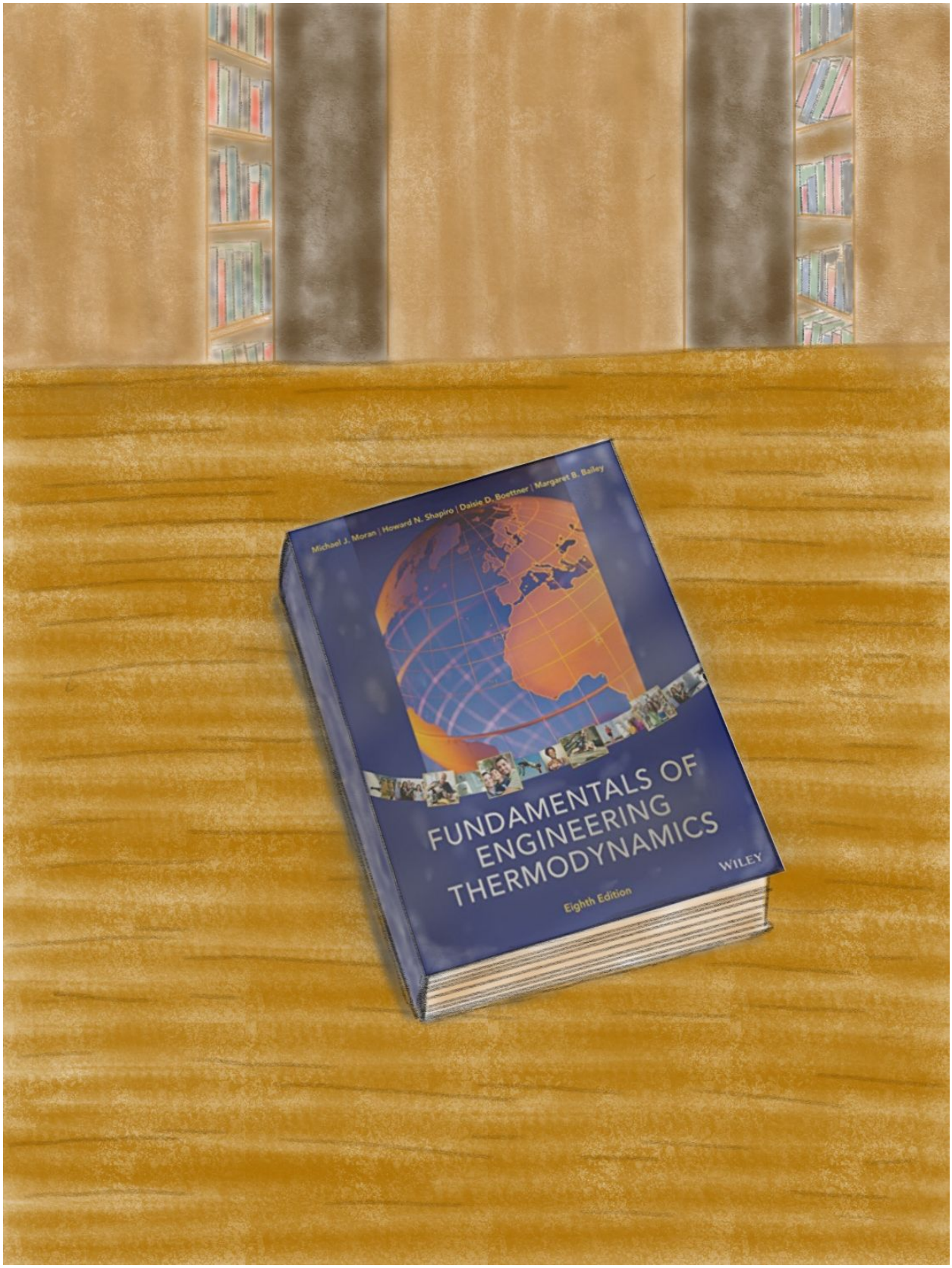
The doors of Grainger Library stood still in the ravaging wind. The lock looked rusty and it took no more than five minutes for the boy to pry it open. Inside were rows of old computers bathed in dust, rendered powerless. They were no more than cold metal sitting in dead silence. The boy travelled to the second floor and found what seemed like all the knowledge in the universe gathered into one location. Rather than overjoyed he felt clueless, knowing no way to begin.

He sat down at one of the tables. The textbook completely covered by dust carelessly laid there and the boy wiped down the dust on its cover, revealing the book title - *Fundamentals of Engineering Thermodynamics*. Many pages are bookmarked with extensive notes, laying out a pathway for the boy to begin his information journey. He murmured under his breath the lines bookmarked in the book, as if he happened upon a miracle, "Throughout the twentieth century, engineering applications of thermodynamics helped pave way for significant improvements in our quality of life...engineers will create the technology needed to achieve a sustainable future."

The boy continued to read on, feeding his brain the dense text which was starving to be given new information. He started onto the beginning passages regarding thermodynamics, a word he had never encountered before. "Engineers use principles drawn from thermodynamics … to analyze and design devices intended to meet human needs" he read, thinking that thermodynamics may be something he will need to know if he wants to improve his village. He continued reading about the various applications that thermodynamics has in life and one stood out to him: power production. The boy felt a fervor run over him, and he continued to read late into the evening.

The boy learned about systems and quickly started thinking of various types. He knew that the body itself was an open system, taking in food (mass) and allowing to exit, while also taking in heat energy from the air and sun (surroundings) through the skin (boundary). He also learned about properties. He thought about his girlfriends, whose health (the property) is not well. In this case, she would be sick (her state). He knew that if she could get more medicine, she could be treated (the process) and return to good health (another state).

