新能源材料：范式进阶！

行业评级：看好

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首页

本报告针对特斯拉2023年4月5日发布的《Master Plan Part 3—Sustainable Energy for All of Earth》（下称宏图计划3）进行细致分析研究，采用“**一页原文，一页译文，一页解读**”的形式展开报告。

通过对宏图计划3的详尽分析，我们旨在展示“新能源材料”未来20年巨大的发展机遇与发展范式。根据特斯拉的测算，建设可持续能源经济的基础设施将花费**10万亿**美元，其中：电动汽车工厂需投入**1.78万亿**美元，电池工厂需投资**2.18万亿**美元，电动汽车材料开采精炼需投资**1.67万亿**美元，制氢电解槽与储氢需**1.88万亿**美元资本投入。

可再生能源经济在未来将需要**30TW**的装机、**240TWh**的电池存储和**6000万英里**输电线路建设支撑，共需**128.15亿吨**材料投入，将催生**700万吨锂/年、700万吨铜/年、300万吨镍/年**的新能源支柱材料需求，由此对应的资本开支分别为：锂 **3740亿美元**，铜 **2150亿美元**，镍 **2020亿美元**。前景极为广阔，我们预计新能源领域将会出现一批世界级企业。

现有新能源经济仅是冰山一角，冰层下蕴藏着巨大的机遇！

摘要

1、总述

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- 更换一次能源种类
- 转变终端能源消费方式

3、电气化经济，消除化石燃料

- 可再生能源供电
- 使用电动汽车
- 住宅、商业和工业中使用热泵
- 高温传热和氢能电气化
- 飞机船舶使用可持续燃料
- 重建可持续经济能源

摘要

4、建立可持续能源经济

- 美国完全可持续能源经济模型
- 发电及储能技术评估
- 最佳的发电-储能组合
- 全球可持续能源经济建模结果

5、投资需求

- 完全可再生能源经济需投资10万亿美元，而维持现有化石燃料经济则需14万亿美元投资

6、空间资源需求

- 全球18.3TW的太阳能电池板组需占陆地面积0.19%
- 全球12.2TW的风力发电涡轮机需占地0.02%

7、材料投入需求

- 30TW的装机、240TWh的电池存储和6000万英里输电线路共需128.15亿吨材料
- 锂/铜/镍年需求量为700万吨/700万吨/300万吨

风险提示

1、可再生能源技术突破受限；

2、可再生能源经济替代进程不及预期；

3、各国对可再生能源经济政策激励不足；

4、全球供应链体系不稳定性增加；

5、翻译错误风险，报告涉及《Master Plan Part 3—Sustainable Energy for All of Earth》等文章译文，或因语法理解、翻译有误、翻译不完整等原因造成与原表述存在偏差的风险，译文内容仅供参考，准确内容请详见原文.

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总述

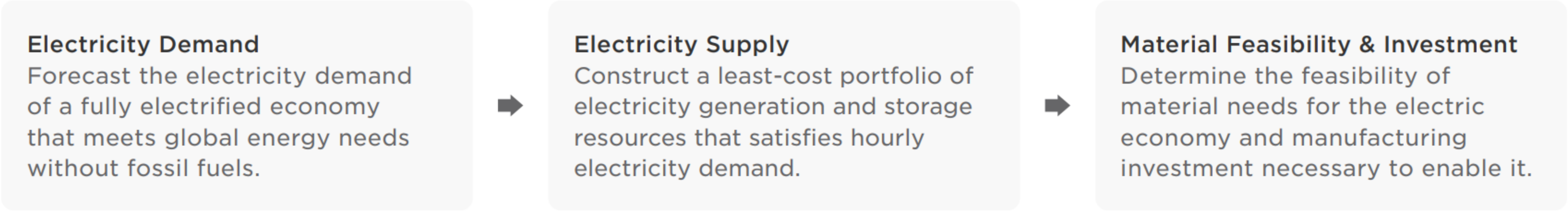
可持续能源经济的逻辑假设

可持续能源经济的实现路径及可行性分析

01 原文：Executive Summary

On March 1, 2023, Tesla presented Master Plan Part 3 – a proposed path to reach a sustainable global energy economy through end-use electrification and sustainable electricity generation and storage. This paper outlines the assumptions, sources and calculations behind that proposal. Input and conversation are welcome.

