Tenkiv

Technical Briefing

1 About Tenkiv

Tenkiv designs, builds, and implements advanced energy systems with the goal of democratizing sustainable water and energy access. Our technology is unique— with a single, modular solar thermal system we can handle energy acquisition, distribution, storage, and conversion while remaining significantly less expensive than fossil fuels.

We can adapt our technology to solve a huge number of vital, global problems, such as clean energy production and water purification. Our current goal is to reduce child mortality rates due to waterborne diseases by bringing our systems to the communities and regions that need them most.

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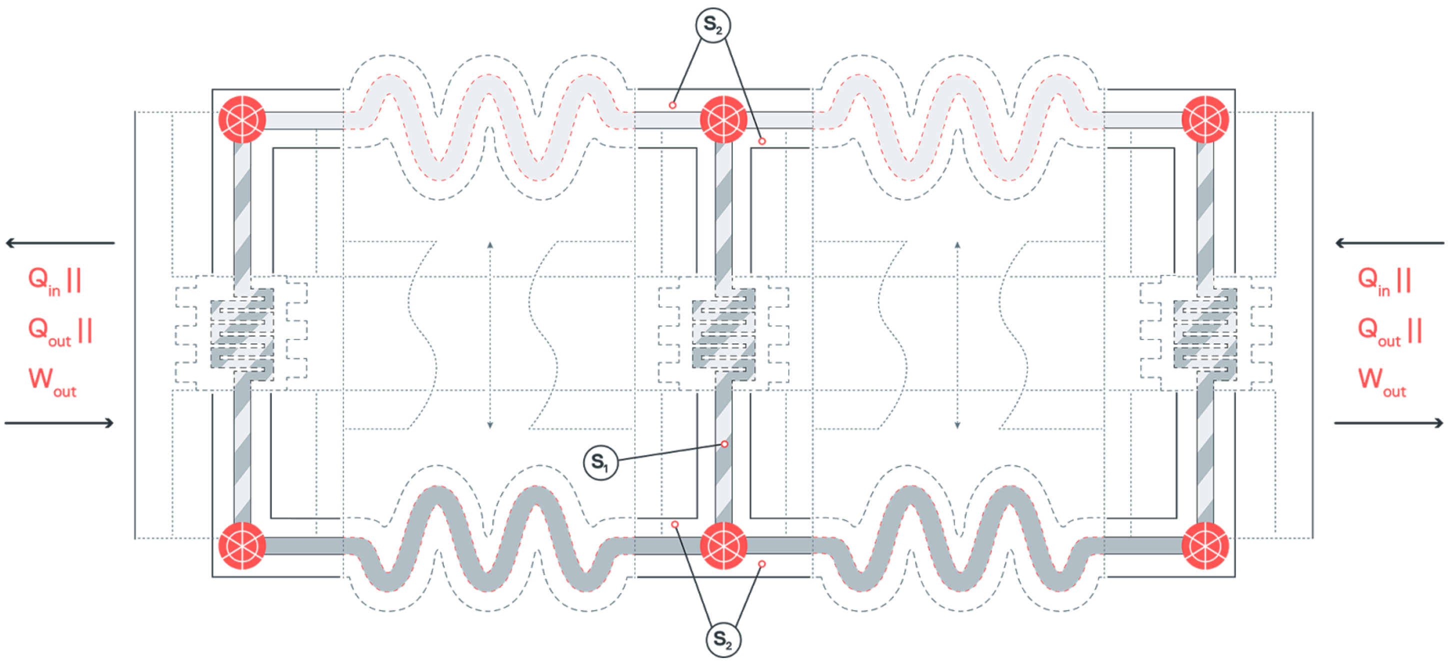
What is the PII Thermal Circuit?

The PII Thermal Circuit (Phasic, Integrated Isolation Thermal Circuit) is a minimal set of structural properties that, if perfectly implemented in a theoretical device, would gather, transfer, and deliver thermal energy throughout a variable system at the maximum thermodynamically attainable energy.



Circuit Structural Properties

1. [One continuously integratable pressure vessel] (**P**) filled with no other fluid than [a dedicated heat transfer fluid] (**F**) such that in [**P** inter-system heat transfer surfaces that are adding heat to the circuit] (**i_{in}**) **F** is in the liquid or lower energy state.
2. **P** is maximally thermally isolated from the environment.
3. The boundaries of **P** along **i_{all}** are as thin as possible and as thermally conductive as possible.
4. The maximum possible area of [all **P** inter-system heat transfer surfaces] (**i_{all}**) are in contact with **F**.
5. The distance between [a **P** inter-system heat transfer surface] (**i_x**) and **i_x** must be minimal.
6. **F** must be maximally restricted from flowing in unproductive directions.
7. Pressure differentials throughout the system must be limited to originate from, and be constant with **i_x**.

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Properties Key

- Text in brackets followed by text in parenthesis defines a symbol. E.g. [A four-sided shape where the length of each side is equal to each other side] (**square**)
- When used, symbols are written in bold. E.g. if the length of one side of a **square** is 2, the length of all other sides is also 2.

Notable / Practical Implications

- As an inherent result of the circuit's properties, all heat transfer naturally occurs via small pressure differential phase change: fluid vaporizes at the location of heat addition (in producers) and condenses at the location of heat removal (in consumers).
- Practically the "layer" used to thermally isolate the pressure vessel will need to bear a vacuum. Meaning the pressure vessel can be made of a very small amount of ballooned material.
- Since the pressure vessel should be made so thin, the material with which it is constructed does not need to be highly conductive as the conductive path is very small.

How fundamental is the PII Thermal Circuit?