The darkness snuck up on him quickly with a sandstorm looming in the distance devouring any glamor of the sunset, leaving nothing but a deadly, yellowish backdrop. The boy carefully wrapped the textbook up with his shirt like a delicate treasure. He was suddenly fueled by this new source of hope. This was an unbreakable promise given to him by the knowledge recovered from ruins and dust. There lies a new future, and it's right here sitting in his backpack.


Michael J. Moran | Howard N. Shapiro | Daisie D. Boettner | Margaret B. Bailey
FUNDAMENTALS OF ENGINEERING THERMODYNAMICS
WILEY
Eighth Edition

The Stirling Engine

The girl fell steadily asleep to the rhythmic beeping of the medical devices that became the sustenance of her livelihood. The boy lit a candle then took out his book again. He was ravaging the book and continuing to scour its pages for any insight possible. He found the section on energy and power and continued to find parallels all over. It takes a lot of electricity (energy) to power the medical devices his girlfriend needs. All of this electricity is being used at a certain rate (the power). If he could get a machine that created power, he could make more electricity and power not just the medical devices, but the whole village.

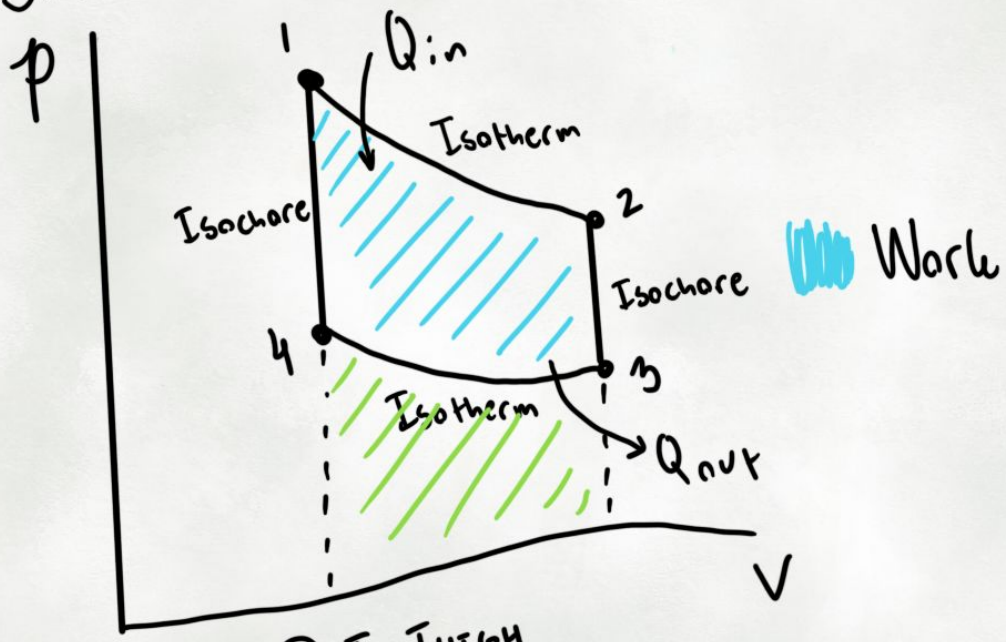
He continued to read and learned about how compressing gases and heating them can create work. He instantly remembered that cars worked on similar principles, before gasoline became scarce. A small engine might be able to provide power to generate electricity. But where would he find the fuel? And what was heat anyway? The term had been thrown around a few times, but the boy had never questioned what it really meant. After some page turning, he found out that heat was just one of many types of energy, much like electricity.

He turned to a new section. The title was the Stirling engine, and upon reading it, his curiosity was instantly piqued. However, he wasn't sure what a heat engine was or the strange looking "n" was on the page. After some feverish page turning, he found out that a heat engine works off the principle that work can be done by a mechanism operating at two different temperatures, or a temperature gradient. He also found out that the "n" symbol was actually Carnot efficiency, a measure of how well a heat engine performs with smaller or larger temperature gradients.

When he looked back at the Stirling engine section, he also was able to pick out the First Law, where in this particular case, work equalled the amount of heat that leaves the system subtracted from the heat put in. In general, he recalled, the first law meant that any energy into a system equalled the energy out. He knew that heat was a form of energy, and realized that if he could harness it somehow, he could put it to work generating electricity. This is where the Stirling engine came in.

The Stirling engine only needs a heat input! It takes in heat, from a high temperature "source" as the book put it, and makes work out of it using a specific tool that compresses gas known as a piston. Using two of these pistons, and a temperature gradient where one was hot and the other was cold, he could create work! There were still plenty of questions, and much to be learned about this machine, but it sure sounded like a way to better their lives in the village and possibly rescue the girl. Why had no one used these prior to the war!?

Stirling Engines Thermal Analysis



Work

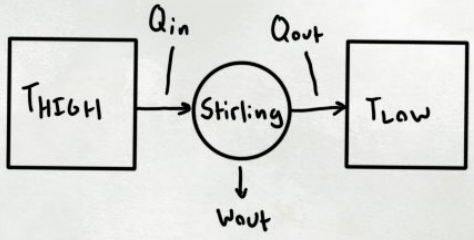
① → ② $T = T_{HIGH}$

③ → ④ $T = T_{LOW}$

Ideal Stirling Engine is a heat engine.

$$\eta_{th} = 1 - \frac{T_{LOW}}{T_{HIGH}}$$

$$W_{out} = Q_{in} - Q_{out}$$



Roads Previously Untravelled

He continued reading until he broke dawn. As he approached the end of the section on the Stirling engine, he discovered a piece of a magazine cover tucked in between the pages. It was a picture of something called the Beacon 10. He noticed on the page that it was in fact a Stirling engine!

