



收稿时间 / Received Date | 中图分类号 / TU982.3/.7
2013-01-21 | 文献标识码 / B

能源来世：冰岛雷克雅尼斯地热梯度规划

Energy Afterlife : Choreographing the Geothermal Gradient of Reykjanes, Iceland

凯瑟琳·德·阿尔梅达

哈佛大学设计学院景观设计学硕士

Catherine DE ALMEIDA

Master of Landscape Architecture, Harvard GSD

翻译 Translated by / 苏博 Bo SU

校对 Proofread by / 李舒雅 Shuya LI

1. 居住地：冒泡泥池、温泉和冒着热气的火山喷气孔表明冰岛北部米湖地区的克拉夫拉火山的南艾弗杰尔存在地热活动。
1. Living Ground: Bubbling mud pots, hot springs, and steaming fumaroles indicate geothermal activity in Námafjall, Krafla, north Iceland in the Mývatn region.

摘要 ……

能源是生命的基础和现代文明发展的推动力。能源产业被重新视为将与各类其他基础设施、经济及生态进行重叠和混合的运作过程。“能源来世”探索了位于冰岛西南部的雷克雅尼斯地热电站产生的地热废水的再利用过程。地热残余能量的再利用是一个再生产和分离的过程，该过程利用地热原理、温度梯度的压缩和扩展创造出了新的景观形式。藻类种植和生产、植被恢复策略，以及对不同温度的体验共同形成了热资源公园。热能再次被证明可作为一种无形的、现象学的设计材料，可通过其内在的传导、对流和辐射特性与技术，以特定的材料和形式加以获取、储存与释放。

关键词 ……

能源；能源生命循环；地热；微气候；温度；梯度

Abstract ...

Energy is the basis of life and the fuel for modern civilization. The energy industry is reconsidered by uncovering where operations can overlap and hybridize with other infrastructures, economies, and ecologies. Energy Afterlife explores the reutilization of geothermal effluent from Reykjanes Geothermal Power Plant in southwest Iceland. Reusing its residual energy creates a post-production, spin-off process that yields a new landscape formed by thermal principles and the compression and extension of its temperature gradient. Algae cultivation and production, revegetation strategies, and temperature's experiential qualities are interwoven to form a thermal resource park. Heat is reexamined as an invisible, phenomenological design material, which can be captured, contained, and released through conduction, convection, and radiation properties and techniques inherent in particular materials and forms.

Key words ...

Energy; Energy Life Cycle; Geothermal; Microclimates; Temperature; Gradients

能源是人类活动和景观建造必不可少的介质，是维持生产和经济活动的重要资源。人类开发利用能源的痕迹也以物理形态的方式嵌入重组到景观中。与我们使用的其他能源不同，地热能是一种可再生资源，是一种空间的材料，其产生于地面之下，体现于地球表面，呈现为景观上的一种热学现象（图1）。然而，现在用于开发地热能的技术和手段仍然延续着过时的化石燃料生产的单向思维：钻探地热井、抽取能源到处理工厂、通过管道和传输网络输送能量，然后丢弃生产废料（图2）。通过对体系中残余能量进行再利用的规划，地热能的生产力还有巨大潜能。

“能源来世”提出了一种利用地热能的新方法，通过开发热力梯度、分散能源利用网络和把握每一次温度变化的机会，引导工业、生态和文化过程形成可见的融合。

冰岛独特的景观蕴含着丰富能源，持续地作用并不断重塑这片严酷的土地。这座位于北大西洋的岛屿完全被地热资源所充盈。冰岛是全球人均产值最高的地热能生产国。其地热能提供了4万亿瓦时的电能，满足了国内25%的能源消耗以及95%的热力和热水需求。冰岛具有世界上最先进的地热能提取、生产和利用技术。冰岛的经济和文化与地热能息息相关。