A common question that is asked about the technology we're working on is usually a variation of *"how fundamental is it?"* In other words: *"Are you working on something which is just your version of an existing technology, a clever new assembly of parts, or something completely new?"*

The answer is complicated and not entirely intuitive because people typically think of and categorize technology based on a collection of prejudices formed over time, rather than on an analysis of the underlying functioning of the technologies in question. For example, why do we categorize the Carnot cycle as its own "thing" rather than listing the processes undergone by a device using heat to do work in a certain way? The answer is that it's a convenient set of properties, assembled by applying the laws of thermodynamics, to group into something — in this case, a cycle. It can be referenced as a specific thing rather than having to describe each aspect of it every time the Carnot cycle is referenced. Also, it's clearly a very "fundamental" technology based directly on thermodynamics (which is very low abstraction) as opposed to being an assembly of things (that are much higher abstractions) like putting a motor, battery, and wheels together to make something called a "car". It's important to note that most "inventions" aren't even as fundamental as the car example. Most inventions are more like putting a specific set of those parts together to make a specific car.

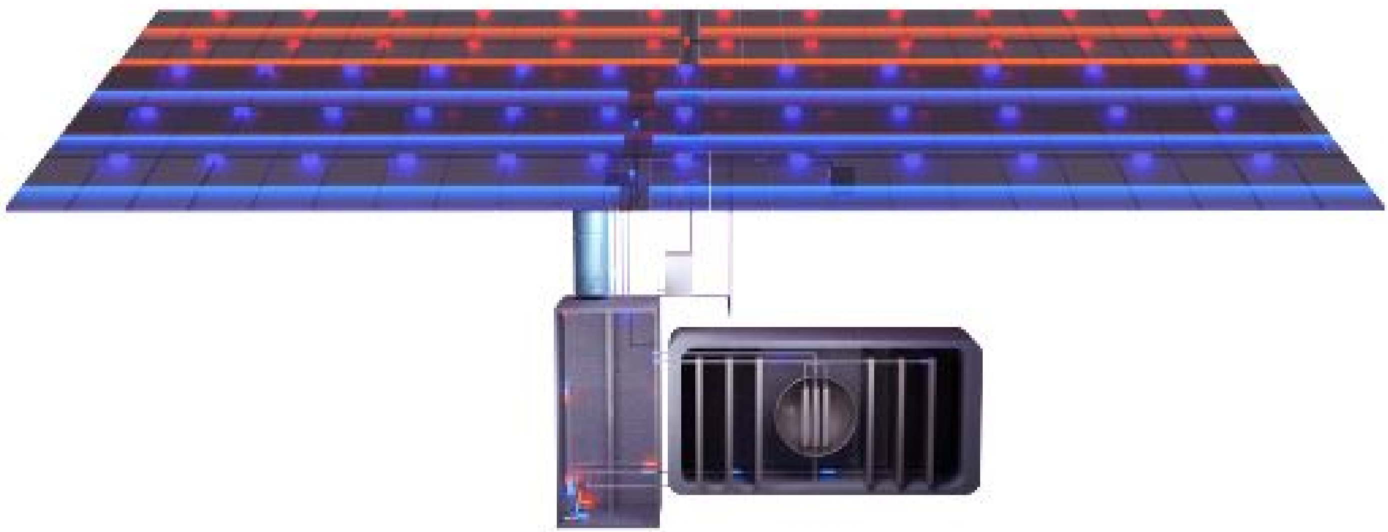
Keeping all that in mind, the PII Thermal Circuit is a fundamental, low abstraction technology. It's based directly on the laws of thermodynamics. It is, of course, related to other technologies that have applied those same principles, but is not an extension of any of them. The only way the PII Thermal Circuit could be more fundamental is if it were actually based on new, basic physical laws that we discovered and formulated ourselves.

5 PII Thermal Circuit

The PII Thermal Circuit is to thermal systems what the integrated circuit is to electronics. When the integrated circuit was invented, each of the individual functions it carried out could be achieved by assembling existing components. However, the integrated circuit allowed for the efficiency of these tasks to be drastically increased. Therefore, the achievable complexity of systems could increase to a point that simply was not possible with discrete components. Almost all modern electronics are based on the integrated circuit, and it's probably one of the most fitting analogies to the PII Thermal Circuit.

6 Tenkiv Nexus

The Tenkiv Nexus is a modular power system that implements the PII Thermal Circuit. It extends all of the properties of the PII Thermal Circuit with a specific purpose; to make as much energy as possible practically accessible for the lowest possible input cost (in terms of energy, money, and other resources).