The boy's eyes lit up with excitement! The Beacon 10 was a working Stirling engine developed right before the nuclear war apparently, but it never got put to good use, seeing as how there was a nuclear war and such. He needed to find out more. He had to go back to Grainger Library. He secured the magazine cover in his back pocket, not realizing the grand path he was on.

The magazine wasn't hard to find. He found posters and research papers on the Stirling engine through the library's archive system. He learned about the history of the Stirling engine, including how it was invented in the 1800's by Robert Stirling. It seemed like it was never very popular due to the abundance of fossil fuels at the time. The Beacon 10, however, was invented by Dean Kamen, an inventor who also thought up the Segway.

He had a vision to provide electricity to remote villages in developing nations. Coupling this with his long standing love for the Stirling engine, he had a clear path forward. Kamen and his research lab DEKA set out to refine the centuries-old multi-fuel engine technology into a workable solution for the developing world. By burning cheap and easily accessible natural gas, the Beacon 10 was purported to produce 10kW of electrical power. The Beacon 10 had the possibility to phase out the need for power lines and form a society dependent solely on natural gas.

It could also be used to heat homes and water, something the boy found was known as "co-generation". Apparently, by using the waste heat of the engine, one could get up to 70-80% efficiency in terms of useful work and heat, as opposed to simply dumping the heat somewhere and losing out on its ability to perform work, or its quality.

The boy dug through all the papers. "Beacon 10 Research Lab a New Development for Green Energy", at the bottom of the box is a newspaper clip with a picture of a Beacon 10 device. The research lab closed down after the nuclear war, spending eighty years buried in dust. It was miles away in the city and likely to be a treacherous journey. The boy didn't think for a second that the difficulty would stop him. His determination to make a difference grew with every fact he learned about this wonder machine.

Popular Mechanics

Are you ready for NUCLEAR WAR?

What happened to:

THE BEACON 10

The failed Stirling Engine co-generator

Hottest Money Managing AI

New AR glasses update causing headaches

The right to privacy in the post-digital era

Walk your dog with this new drone!

The Lab

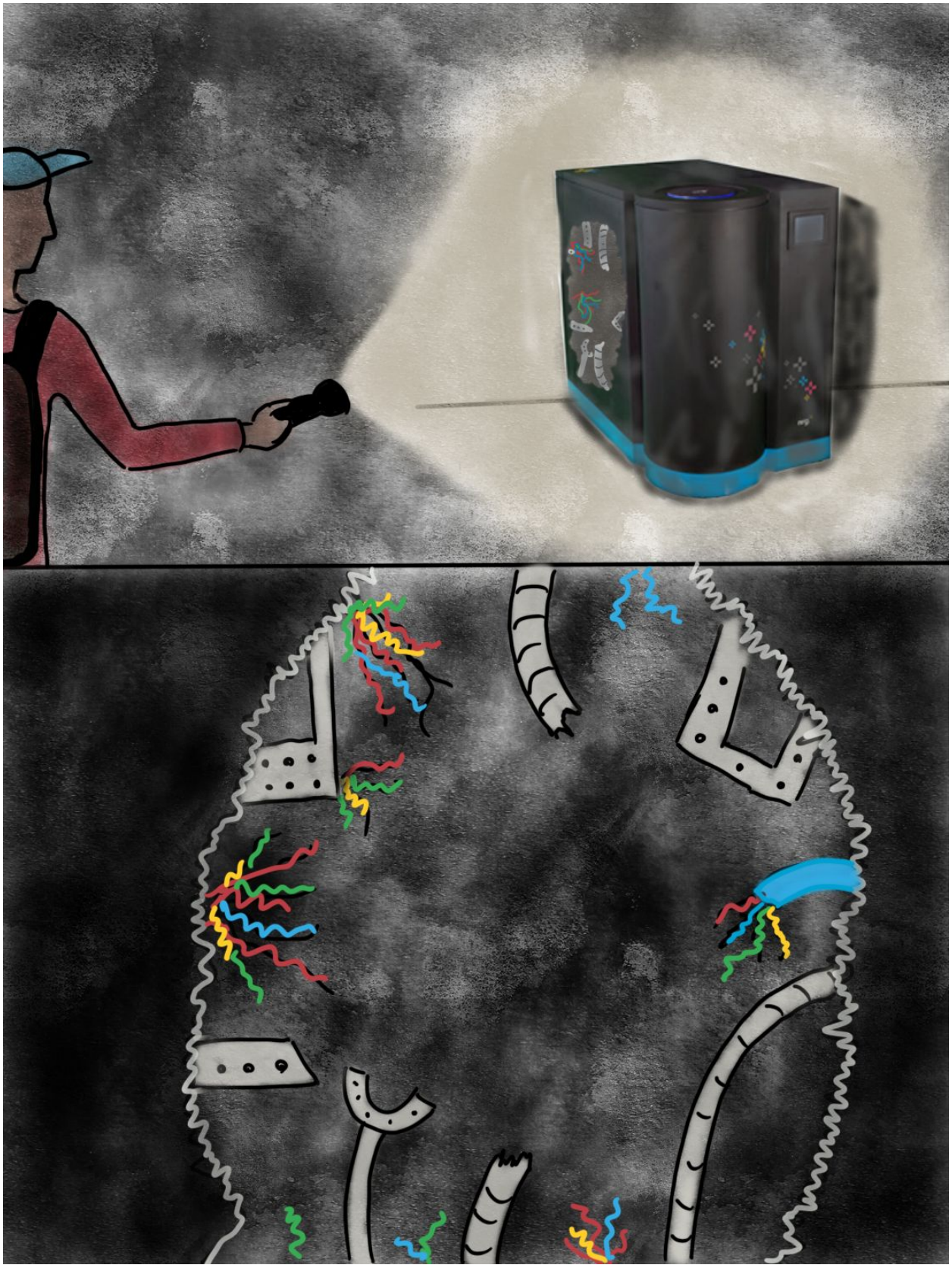
The research building looked surprisingly wholesome with most of its windows intact. The boy climbed over a window into the lab. The room was cold and dank. The beat of dripping water on concrete echoed in the cavernous room. The narrow beam of his flashlight revealed a great domed chamber. The room was filled with work benches. Each bench's surface was covered with equipment and instruments the boy couldn't begin to guess the purpose of. He walked farther in as his footsteps echoed and the yellow beam glinted off the polished steel surface of the exquisite machines that occupied the room.