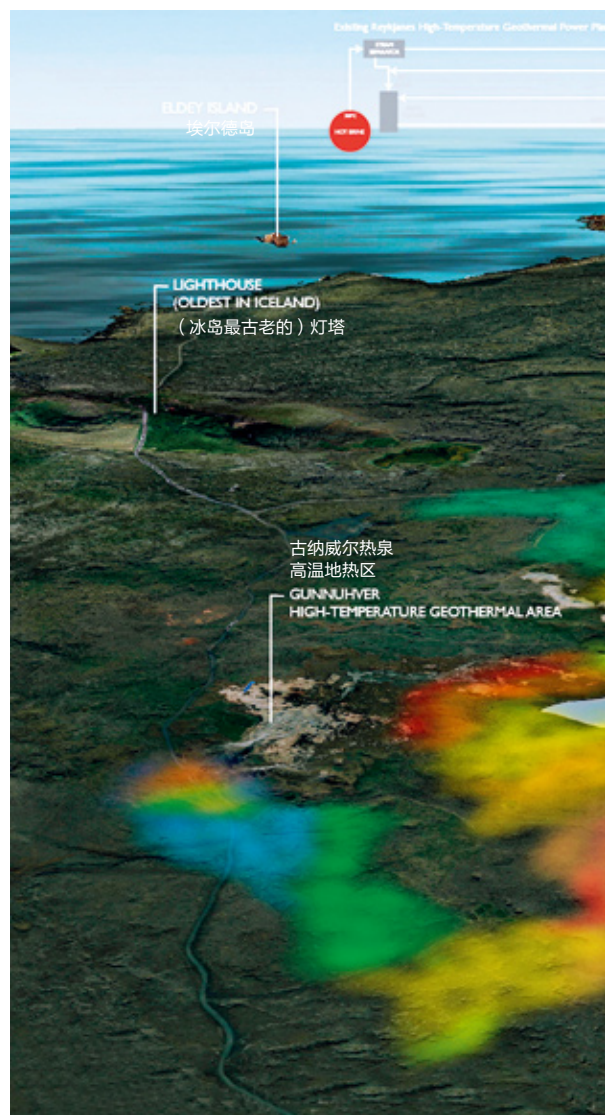
尽管近年来技术在不断进步，但是我们对这种能源的整个生命循环周期尚未形成一个完整的认识。在冰岛的调研中发现人类活动对地热能的利用仅限于某一温度区间。不同利用方式所剩余的地热能仍有被进一步利用的可能。“能源来世”试图在冰岛最新的发电厂中寻求发挥那些被忽视的地热废水潜能的方法。通过更换系统中的设备，可以在不同的利用方式之间设计出地热梯度，这是一种把某种用途中剩余的能量投入到另一种用途的生产性功能中去的策略。

雷克雅尼斯地热发电厂于2006年开始运营。这个发电厂产生的冒着热气的废水排放到冰冷的海水中，其影响尚不可知。发电厂的15眼钻井通向地下1.6~3km深处，并抽取300℃的海水。温度极高的水

通过管道运输到发电厂，通过蒸汽分离器将水与矿物质从蒸汽中提取出来。蒸汽通过两台5万千瓦的涡轮机，产生1万千瓦时的电力，供应给位于海湾的铝生产企业。高温的含盐废水在经过净化之后温度仍高达190℃，通过管道输送到冷却器，在那里与8℃的海水混合，以降低排放时的温度。当水温降至57℃时，废水流入800m长的混凝土涵洞，以4m³/s的流速排放到大西洋（图3）。在“能源来世”中，这些热水将不再被迅速地排放到海洋中，而是转变为一种生产过程，它的温度梯度可以用作景观中的一种热力手段，创造出微型栖息地并产生气候、生态和经济效益。

“能源来世”将温度视为景观中一种无形的现象学设计素材，通过充分利用热学基本原理来对其进行探索，并利用其内在的传导、对流和辐射等性质和技术，以特定的材料和形式加以获取、储存与释放。“获取”和“释放”的过程都在热量转移的过程中呈现出其内在的微观梯度，而“储存”则具有更高的热能均质性。这些概念在设计用于场地内运输废水的管道系统时得到了强调（图4）。