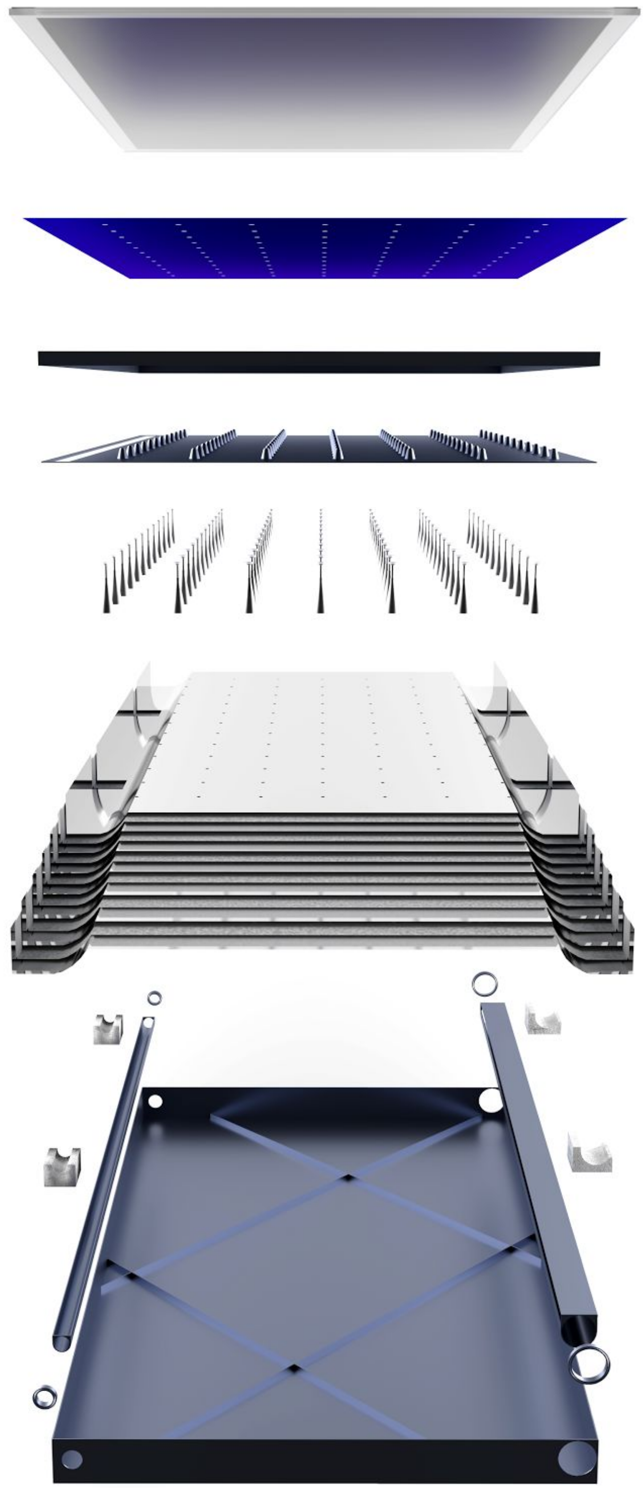


Components

Due to the implementation of the PII Thermal Circuit, the Tenkiv Nexus is so tightly integrated that, in many cases, breaking it down into components isn't the ideal mode of analysis. However, as long as the integration is understood and kept in mind, sorting things into components can be very useful. To get a rough understanding for what is meant by integration in this context, refer to the section on the **PII Thermal Circuit**. With that said, here is a rough way of categorizing the components.

7 Tenkiv Nexus

Solar Collector



8 Tenkiv Nexus

As a result of using the PII Thermal Circuit, the Tenkiv Nexus reacts to thermal energy added from any source or used by any consumer in the exact same way. The collector is classified as a component only because it is the primary energy provider for the Tenkiv Nexus. Because the solar collector provides almost all of the system's energy, much of the layout of the system is built to accommodate the solar collector. If the collector is separated from the system and made to run as a standalone circuit it would boast very impressive stats, performing far better than other solar panels that run in the same temperature range.

Storage Tank

The storage tank behaves like any other module but it is listed separately because of its exceptional importance. Because of the inconsistency of solar radiation hitting the earth, it is a practical necessity for a solar power system to have the capability to store large amounts of energy if it's going to provide a significant portion of a region's power. Part of the reason for using heat as the main energy medium in the Tenkiv Nexus is the cost-effectiveness of storage. The massive amount of energy that is typically produced by the collector can be stored for up to several months, giving the system the ability to be effective through almost any conceivable storm or times of little or no sunshine.

Heat Distribution Network

Similar to the solar collector, but with a different purpose, the heat distribution network is solely an implementation of the PII Thermal Circuit. It's a dynamic network that will typically handle all heat distribution without any intelligent controls. Still, the intelligence and control circuits are there to easily reconfigure it when required. The distribution network, along with the entire system, can be scaled without significantly increasing complexity or decreasing efficiency.

Thermal Processors (Modules)

The Tenkiv Nexus can, through the PII Thermal Circuit, integrate devices to process heat for conversion to other forms of energy or to do other work. Following are some potential examples of modules:

- A **Heat Engine**, which converts heat to electricity.
- An **Absorption Chiller**, which uses heat to pump heat. This is typically used to cool a zone, but can also be used to heat a zone more efficiently than if the heat were put directly into it.
- A **Thermal Distillation Filter**, which uses and recycles heat to distill impurities out of a substance (usually water).

Intelligence and Control (IC)

The intelligence and control subsystem monitors many system and environmental factors (weather, collector temperature, energy use, etc.) and automatically reconfigures the system accordingly. For example, if it's night, the IC subsystem will reconfigure the Tenkiv Nexus to take energy *from* the tank rather than *adding* it to the tank.

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After this reconfiguration is made the PII Thermal Circuit will continue to allow heat to dynamically flow throughout the system, with no further interference from the IC subsystem.

The IC subsystem is split into three basic parts:

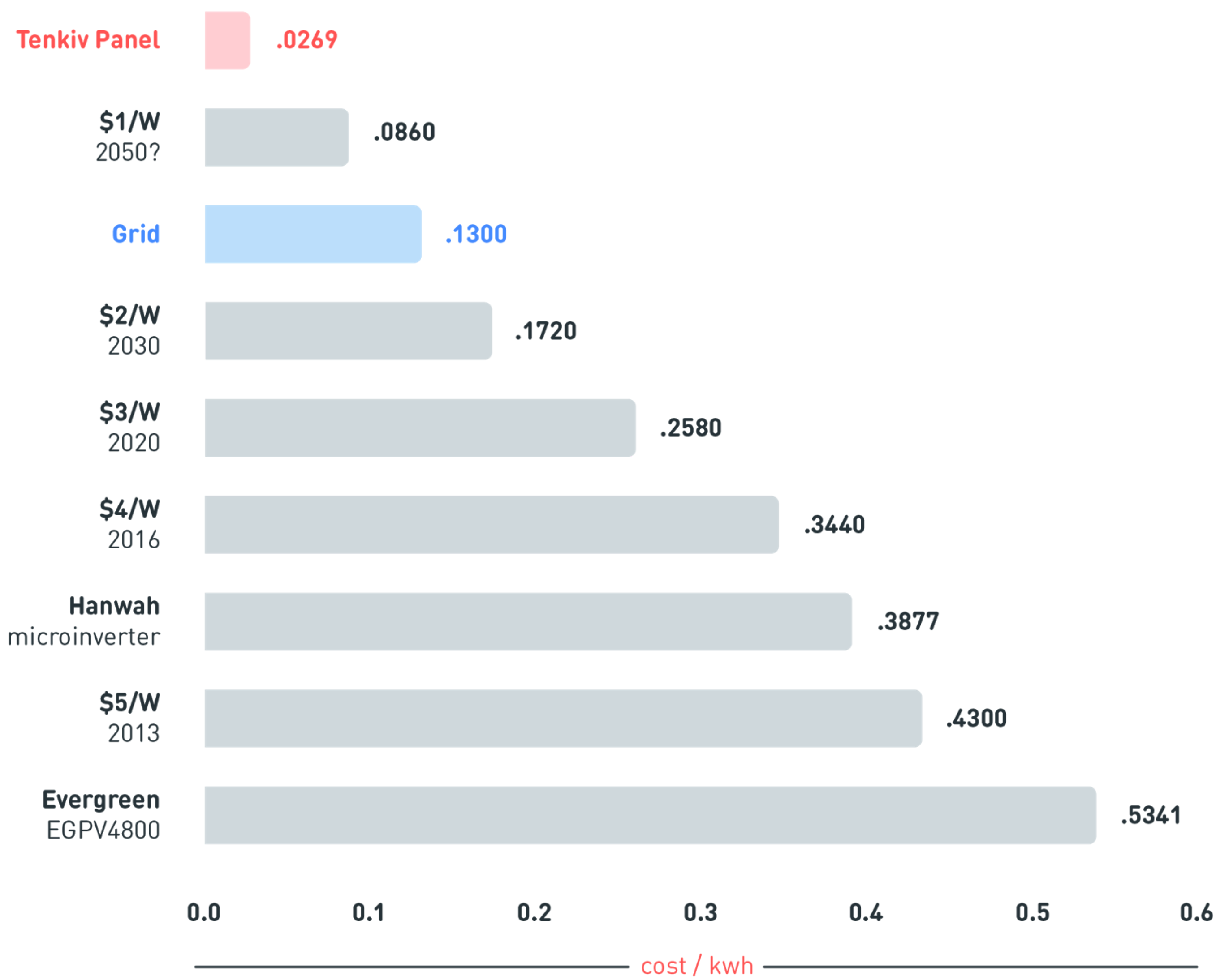
1. The **Tekdaqc**, or in larger systems, multiple Tekdaqcs, which are used with a variety of sensors to collect data about the Nexus. The Tekdaqc is also used to control the Nexus with various pumps, valves, and other switches. See the **Tekdaqc** section for more information.
2. A **central server** or **server cluster** takes the data from the Tekdaqc and uses it to decide the optimal run configuration of the Nexus in addition to ensuring everything is running smoothly and there is nothing that requires maintenance. The control software, called the Nexus Brain is currently in its infancy and only completely stable for single module Nexus installations. As Nexus Brain matures we will allow third party developers to extend it with plugins for controlling their own modules. The Nexus Brain is currently written entirely in Kotlin targeting the JVM and the plan is to continue with that model for the foreseeable future.
3. The third part is the **client program** so users can easily monitor and control the Nexus. The top priority client target is Android because it's very popular, open source, and JDK compatible. Since the client isn't mandatory for many Nexus installations it won't be a high priority until Nexus Brain is more mature.

Cost-effectiveness

Our objective when designing the Tenkiv Nexus was to "produce the largest quantity of energy, with the smallest resource input, on a global scale". This translates to maximizing cost-effectiveness, i.e. energy produced/input cost. According to our current models, we have succeeded in this goal. When analyzing the data as unfavorably as possible, powering a building with the Tenkiv Nexus is about a third of the price (with no subsidies or incentives) of powering the same building with fossil fuels. This is also not including the cost savings from integrating the Tenkiv Nexus with other infrastructure (like buildings) instead of having to make all the infrastructure from scratch. All of this is made possible by the PII Thermal Circuit. For more technical details on how we're able to this, refer to the section on the **PII Thermal Circuit**.

Tenkiv Nexus

$ / KWH for Tenkiv Nexus vs. PV & Grid Power



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Future of the Tenkiv Nexus, the PII Thermal Internet

Because the PII Thermal Circuit and, by extension, the Tenkiv Nexus, is practically infinitely scalable, “individual systems” can be linked together. Imagine a city where 50% of all the buildings are Tenkiv Buildings. These buildings can very easily be linked together and automated in the same way they function internally. A good analogy is the internet compared to a local computer network — they both work exactly the same, the only difference is scale. In this example, the computer systems can range in power and complexity. You might have a Google server bank as one node or collection of nodes (which is obviously very power dense) and Bob’s 1995 Dell as another (which, of course, is less powerful). Similarly, in this PII thermal internet you could have a 5 GW solar farm as a part of the internet and a 500 square foot Tenkiv Building as another. The result is a distributed, dynamic, intelligent, scalable energy infrastructure, as opposed to the relatively static, centralised infrastructure we currently have.