As he approached the other side of the chamber his light fell on one device in particular. The boy let out a small gasp that reverberated into the emptiness. There, against the wall was the black monolith that had adorned the cover of the magazine he found earlier. He expected such a prized device would have been looted long ago. It seemed, for the moment, that the tides of fate were flowing in his favor. But just as he had finished that thought and begun investigating the device further his heart sunk. It looked like someone, or something, judging by the ferocity with which device metal enclosure had been rent something, had got here first.

On the side of the device was a great wound, an abscess framed by frayed and broken tubing where some part from deep within the machine had been ripped from the greater whole. "Damn" shouted the boy into the black void of the chamber as he slammed his fist against the hard metal of the machine. He sunk to the ground the room seeming to spin around him and he was left alone with his despair amongst the great wreck of the lost age.

He thought about all the work that now needed to be done on the machine. He had found out that the Stirling engine used a "working gas" to extract kinetic work from the heat supplied to it. This working gas was housed inside the engine as a closed system. When heated, it would expand, be cooled, contract, be heated, expand, over and over again in a smooth cycle. No fuel ever entered it, a purely external combustion engine as he read in the textbook. Surely if a part of the machine had been ripped out, he now needed to refill this working fluid, but seeing as how that was usually helium, he thought he was surely out of luck for finding and compressed helium tanks.

A web of tangled wires had also been left for him to unravel and surely plenty of parts had rusted out or simply fallen into disarray. This machine was going to be a nightmare to fix.



Putting the Pieces Together

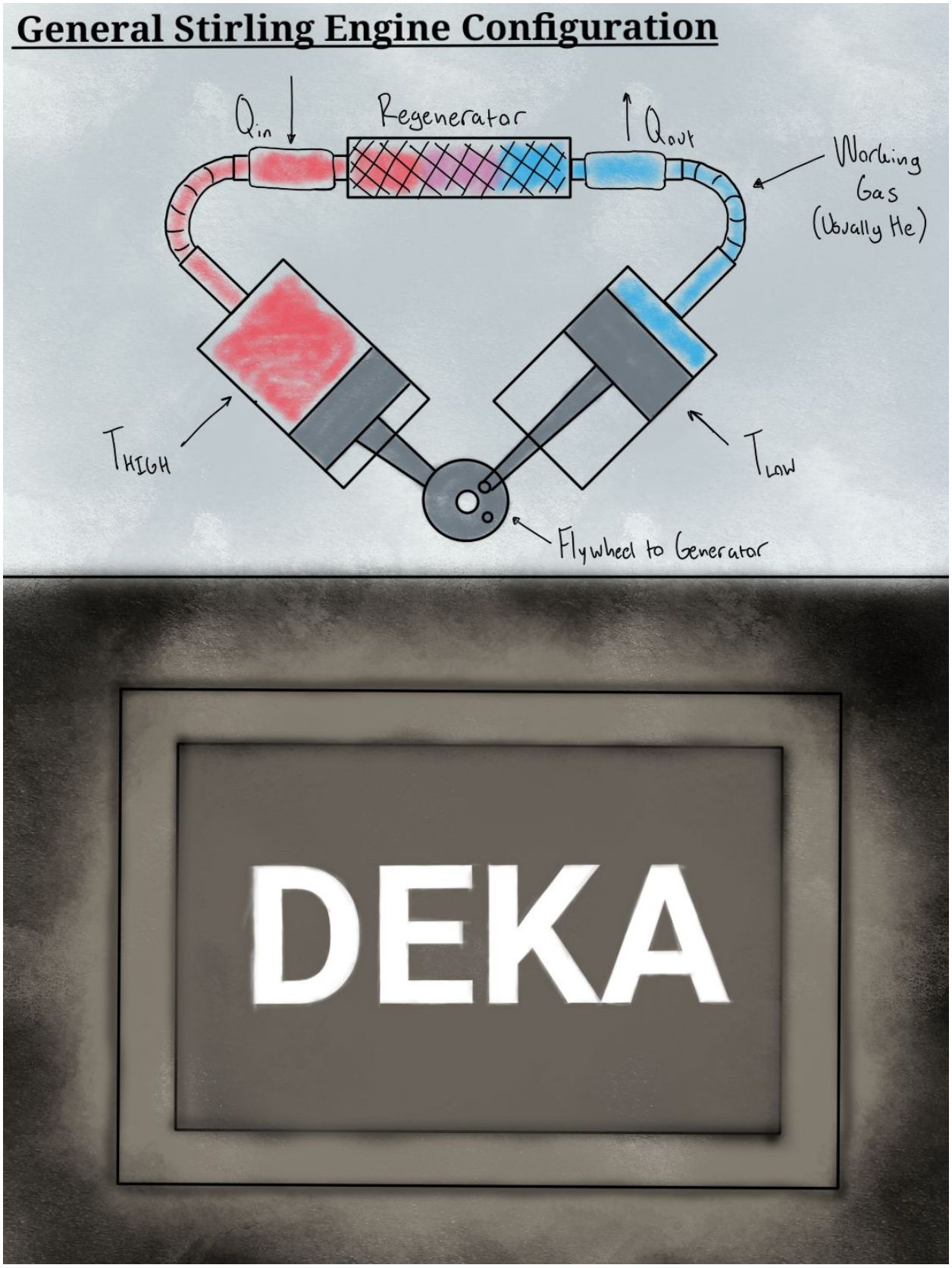
His thoughts turned to the girl: her smile, her laugh, the way the evening sun lit her hair ablaze like a thousand golden threads. He could not allow a vulgar world such as this to drag her under. “No” he roared as he planted his foot firmly on the ground. “I can not allow her to die like this” he said to himself, his voice now strong with his new found resolve. He strode over to the nearest table and flung its contents to the floor with a great sweep of his arm. He strew the documents from his bag across the table and began reading over them fervently.