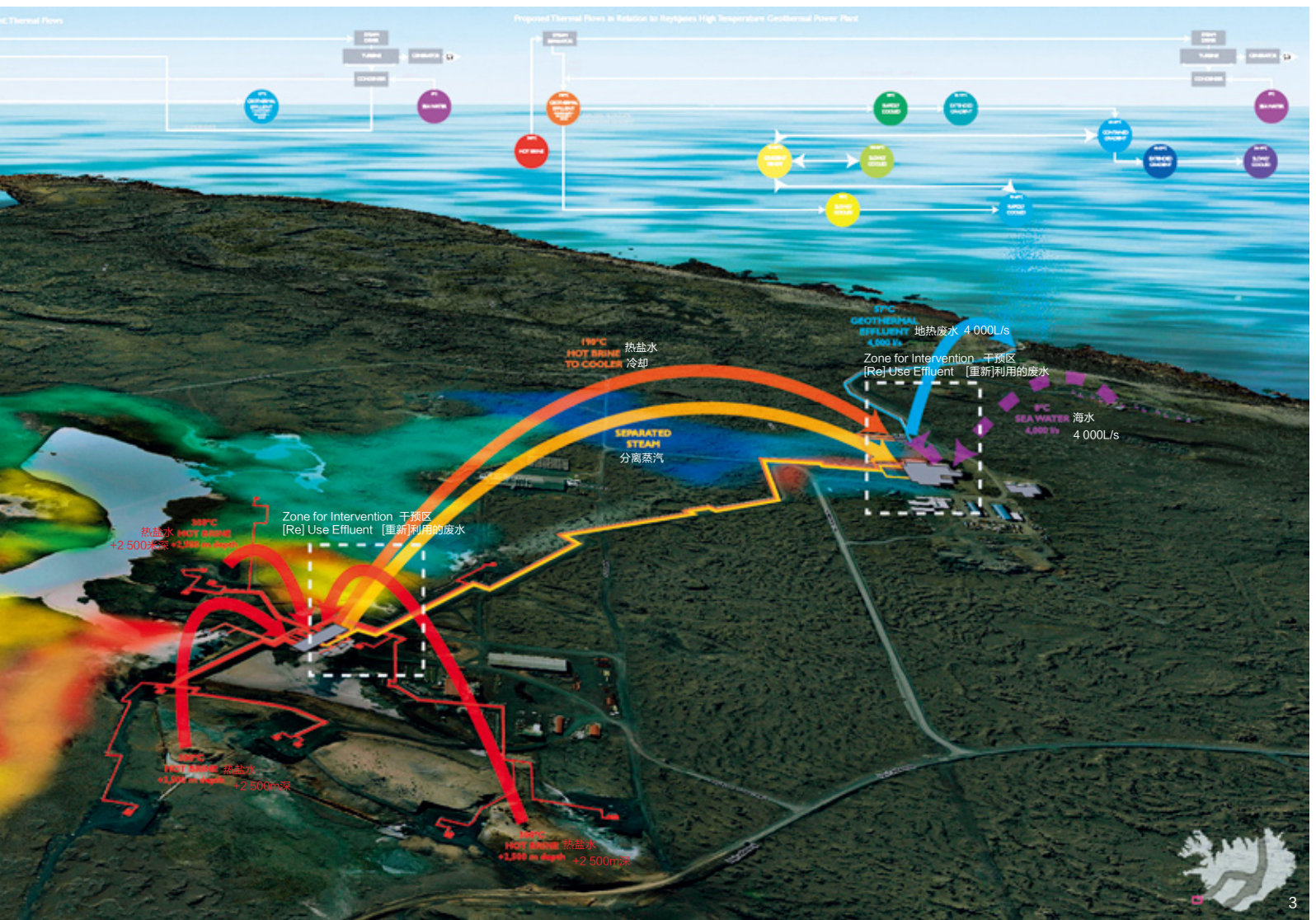
热能梯度的不同应用方式体现在展现不同温度功能的“热能世界”（图5）



2. 充满活力的景观：地热水通过管道从原地钻孔输送至位于亨吉尔——一个位于冰岛西南部的活跃的火山脊——黑德里舍地地热发电厂。
3. 雷克雅尼斯地热发电厂：项目现有的热流量及其覆盖的热力梯度框架。

2. Energetic Landscape: Pipelines transporting geothermal water from in situ boreholes to the Hellisheiði Geothermal Power Plant in Hengill, an active volcanic ridge in southwest Iceland.
3. Reykjanes Geothermal Power Plant: Existing thermal flows with overlaid thermal gradient framework of the project.