Data & Statistics

There’s a reason the Tenkiv Nexus uses the sun as its primary power source. **There’s much more power coming from the sun than all other sources available on earth combined.**

Energy Available by Source (ExaJoule)

12 Tenkiv Nexus for Cleaning Water

We use two different modules with the Tenkiv Nexus in order to clean water.

Sanitation Module

Sanitizing water means killing all the biological contaminants in the water. Our sanitation module uses very little energy but is only useful for filtering water without hard contaminants like lead and arsenic.

Distillation Module

Distillation is the process of evaporating a liquid and recondensing it in order to remove contaminants. This process can completely purify water from practically any source but uses a significant amount of energy.

Sanitation

The intended use for the sanitation modules is in remote parts of the world that primarily face issues with biological contaminants in their water. Our sanitation process is very intuitive and falls into the World Health Organizations highest tier for efficacy. We essentially use a pasteurisation process where we heat up the contaminated water to around 100°C for about 2 minutes. According to the WHO, this should kill 99.9% of biological contaminants in the water. The reason this process is so efficient is we can recycle almost all the heat by cooling the pasteurized water back down to the temperature of the source. We recycle heat by transferring it from the water that was just pasteurized to the new water coming in from the source. This is standard practice in pasteurization processes. Nexus installations used for water sanitation usually provide optional hot water as well. If users are using a lot of hot water the efficiency of the sanitation process will drop since we can't recycle the heat from the hot water taken out by the user.

Tenkiv makes the sanitation module completely in-house.

Distillation

Recycling heat is an extremely important aspect of thermal distillation. Without any recycling, the distillation process is almost as simple as the sanitation process but it would also be prohibitively inefficient. This is why various methods are used to recycle the heat used to boil water in distillation processes. As with sanitation, recycling the heat used for distillation can increase efficiency by several orders of magnitude. However, the heat recovery process is quite a bit more complex in a distillation process than a sanitation process so Tenkiv does not currently make the distillation module in-house. Instead we modify thermal distillation units from Alfa Laval to be useable as a Nexus Module (which requires very little effort).

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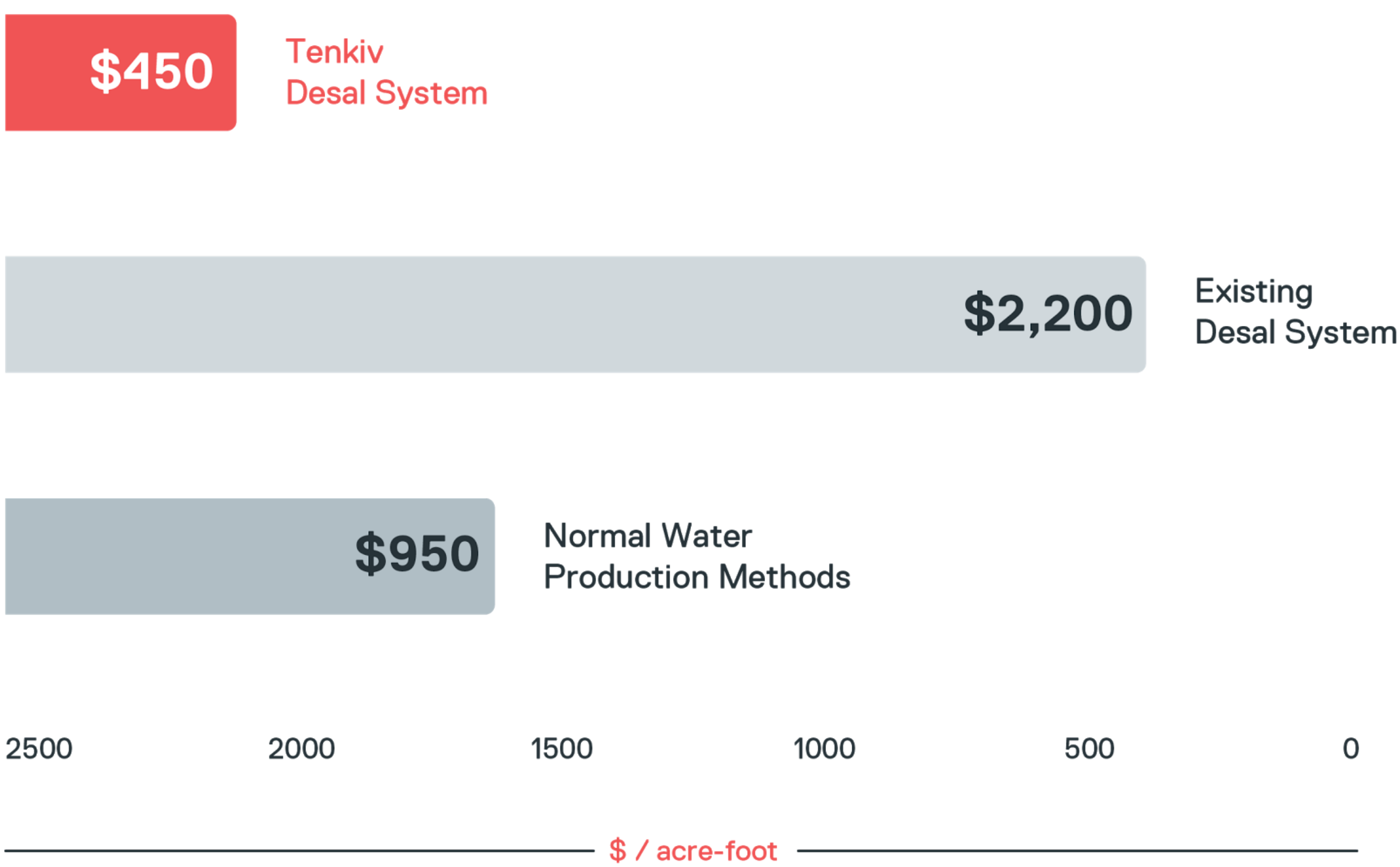
Comparison to reverse osmosis (RO)