The texts spoke of a device that seemed to fill the gap that was missing from the machine. It was the linchpin of the device. The regenerator. This device created a smooth temperature gradient between the hot and cold pistons. This allowed the engine to function on a lower heat input, and therefore at lower temperatures, yet greater efficiencies.

He tried to think of comparisons, and thought of the regenerator as a sort of swing. Heat input would be the person pushing someone on the swing, while the momentum of the person swinging is similar to the regenerator storing heat along a temperature gradient. After a while, the person pushing only has to push a little bit. This was the critical piece of the Stirling engine that so many had failed to refine before the war broke out. It was what he needed to get right.

The same page detailed an experiment that had not been completed before the engine was abandoned. The original regenerator was metallic. It’s properties meant the exchange of heat within the engine was too slow and held it back from it’s full potential. Pictured on the same page, however, were new carbon nanotube-based regenerators that the scientists had been experimenting with. According to the papers, their ability to transfer as well as store heat were remarkable, a near order of magnitude better than the copper one used prior. “There must still be one somewhere” he mumbled to himself. He began searching the room fervently, tossing pieces aside as they fell to the floor with reverberating clangs. “Ah!” he shouted as he opened a box to reveal the shiny black surfaces of one of the carbon prototypes pictured in the article. He rushed over to the engine and with liberal use of kapton tape and a great deal of force installed the regenerator.

Wiping the sweat from his brow he stood up from the side of the machine and pressed the power button on its top. The small screen on the device began to bloom with light. It went black again and then a logo lit up the screen and a humming began to rise from the device. Slowly the room began to glow as a ring of lights around the ceiling came to life. Machines that long stood sentinel around the engine began to hum and whirl with life. Screens began to flicker on and text began to dance across them. The whole chamber came to life in an instant. Everything seemed to pick up where it had left off decades ago when the world was a different place.


General Stirling Engine Configuration
Qin
Regenerator
Qout
Working Gas (Usually He)
THIGH
TLOW
Flywheel to Generator
DEKA

Clean Water

After convincing a few friends that he had indeed been able to power on a device from before the war, the boy was able to get the Beacon 10 all the way back to his village. At first, there was no proper gas line setup, which is the most favorable way to introduce heat into the engine. Instead, the boy simply burned wood and funneled the heat to the hot side of the engine. Because the engine is an **external** combustion engine, all one needed to do was introduce head and give it a start and the engine produced power. It took a while to start, but the engine was able come on eventually at half-power output. The village was ecstatic at the discovery.

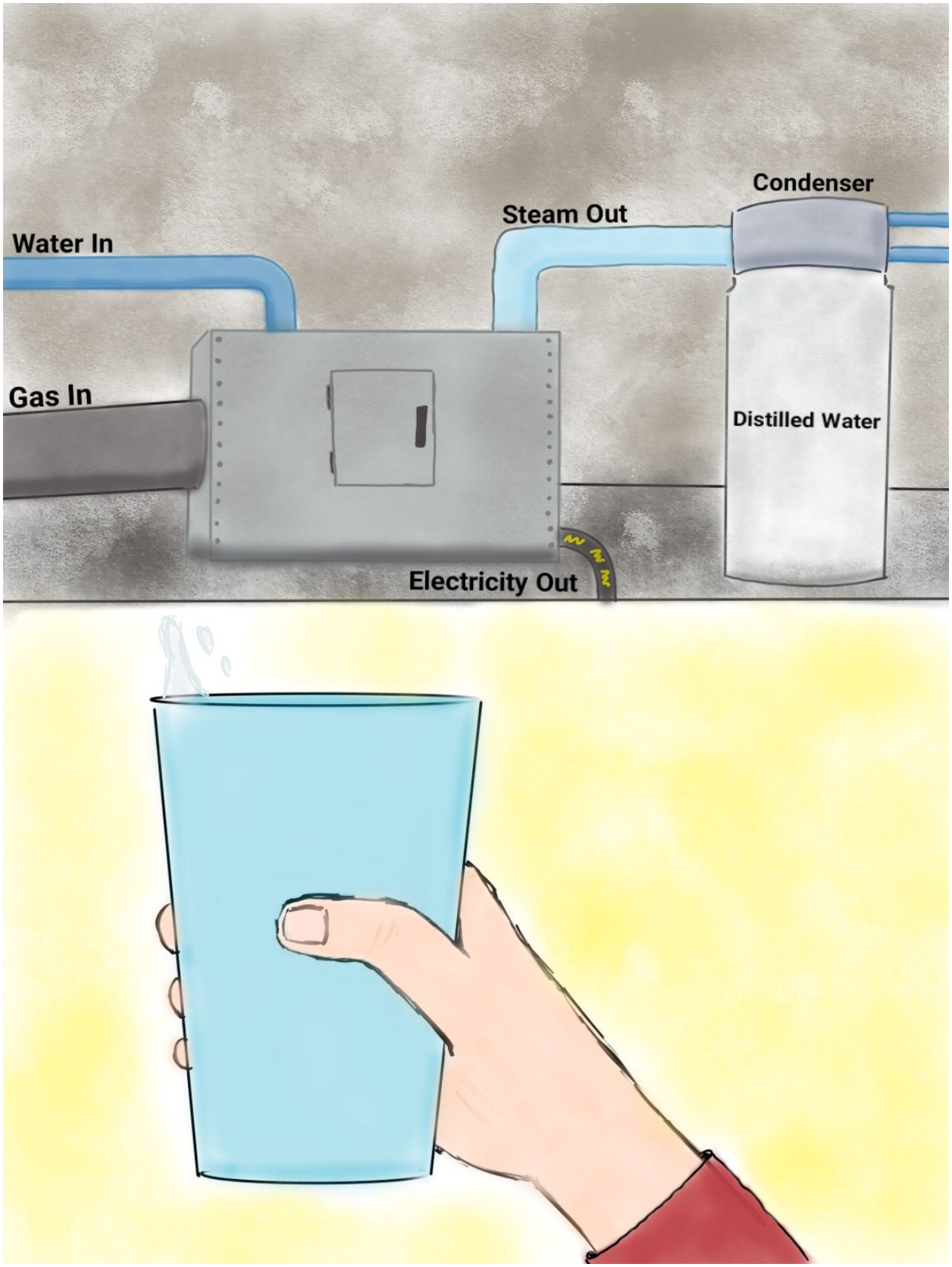
No one had ever seen much old technology function besides that of the medical devices in the hospital. When this was started in view of everyone, cheers rang out and the boy was instantly a hero. They paraded him through the town and a small fest was held in celebration of the new machine.