中。在热能世界中，这3种相互作用的利用方式创造出了热能的不同用途区域：生产生物燃料、营养品、食物和饲料的水藻区；植物园和地热生态学的研究区域；以及一个作为教育和文化设施的热能资源公园，这个公园能够为游客提供充分体验不同温度感观的难得机会。咸水池、蒸汽浴和桑拿伴随着与之所需温度区间相同的水藻群落、植物群落和动物群落，通过彼此传递的热量而相互促进。为了配合其用途，场地的围合、地形和植被的设计强化了日照，弱化了风力，创造了新的气候波动。这种热能开发在项目进行过程中为特

定的利用方式在特定的时间提供了必需的温度。项目使用空间界线来实现温度梯度的转换，使用不同热度界线来确定利用方式、生态类型和体验。

水生藻类和陆生植物的生态梯度随地热梯度的出现而自然产生。每个物种都具有独特的外观——形成从绿色到蓝绿色、少量红色到紫色的色调梯度。温度的差异通过不同水体培养环境中所生长的不同藻类群落在视觉上呈现出来。这些利用方式的表象——它们的色彩、纹理和温度则成为了满足生产性景观的热能梯度的指示器（图6）。

“能源来世”证明了规划热能梯度的可能性。这种可能性在两个特别的热能世界中显得尤为突出，那就是“极度高温”（Extreme Heat）和“超级水藻”（Extreme Algae）。极度高温创造出了一块通过辐射和对流使人们在远处就能感受到热度的区域。热量通过特定的材料来获取和传递，以辐射形式散发。例如，金属嵌入物通过吊在热水上方的悬臂，向土壤散发热量，并储存热量形成微生态。用柱子支撑在冒着蒸汽的热水上方的设备则吸收传导过程中产生的热量（图7）。它们沿着在流动中逐渐冷却的水流汇聚，并创

造出一种类似桑拿的环境，以此来感知波动的温度梯度。超级水藻有着相反的特征：它的温度满足所有利用方式的发生条件，因此可在土地上以条状形式“蔓延千里”。地形能够储存热量并在较低的地区维持相对稳定的温度，从而可以在极端的温度变化中保护藻类。供人使用的池塘位于较高的地区，以体验由其项目内热能相互作用而产生的外部热量（图8）。热能世界中的3条通路——获取、储存与释放——创造出了不同的微气候，这些微气候具有不同的湿度和温度，但是都保持了高温路径的持续高温（图9）。不同的温度控制形成了巨大的温差，这就使直接体验不同的温度并直至这种变化最终消失成为了可能。

通过探索热量的传导和交换如何在人类和非人类生命体系、利用方式和生态之间形成不同的相关关系，能源生命循环得以建立起来。极端环境会鼓励游客把他们的身体作为体验个体温度极限的一种“工具”。热能机制控制着景观中的梯度。反过来，温度临界值也成为了利用方式设计的基础。这样的互相作用被看作是热能世界中的一个系统。由热量交换产生的、具象化的温度—场地对应关系，建立起了新的文化景观。

水是冰岛文化独特的基础元素。在“能源来世”中，处于不同状态和温度下的地热水材料既是媒介也是对象。它吸引人们的感官，并引发游客思考它的热能梯度：它的影响、它的机制，以及它产生的自然过程和一种新的收集、运输和布置热能材料的文化过程。它鼓励游客不仅要参观场地，还要体会和理解它作为一种热量衰减的逻辑，并强调它的体验性和生产性特质。地热盐水环境非常少见，通过研究、教育和休闲体验它们的机会也非常有限。因此，这个项目以其独一无二的场地特性创造出了一个新的景点。一种“能源来世”的景观已经形成：与其排放掉废水，不如进行再利用并赋予其新的用途，使其从地热能生产过程中的残留物变成具有额外价值的收益。LAF



Energy is the medium that feeds human activity and its constructs on the landscape: an essential source for sustaining production and economy. Evidence of human energy use is reconstituted and reassembled as physical insertions in the landscape. Unique from any other energy source we use, it is a renewable resource and spatial material whose processes occur below ground and on the Earth's surface, manifesting as thermal phenomena on the landscape (Fig. 1). However, the current technologies and approaches used to develop geothermal energy are borrowed from the outdated and single-streamed mentality of fossil-fuel production: drilling extraction wells, pumping the energy source to a processing plant, distributing it through a network of pipes and transmission lines, and discarding waste products (Fig. 2). There is an overwhelming potential to reconsider the capacity of geothermal energy by strategizing the reuse of residual energy in the system. Energy Afterlife proposes an alternative methodology for using geothermal energy by exploiting the thermal gradient, decentralizing the network of energy use, and seizing every opportunity for programming across multiple temperature scales — thereby moving towards a visible hybridization of industrial, ecological, and cultural processes.