It currently takes more energy to distill a certain quantity of water than it does to purify it using reverse osmosis. Theoretically, however, there's no reason why there *should* be a difference, and this practical gap likely comes from the fact that there has been much more resources put into RO than thermal distillation. We could power a reverse osmosis module with the Tenkiv Nexus but pretty much all of the energy used by RO systems is for running pumps. To do that kind of mechanical work at reasonable efficiencies means we need low entropy, and getting lower entropy decreases the efficiency of everything besides the purification process itself. There are additional drawbacks to reverse osmosis like it's heavy reliance on filters that need frequent replacement and its inability to create dry waste. Since the Tenkiv Nexus can make the high entropy energy needed by distillation process for an absurdly low cost it ends up being significantly cheaper for us to use thermal distillation than RO even though existing thermal distillation is less efficient. Thermal distillation processes have essentially no moving parts, require almost no maintenance, and can remove contaminants as dry waste. The process is vastly preferable to RO if you have a cheap source of heat, like we do. Below we have a cost comparison of doing thermal distillation with the Tenkiv Nexus vs RO with grid power.

Cost of Clean Water Production



— Carlsbad Desalination Project, Bloomberg

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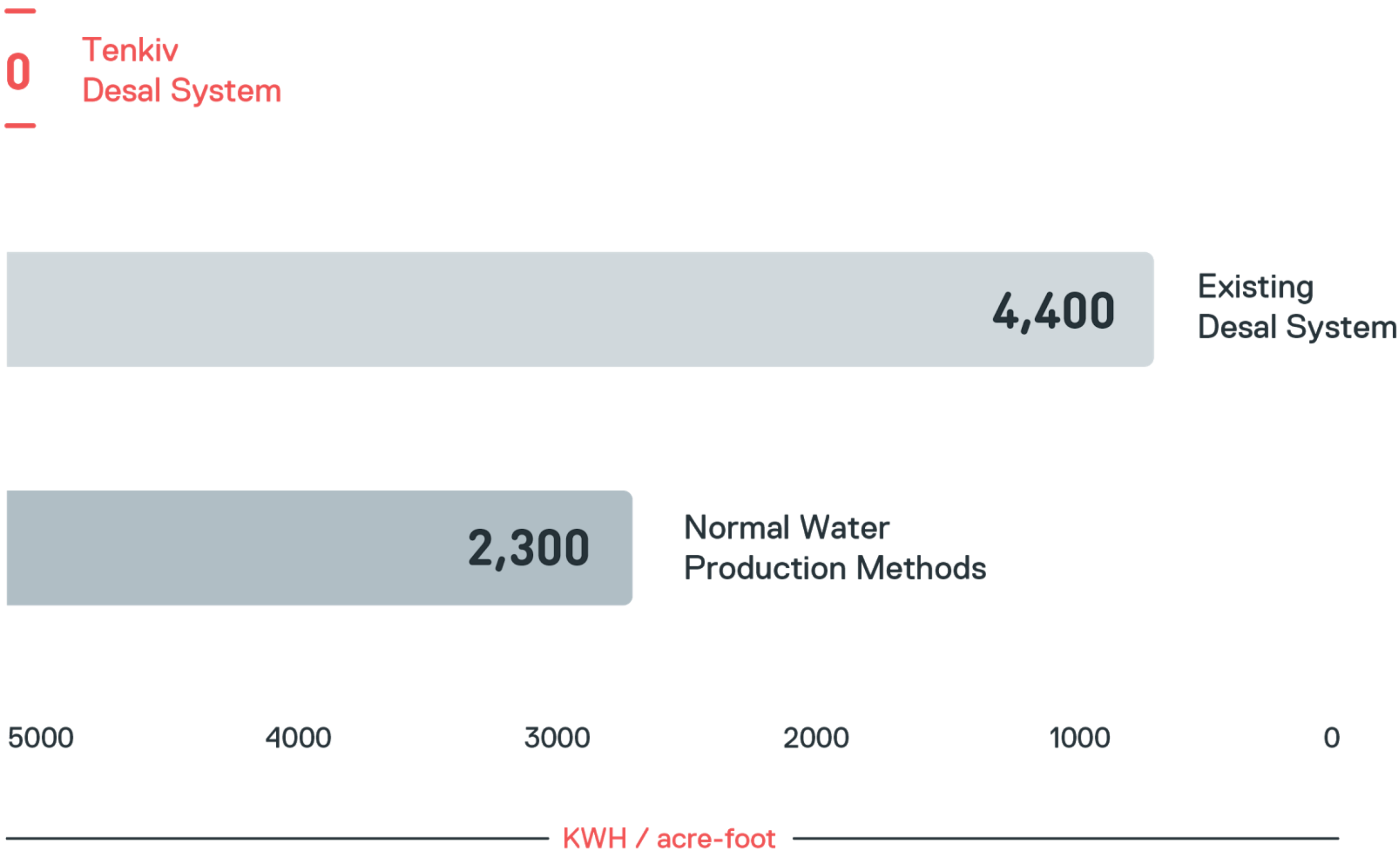
External Energy Input of Clean Water Production