However, the next day, the first questions as to its use started to spring up. It was pretty obvious how to extract electricity from it, seeing as how it came straight out of a plug in the machine. What about anything else? Seeing as how it was summer, no one needed the waste heat to stay warm, so what could it be used for?

The boy had an idea. He knew how much waste thermal power came from the device: approximately 40 kW worth. He also figured that the village could use a proper water purification system. He looked back through the textbook and found tables that described the necessary change in enthalpy, a term used to describe change in internal energy added to the product of the pressure and volume, to boil water. He found that even running at half input, the engine could create 5 kW of electrical power and 20 kW of thermal power.

With all this information, and a few useful formulae found in the text as well, he found that he could use what is normally the cooling water from a nearby pond as the source for all the water in the village. Running only at half power could provide for nearly 300 peoples' water needs every day. This was plenty for his small village.

For so long, clean water had been difficult, if not impossible, to find. He quickly built a crude version of the system from surrounding pipes and drug a bucket of water up from the nearby creek. The water was a musky brown, full of things people would never dare to even ask about. However, he tested it in the machine anyways. Much to his surprise, the water on the other side came out sparkling and clear; he had never seen water quite like this before. One sip from that cup and he knew the world was only a few years from change now.


Condenser
Steam Out
Water In
Gas In
Distilled Water
Electricity Out

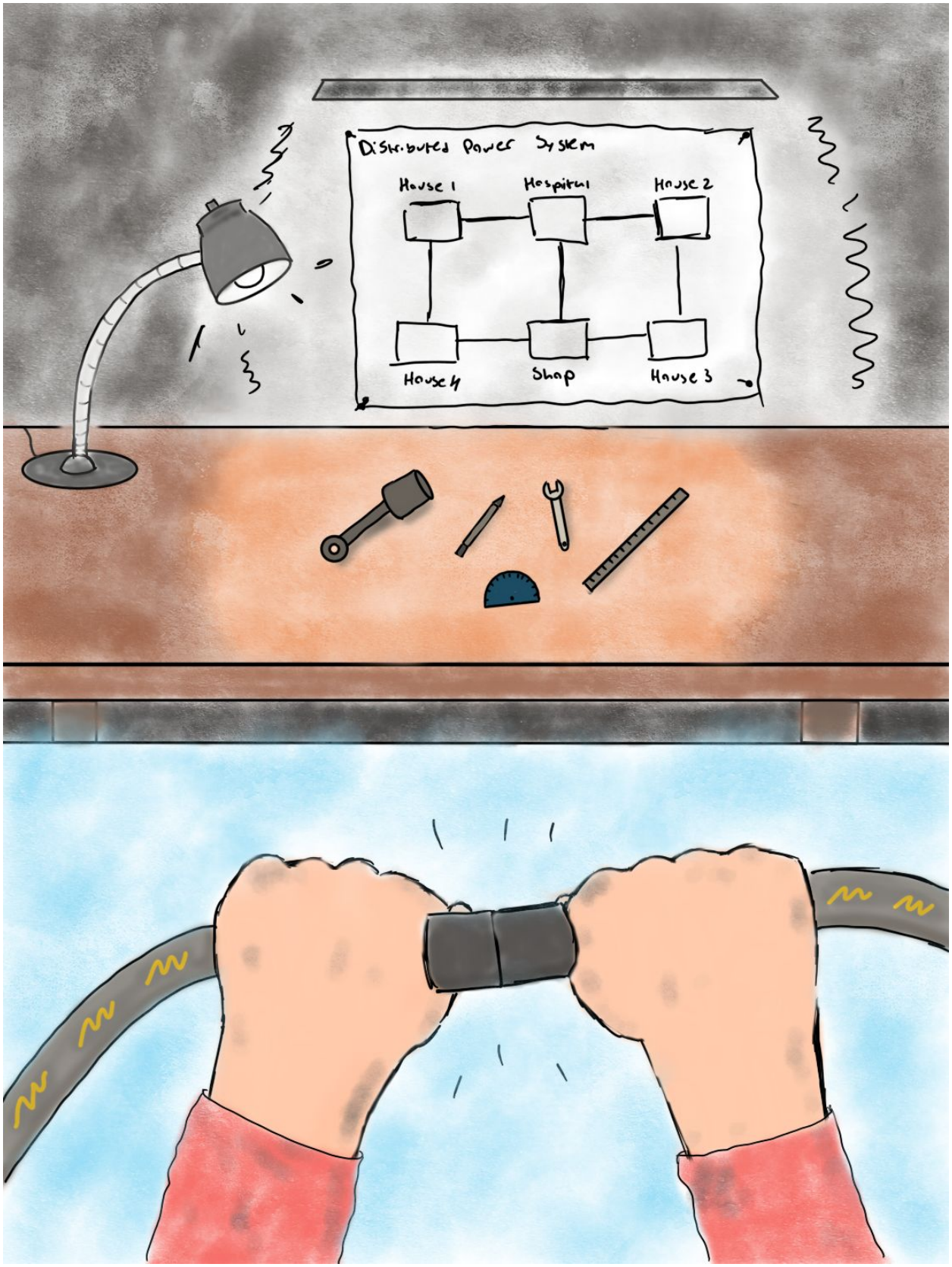
Distributed Power Generation

Years had passed since the boy had first brought the engine back to the village. It had provided power for the machines in the hospital and clean drinking water for the village in greater quantities than they could have hoped before. It's impact upon the village was so great that a group of villagers, spearheaded by the boy of course, began studying the machine in greater depth. Through careful measurement and calculation they managed to reproduce replicas of the machine. At first these machines were crude in comparison to the relic. They groaned and grinded and produced far less energy. The boy knew that these machines could be refined piece by piece overtime, but if there was one thing the post apocalyptic wasteland tended not to instill in its inhabitants was a grand sense of time. The boy wanted these machines to be able to support the village now.

Sitting in his study one night he picked up the magazine he had once found as a child. It always brought him a great sense of nostalgia whenever he revisited it. He must have read it at least a hundred times, but this time something stood out to him that had not before. A passage explained how these machines were not meant to stand alone. Rather its creator had envisioned that the machines would be linked together to form a collective and contribute to a greater power grid. He paused in thought for a moment before rustling through a drawer in his desk.

He unrolled a great piece of paper on the surface of his desk, depicted upon it was a careful drawing of the village. Grabbing a pen he began fervently sketching on the scroll. What began to emerge was a great network crisscrossing the village. Each building would have one of these machines. When one home needed more electricity and another needed less the power would be routed from the house of lesser need to that of greater need. If one machine were to fail and need repair, others would step in to take up its former burden. Together the machines would work in lockstep, just like the villagers did, to bring the little town out of filth and darkness.

This sort of distributed power generation was critical to survival. Groups were stronger than individuals for exactly that reason of redundancy. This is what the grid was like prior to the war anyway, with many separate plants located across the country, operating on local fuel sources. Luckily, the natural gas lines that were installed before the war were able to be traced back to a usable source some years back. The man found that the amount of fuel required by the village would grow drastically, but that source seemed nearly infinite when it was first surveyed. This was not his main worry right now.