The analysis has three main components:



Electricity Demand
Forecast the electricity demand of a fully electrified economy that meets global energy needs without fossil fuels.

➡

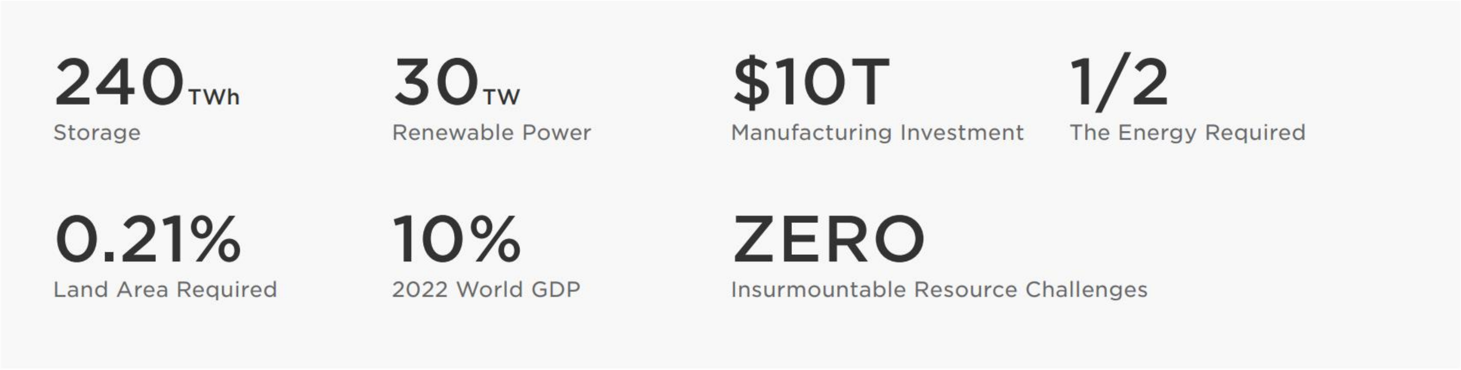
Electricity Supply
Construct a least-cost portfolio of electricity generation and storage resources that satisfy hourly electricity demand.

➡

Material Feasibility & Investment
Determine the feasibility of material needs for the electric economy and manufacturing investment necessary to enable it.

Figure 1: Process overview

This paper finds a sustainable energy economy is technically feasible and requires less investment and less material extraction than continuing today's unsustainable energy economy. While many prior studies have come to a similar conclusion, this study seeks to push the thinking forward related to material intensity, manufacturing capacity, and manufacturing investment required for a transition across all energy sectors worldwide.



240 TWh Storage	**30** TW Renewable Power	**$10T** Manufacturing Investment	**1/2** The Energy Required
0.21% Land Area Required	**10%** 2022 World GDP	**ZERO** Insurmountable Resource Challenges	

Figure 2: Estimated Resources & Investments Required for Master Plan 3

01 译文：概要

2023年3月1日，特斯拉发布《宏图计划第3部分》，提出了一条通过终端电气化、可持续能源发电和储能实现可持续全球能源经济的路径。本文概述了该提议的假设、来源和计算。欢迎讨论。

该分析包含了三个主要的部分：

电力需求

预测一个完全电气化的经济体的电力需求，该经济体在没有化石燃料的情况下满足全球能源需求。

➡

电力供应

构建成本最低的发电和储能资源组合，以满足每小时的电力需求。

➡

材料可行性&投资

确定实现电力经济的材料需求可行性和实现这一目标必须的制造业投资。

本文发现，可持续能源经济在技术上是可行的，且与当今的不可持续能源经济相比需要更少的投资和材料开采。虽然之前的许多研究都得出了类似的结论，但本项研究试图推动与材料强度、制造能力和制造投资相关的思考，这些是全球所有能源部门转型所需的。

240 TWh	储能
30 TW	可再生能源
$ 10T	制造投资
1/2	所需能量
0.21%	所需土地面积
10%	2022 全球GDP
0	无法克服的能源挑战

02

现有能源经济

能源利用率低

更换一次能源种类

转变终端能源消费方式

原文：The Current Energy Economy is Wasteful

According to the International Energy Agency (IEA) 2019 World Energy Balances, the global primary energy supply is 165 PWh/year, and total fossil fuel supply is 134PWh/year[1ab]. 37% (61PWh) is consumed before making it to the end consumer. This includes the fossil fuel industries' self-consumption during extraction/refining, and transformation losses during electricity generation. Another 27% (44PWh) is lost by inefficient end-uses such as internal combustion engine vehicles and natural gas furnaces. In total, only 36% (59PWh) of the primary energy supply produces useful work or heat for the economy. Analysis from Lawrence Livermore National Lab shows similar levels of inefficiency for the global and US energy supply[2,3].