— Department of Water Resources, San Diego County Water Authority

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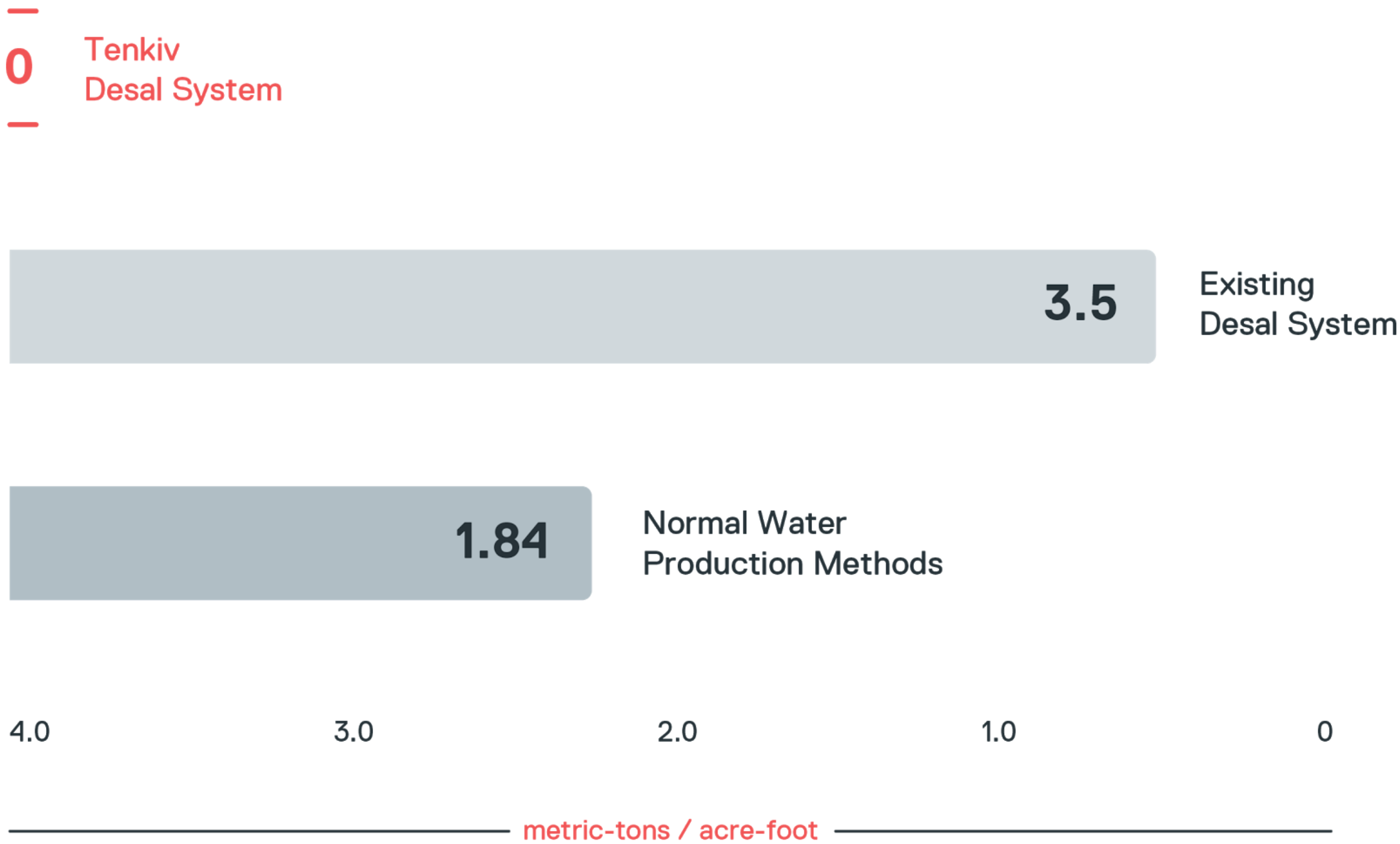
CO2 Emissions of Clean Water Production



— PG&E

16 Tenkiv Building

The Tenkiv Building is a new, intelligently-automated building that can generate more power than it uses.

A New Kind of Building

Deciding how to categorize things is always an interesting problem because we have to put our product in terms of what makes sense according to the existing paradigm so that you have a set of common references with people who aren't familiar with Tenkiv. We could call the Tenkiv Building "a building with the Tenkiv Nexus and additional modifications", which, at its core, it *is*, but integrating our technology with a building in an optimized way changed so many core systems of the building in such drastic ways that it ended up being more accurate to categorize this as an entirely new kind of building.

Integration

As is the case with the technologies the building implements (PII), one of the building's greatest aspects (aside from what has already been described in the **Tenkiv Nexus** section) is its self-integration. The Tenkiv Nexus is already extremely cost-effective, and by eliminating redundant components in the Tenkiv Building we only increase this effectiveness further.

17 Tenkiv Building

The result of this integration in the long term is that, even in a hypothetical case where the Tenkiv Building generated no power whatsoever, it would still be more cost-effective than a traditional building because it simply costs less to make. The Tenkiv Nexus also generates far more power than a traditional building uses, resulting in unprecedented levels of cost-effectiveness. Our design philosophy when making the Tenkiv Building was that we weren't going to accept compromise in any area. It wasn't enough to make huge leaps in some areas if we are going to ask for even minor sacrifices in others. We wanted every aspect of this building to be better than what currently exists— some by a wide margin, and others less so, but overall everything is improved. This can be divided into three categories.

Energy

A traditional building uses a lot of power and generates none. If you want to add the ability for it to produce energy, more components need to be added to the building and more resources need to be invested. Any addition that *could* produce energy would not be as cost-effective as just buying energy made from fossil fuels off the grid.