Distributed Power System
House 1
Hospital
House 2
House 4
Shop
House 3

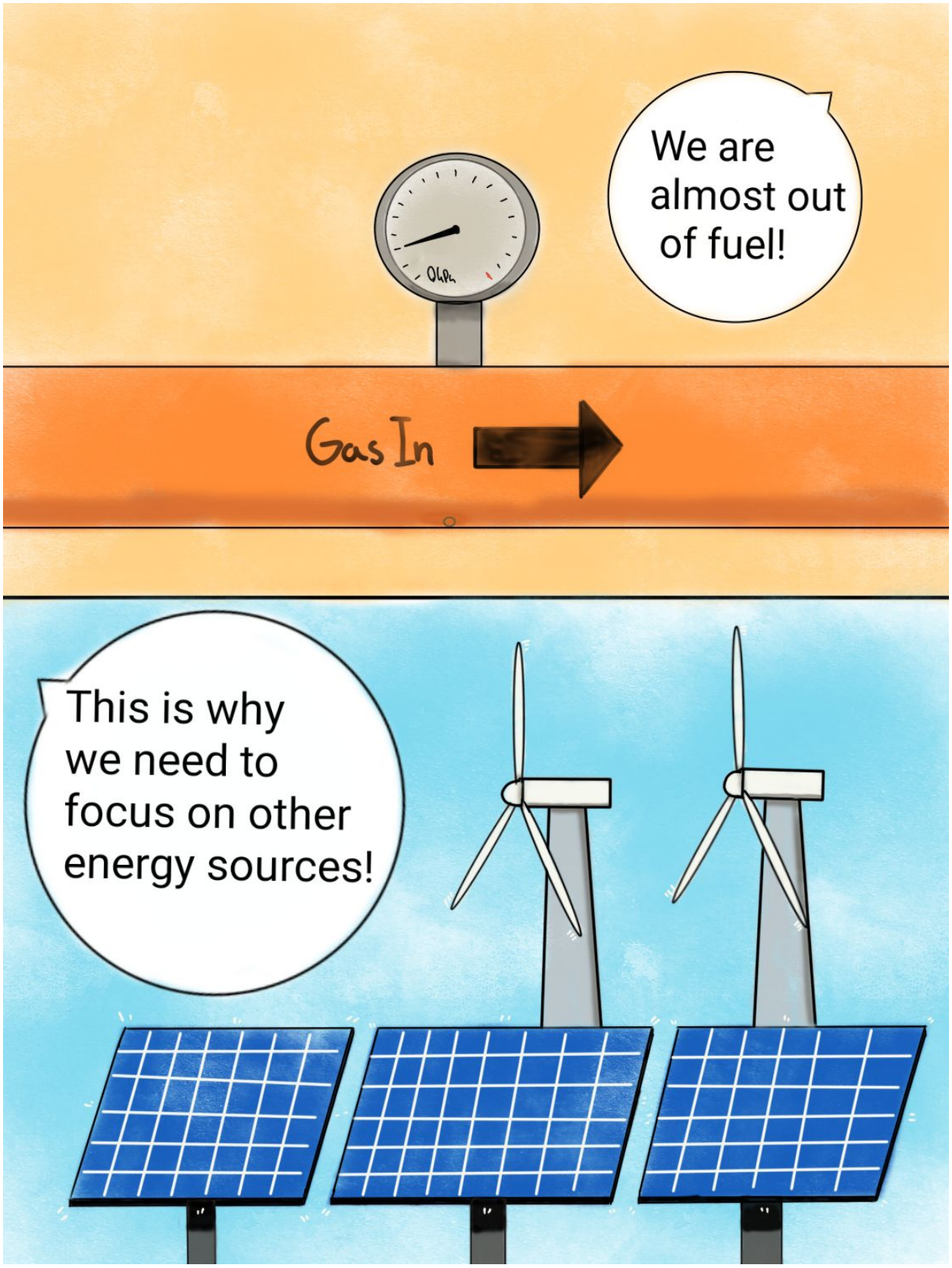
Fragile Fuels

Although the engines had been providing much needed power for so long, there remained some issues. The engines were not perfect and would over time lose pressure due to issues with their piston seals. This lead to energy production losses or down-time for maintenance. Luckily, with a fully decentralized grid system now, this wasn't as much of an issue as it was an inconvenience. The man realized that this was likely the reason these engines never became more than toys or laboratory specimens in such a highly cost-cutting world as the pre-war days.

The bigger issue came when it was realized that the natural gas source was running low. Consistent pressure drops had been noticed in the feed line, choking the system of its primary source of heat. The residents of the village could live off burning wood and other materials to continue the power generation that they sorely relied on nowadays, but many were getting to a point of serious distress.

The man was doing his best to rectify the issue and assure those around him that there was no cause for concern just yet. However, those around him demanded he do something. Suddenly the man thought back to being a boy, and reading the textbook. He had realized how dependent society became on certain fuels. He also knew that this caused to great tension between the then-formed countries, and ultimately is what led to armed conflict and nuclear devastation. Even on this much smaller scale, he did not want those around him to worry.

He returned the library where he first started the adventure, hoping someone had thought of this issue in the past. Out of the corner of his eye, he saw a book detailing integrated power systems. The topic was intriguing, and exactly what he had been looking for. As he read, he took notes of building solar panels, making a network for backup and storage power supplies, and how the system increased energy yield by more than he could possibly imagine. Upon returning to the village, he gathered as many people as he could to help him begin the project. It took months to finish the designs and outfit all the homes with solar panels, but the project proved successful. Within a few moments of turning the grid back on, the whole town seemed to be full of more energy: machines and people alike. This was the future they had truly dreamed of. Not knowing what the future may hold next, the man sat in awe of how far everything had come, just hoping that it would all be enough one day.


We are almost out of fuel!
Gas In
This is why we need to focus on other energy sources!

Rise of Renewables

The boy stepped on to his porch, his face now weathered and creased by age. He ran his fingers through his long white beard as he looked out to the plains before him. Great clouds floated across the landscape where the grass had begun to retake the land. The green plains where punctuated by speckles of silvery blue. Just as the march of time had brought back the grass it had begun to part the sky.