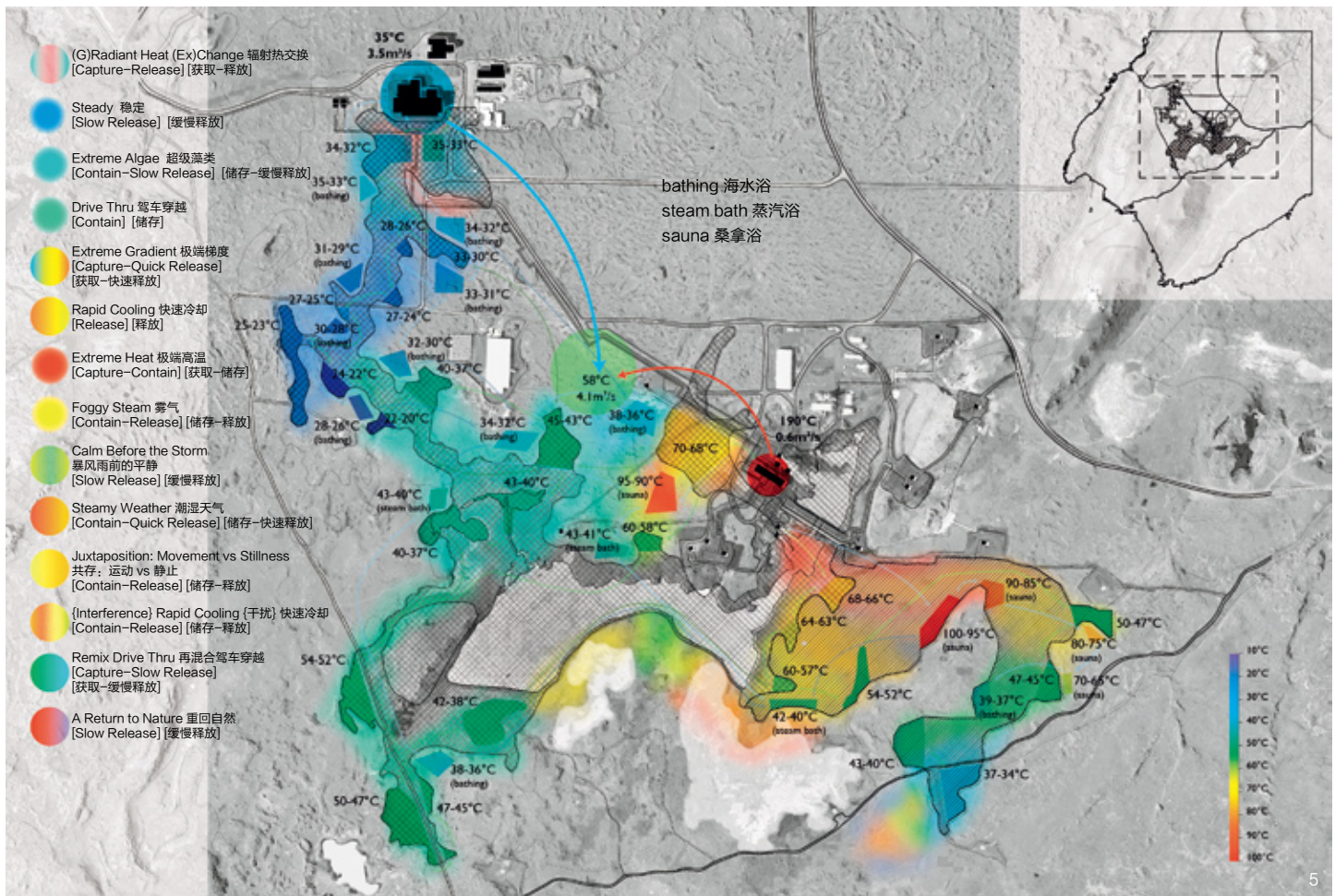
Iceland's austere land is gradually and continuously being reshaped by the landscape of embedded energy. Situated in the North Atlantic, it is completely engulfed by geothermal resources. Iceland is the highest per-capita global producer of geothermal power. Iceland fulfills 25% of its energy consumption with geothermal energy, providing 4 terawatt-hours of electricity and 95% of the island's heat and hot water needs. It has the world's most advanced technologies for extracting, producing, and utilizing this energy source, and Icelandic economy and culture are intrinsically tied to geothermal energy.