Because of its integration-focused design, the Tenkiv Building generates *more* power than it uses at no additional input cost aside from the minimal maintenance that needs to be done. The extra power can be sold, meaning a Tenkiv Building can actually *make* money over time.

Input Costs

In the long term, the Tenkiv Building should cost about 80% of what a corresponding traditional building costs (in terms of size, luxuriousness, etc.).

Living Experience

The Tenkiv Building is meant to totally change a resident's / user's living experience.

The user will have massive amounts of energy available to them at practically no cost. This means they can do things like heat their pool to 32°C in the middle of winter, not worry about how long their shower is, charge their Tesla overnight with no costs, or even run a hobbyist machine shop in the garage without worrying about how much electricity is being used.

The IC subsystem automates many tasks a resident of a traditional building would have to do themselves, and makes many other tasks much more convenient. In a Tenkiv Building, the resident doesn't have to think about setting thermostat schedules, making sure everything is ok when they go on vacation, or turning off the alarm when they get home. A Tenkiv Building takes care of the resident, not the other way around.

18 Tekdaqc

The Tekdaqc (Tenkiv Data Acquisition and Control) is a general purpose, lab-grade data acquisition and control board. Its primary purpose is to serve as a means of interfacing our control system with the real world devices which make up the Tenkiv Nexus.

19 Tekdaqc

Design Requirements

The primary design requirements of the Tekdaqc are the reliability of operation and safety of the Tenkiv Nexus. These requirements have resulted in a device which is capable of performing a similar role in a wide variety of applications. A secondary, but nonetheless important, design requirement was to have a unit cost (when calculated for 1K+ unit quantities) which is significantly lower than a similar device currently on the market (in order to justify developing our own board as opposed to buying an existing one).

Use in the Tenkiv Nexus

In order to maximize the energy handling capability of the Tenkiv Nexus, we need a way of determining the thermodynamic state of the various energy sources and consumers in the system, as well as a means of interacting with it to control devices such as pumps and valves. To facilitate determining the thermodynamic state, the Nexus is outfitted with pressure and temperature transducers. These devices measure various physical properties and output a signal which is (in most cases) a voltage proportional to the the measured physical value. For example, we will be using numerous thermocouples, which are metal wire sensors that generate a very small voltage that is proportional to the temperature they are exposed to. These voltages are incredibly minute and require a very well designed, very precise circuit to be able to get useful information from them.

Generic computer equipment such as desktop computers, phones, tablets, etc do not possess the means of controlling such equipment or measuring the voltage signals in question. The output of most sensors is in the form of a variable voltage. This is known as an analog signal. By their nature, computers can only process digital signals. Instruments known as analog to digital converters exist to translate the analog signals to a digital one which the computer equipment can understand. Generic computer equipment also lacks the ability to provide the relatively high amounts of electrical current that are required to activate devices such as valves, motors, etc. Devices of varying complexity exist that allow the small currents of computer equipment to control higher current loads (such as the valves and motors mentioned before). These devices are known as transistors and are essentially electronically controlled switches. They are the foundation of all modern electronics.

By building a circuit board which integrates a simple control processor with the analog to digital converters and various transistor equipment to drive outputs, we can effectively interface a generic computer controller to these real world sensors and loads. In order to accomplish our primary goals of reliability of operation, there is more that needs to be done. Interfacing electronics to the real world comes with many risks to the safety of the equipment and special precautions must be taken if you expect to use it outside of a laboratory environment. The dangers include, but are not limited to: high electrical potential differences between two physical locations (such as two sensors which go to different places), a user connecting an unsafe voltage to an input/output of the circuit, connecting a load which exceeds the ability of the circuit, a fault in one of the inputs/outputs, and many others. Early on, it was decided that every reasonable precaution to protect the Tekdaqc board would be taken to help ensure its reliability.

In order to accomplish the required protection, we incorporated numerous safety measures into the design of the circuit. These include:

- Fully isolated power supplies.
- High isolation, optically controlled solid state relays for all inputs, digital and analog.
- Reverse polarity protection diodes.
- Digital output drivers that are thermally, overcurrent, and short circuit protected on a per channel level.
- Independently isolated analog channels.
    - This means that if a sensor is attached to a power line, it would do no damage.

In order to accomplish the second primary requirement, we have made an attempt to keep the design as simple as possible. To this end, we have provided for there to be a sufficiently large amount of processing capability while at the same time trying to keep the executed code to a minimum. End users would be able to add to this code, however it is not something we plan to do internally. The effect of this is that the processor spends a good deal of its time waiting for the physical world to “catch up”, ensuring that it is never overloaded with data.

Resulting Product

Tekdaqc

We have created a control board that is exceptionally robust, precise and generic. There is an obvious potential for the Tekdaqc to be utilized in other applications beyond what we have created it for. To this end, we have done our best to generalize the board as much as possible. It is capable of switching fairly large DC electrical loads with no additional components such as motors, lights, solenoids and relays. This makes the Tekdaqc well suited to applications such as home and theatre automation (heating/cooling, doors, pool control, irrigation, etc.). The planned incorporation of isolated/protected Pulse Width Modulation (PWM) drivers allows for very precise control of motors, servos, and other electrical loads capable of being driven in this manner (such as electrical heating elements). Combined with the capability of accurate and protected voltage measurements of sensing devices (such as pressure and temperature transducers), the Tekdaqc is perfectly suited for process control, kiln control, robotics/animatronics, and much more.

We made the Tekdaqc publicly available in early 2014 and have sold units to researchers all over the world. In addition to bringing in revenue, this has given us an opportunity to be involved in a wide variety of research projects and get valuable feedback to improve the Tekdaqc.