As the fossil fuels to be scavenged became fewer and fewer and the sun began to come back solar panels began to dot the landscape. When the sun shone bright the panels far outstripped what the network of stirling engines could manage. But the rain clouds had darkened the landscape for days.

A beep emanated from inside his house, followed by a small hum and then silence. A small smile broke across the man's face as he realized the Stirling engine that he had found in those ruins all those years ago, and since had moved to his basement, had sprung to life. During weeks like this when the skies became obscured his engines would spring back to life, filling in the gaps that the solar panels and the wind turbines could not.

Together the vast array of interconnected power sources provided a strong framework that could supply near constant power for the surrounding area. It provided a backbone for the society that was slowly beginning to rebuild around it. A backbone that had all sprung forth from the engine that now whirred in the background.

He took a last glance at the plains, still smiling, as he turned back inside to enjoy breakfast with his wife. She was once was so sickly and frail, but now was able to live out a full life. He looked at her and saw a reason for all of this, and with this he was at peace with his world.


Initializing . . .

Additional Notes

This story is one of many meant to explain particular aspects of Thermodynamics. It is part of a class known as ME300, taught by Professor Liebenberg, at UIUC.

It was the group's intention to provide a look at the device known as the Stirling Engine. This device, as described, is an entirely external combustion engine developed in the 1800's and mostly left to history as it was trampled by the internal combustion engine.

Many issues still plague its development and use as a reliable power generation device, especially issues regarding the regenerator and the seals. Maybe when a true carbon nanotube regenerator is fabricated can we start using these engines reasonably.

It does have the possibility to provide great support to developing nations and zones, even with its issues. This was the whole vision of Dean Kamen, the Beacon 10's creator. This story is meant to parallel some of the possible problems that could be faced in poverty-ridden conditions and display possible solutions utilizing the Stirling engine. They are in no way for certain, however, they are the team's imagining and reasoning that some issues, such as clean water, could truly be taken care of while generating electricity for a variety of purposes.

If there are any questions about this story or its contents, feel free to contact connorl2@illinois.edu.

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