Despite recent technological advances, the full life cycle of this energy has yet to be entirely imagined. The investigation in Iceland revealed that human activity utilizes geothermal energy across a temperature scale. Residual thermal energies from different uses have the potential to be repurposed. Energy Afterlife seeks to unlock the potential of neglected geothermal effluent from Iceland's newest power plant. By retooling the system, a geothermal gradient can be choreographed between multiple programs: a strategy for cascading leftover energy from one use to productive functions for another.

The Reykjanes Geothermal Power Plant, opened in 2006, produces more effluent, sending steaming water into the frigid ocean with unknown repercussions. The power plant's 15 boreholes access and withdraw

300°C thermal brine from 1.6 ~ 3km below grade. This critically hot water is piped to the plant, passing through steam separators, which extract water and minerals from steam. It goes to two 50MW turbines, producing 100MWh of electricity for the aluminum company Norðurál in Hvalfirði. Thermal brine effluent is 190°C after the purification process, and is piped to a cooler where it is mixed with 8°C sea water to reduce its temperature before disposal. At 57°C, the effluent is sent down an 800m long concrete culvert. Released to the Atlantic Ocean at a rate of 4,000 liters per second (Fig. 3). This hot water will no longer be discarded into sea and away from the production process, its temperature gradient is used as a thermal device in the landscape to create micro-habitats, climates, ecologies, and economies.

4. 热传递利用——获取、储存、释放与辐射、传导、对流：在加热地面设计了3种类型的导管系统来建立微气候，加热过的空气凝结并形成潮湿、湿润的环境，或形成两者混合的环境。
5. 热度世界、水温与热传输流：14种热能世界界定出一个具有多种可以对温度进行控制和体验的框架。作为一种场地设计方法，每一个微环境都被定义为大型设计方案中的一个特定的热能过程。
4. Heat Transfer Utilization — Capture, Contain, Release with Radiation, Conduction, Convection: Three types of conduit systems were designed to establish microclimates of heated ground, heated air that condenses and produces moist, humid environments, or a hybridized condition of both.
5. Thermal Worlds, Water Temperatures, and Heat Transfer Flows: Fourteen Thermal Worlds define a framework of the multitude of ways temperature can be manipulated and experienced. As a site approach, each microenvironment is defined as a specific thermal process within the larger design scheme.



Energy Afterlife explores temperature as an invisible, phenomenological design material in the landscape by exploiting basic thermal principles. Heat is captured, contained, and released through conduction, convection, and radiation properties and techniques inherent in particular materials and forms. The process of “capture” and “release” both have micro-gradients within them as the transition is occurring, while moments of “contain” become more thermally homogeneous. These concepts are highlighted in the conduit system designed to transport the effluent across the site (Fig. 4).