Today's Energy Economy (PWh/year)

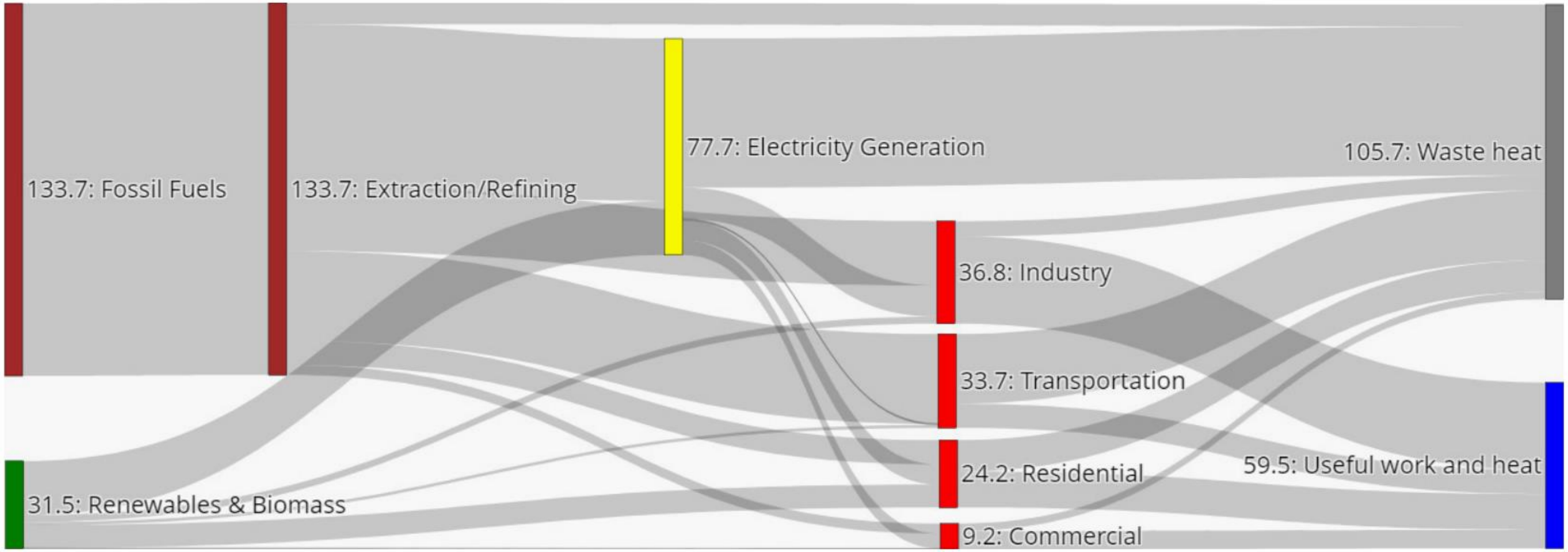


Figure 3: Global Energy Flow by Sector, IEA & Tesla analysis

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a The 2021 and 2022 IEA World Energy Balances were not complete at the time of this work, and the 2020 dataset showed a decrease in energy consumption from 2019, which likely was pandemic-related and inconsistent with energy consumption trends.

b Excluded certain fuel supplies used for non-energy purposes, such as fossil fuels used in plastics manufacturing.

译文：现有能源经济浪费严重，能源利用率仅36%

根据国际能源署(IEA)《2019年世界能源平衡》，全球一次能源供应量为165 PWh/年，化石燃料总供应量为134PWh/年[1ab]。37% (61PWh)在到达最终消费者之前被消耗，包括了化石燃料行业在开采/精炼过程中的损耗以及发电过程中的转化损失。另外27% (44PWh)在低效的终端用途(如内燃机车辆和天然气炉)中损耗。总的来说，只有36% (59PWh)的一次能源转化为有用的功或热。劳伦斯利弗莫尔国家实验室(Lawrence Livermore National Lab)的分析显示，全球和美国的能源供应效率低下程度相似[2,3]。