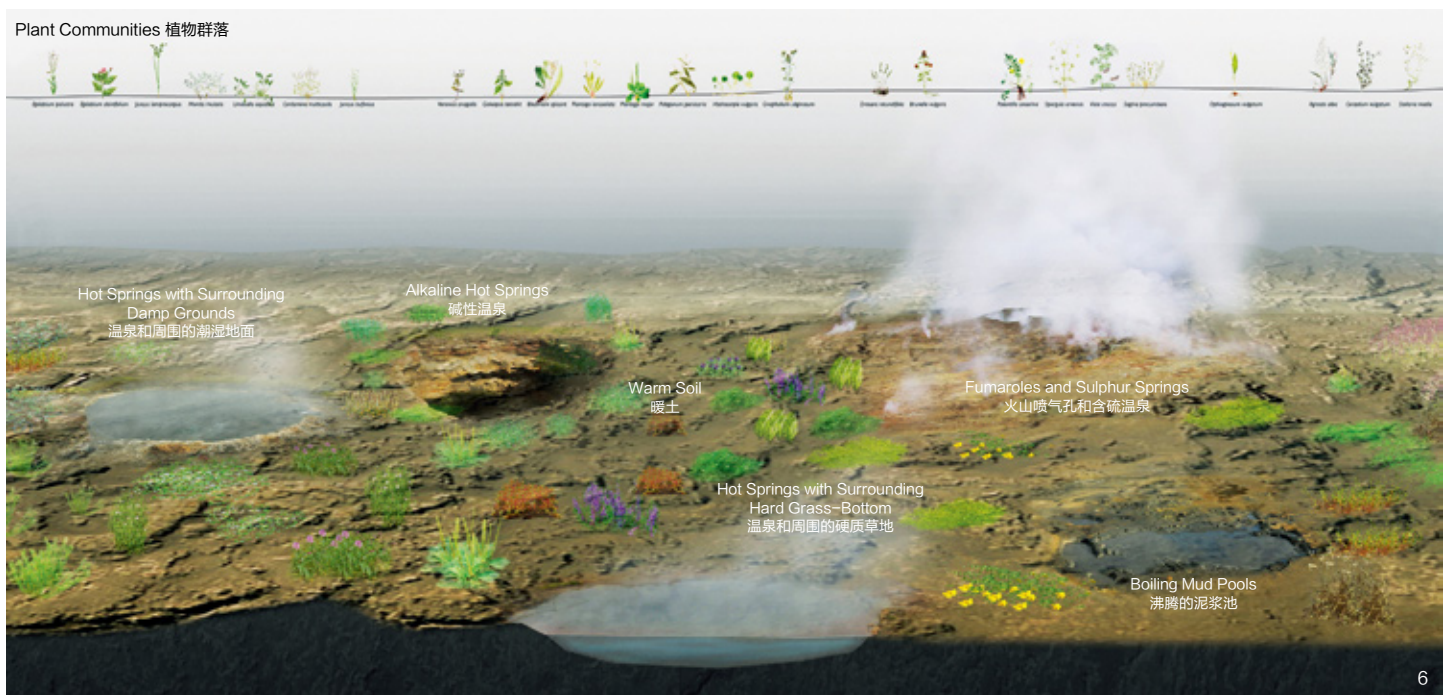
The variable uses of thermal gradients in relationship to multiple programs are manifested as Thermal Worlds (Fig. 5), assigning meaning to temperature. Within the Thermal Worlds, three programs intersect to create thermal friction: algae cultivation for biofuels, nutrition, food, and feed; a botanical garden and research area for geothermal ecology; and a thermal resource park to act as an educational and cultural destination, presenting the rare opportunity of encountering temperature’s experiential qualities. Salty pools, steam

baths, and saunas are paired with thermally associated communities of algae, flora, and fauna, fueled by one another’s transferred heat energy. To engage with programming, the placement of enclosures, landforms, and plantings maximizes or minimizes solar and wind exposure, creating additional climatic fluctuations. This thermal exploitation provides the necessary temperature for a given program at a particular moment in time along the armature of the project. Physical boundaries are used to transform the temperature gradient, while thermal boundaries are used to define programs, ecologies, and experiences.

Ecological gradients of aquatic algae and terrestrial vegetation occur naturally in geothermal manifestations. Each species is characterized by a different hue — a gradient of greens to blue-greens and few red to purple tones. The registration of temperature becomes visible in the various algal communities present in different cultivation waters. The presence of these programs, their color palettes, textures, and temperatures, become indicators of thermal gradients

feeding a productive landscape (Fig. 6).

Energy Afterlife manifests opportunities to choreograph the thermal gradient. They are highlighted in two particular Thermal Worlds: Extreme Heat and Extreme Algae. Extreme Heat creates a territory whose heat is experienced from a distance, through radiation and conduction. Heat in the form of radiation is captured and transferred with the use of materials. For example, metallic insertions are cantilevered over the hot water, releasing heat into the soil, and containing it to form micro-ecologies. Stilted structures hover over the steaming water, capturing the heat formed by conduction (Fig. 7). Their aggregation along the moving, cooling water creates sauna-like environments to experience fluctuating temperature gradients. Extreme Algae takes on an opposite character: it is a world whose temperatures, which are optimal for all programs to occur, are stretched and retained across a large swath of land. Landforms are used to contain heat and maintain relatively consistent temperatures in lower areas, protecting algae from extreme thermal fluctuation. Human pools reside in higher



areas to experience external thermal forces interacting with those within the project (Fig. 8). Pathways between thermal worlds exist in three forms of “capture”, “contain”, and “release”. They create different microclimates contrasting in moisture and temperature, but maintain a consistently heated path (Fig. 9). Various heat manipulations create large temperature gaps, allowing the differences between temperatures to be experienced in direct relationship to the last thermal encounter.

An energy life cycle is established by exploring how heat transfer and exchange form different correlations between human and non-human living systems, programs, and ecologies. Extreme environments encourage visitors to be conscious of their bodies as instruments for perceiving individual thermal limits. Thermal mechanisms as physical insertions manipulate the gradient across the landscape. Temperature thresholds, in turn, provide the basis for the orchestration of programs. This interchange is viewed as a system within individual Thermal Worlds. Concretizing temperature-based codependencies yields a new cultural

landscape established by thermal interactions.

Water is an element essential to Icelanders' cultural identity. In Energy Afterlife, the material of geothermal water is both medium and subject, in all of its states and temperatures. It engages the senses and invites visitors to consider its thermal gradient: its effects, its texture, and the way it generates a natural process of making and a new cultural process of gathering, transporting, and arranging the heated material. It encourages the visitors not only to see the site, but to experience and understand its logic as a thermal regression and heightening of its experiential and productive qualities. Geothermal saline environments are very rare, and opportunities to experience them through research, education, and recreation are limited. Therefore, the project creates a new destination with the site's unique characteristics. A landscape of Energy Afterlife is formed: rather than disposing effluent waste, it is reused and repurposed, becoming a value-added benefit from a residual geothermal energy production process. **LAF**

6. 地热环境和植物群落：地热环境及其植物群落遍布冰岛，包括具有硬质地和潮湿地面的温泉，这些温泉都是碱性的、带有喷气孔的含硫温泉。
7. 超级水藻规划框架与热能重合：地形成为了水藻池塘的庇护所。供人使用的池塘位于较高的地区，以获得更为开阔的视野。管道系统与人行线路相重合，为人类和非人类创造了高温通道和微环境。
8. 超级水藻共存方案：该图显示了工业、发电厂、生态、文化和休闲之间的并存关系。地热能作为一种视觉连续，贯穿整个项目始终，突显了热能副产品的利用机遇和潜能。
9. 极度高温热能与大气相遇：该图展示了如何将废水中的热能储存下来，并创造后一种工业过程与生态和文化相融合的环境的多种条件与方法。几种热能利用方式通过体现热能差异来创建视觉联系。超级水藻成为了体验方法的一种场地形式，在这里，热能能够被储存下来，并带给人们更加直接的体验。
6. Geothermal Environments and Plant Communities: A wide range of geothermal environments and their plant communities exist in Iceland, including hot springs with hard grass bottoms, with damp grounds, those that are alkaline, fumaroles and sulfur springs.
7. Extreme Algae Programmatic Framework and Thermal Overlaps: Topography is used to shelter algae ponds. Human pools are situated in higher areas for exposure and views. The conduit system is overlapped by human circulation, creating heated paths and microenvironments for humans and non-humans.
8. Extreme Algae Juxtaposition: The view presents juxtaposition between industry, the power plant, ecology, culture and recreation. A visual connection is retained to the geothermal energy source throughout the project, highlighting opportunities and potentials that exist from the byproduct.
9. Extreme Heat Thermal and Atmospheric Encounters: The view and model capture various conditions and methods for how heat from the effluent is contained to create environments where this post-industrial process melds with ecology and culture. Visual connections are made between the programs, registering thermal differences. Extreme Algae becomes a venue for experiencing methods in which heat can be contained and more closely experienced.