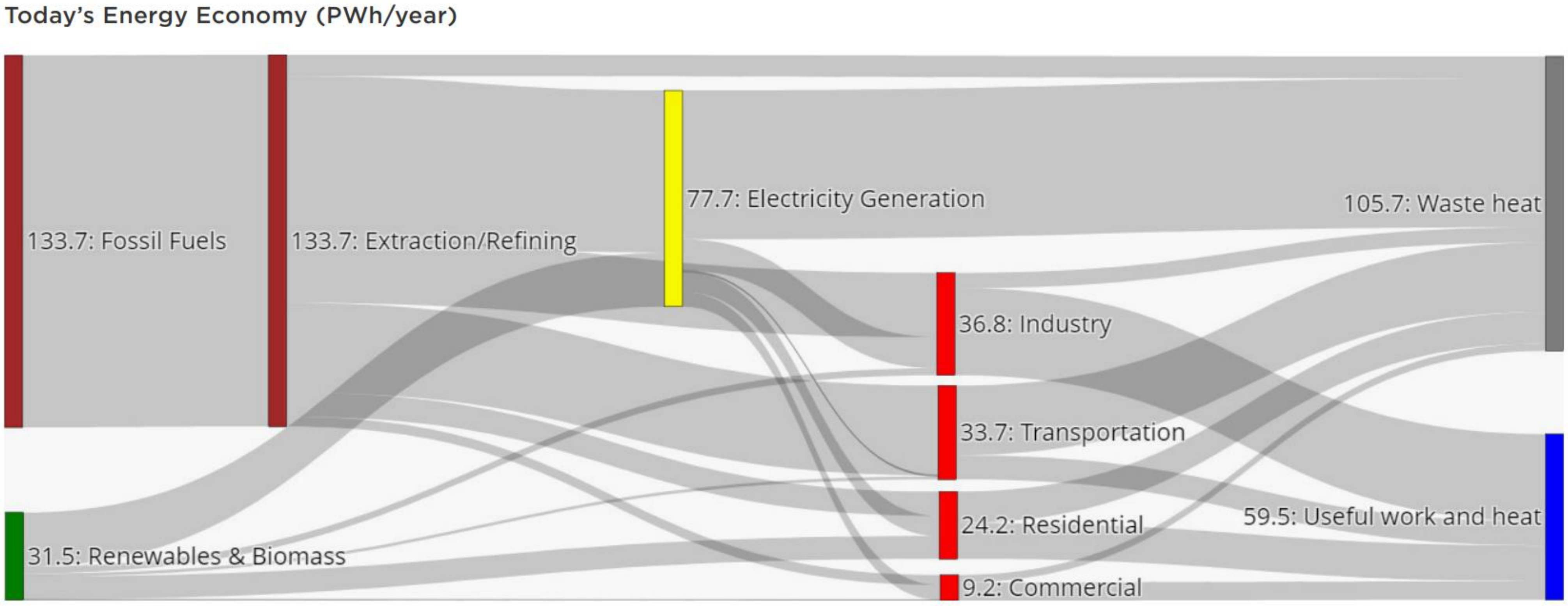

Figure 3: Global Energy Flow by Sector, IEA & Tesla analysis

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a 在开展这项工作时，2021年和2022年国际能源署的《世界能源平衡》尚未完成，2020年的数据集显示，能源消费较2019年有所下降，这可能与大流行有关，与能源消费趋势并不一致。
b 不包括用于非能源用途的某些燃料供应，如用于塑料制造的化石燃料。

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

02 我们的理解

解决能源利用效率低的问题

能量来源 → 更换一次能源种类

能源利用 → 转变终端能源消费方式

03

电气化经济消除化石燃料

可再生能源供电

使用电动汽车

住宅、商业和工业中使用热泵

高温传热和氢能电气化

飞机船舶使用可持续燃料

重建可持续经济能源

03 原文：The Plan to Eliminate Fossil Fuels

In an electrified economy with sustainably generated energy, most of the upstream losses associated with mining, refining and burning fuels to create electricity are eliminated, as are the downstream losses associated with non-electric end-uses. Some industrial processes will require more energy input (producing green hydrogen for example), and some mining and refining activity needs to increase (related to metals for batteries, solar panels, wind turbines, etc.)

The following 6 steps show the actions needed to fully electrify the economy and eliminate fossil fuel use. The 6 steps detail the electricity demand assumptions for the sustainable energy economy and leads to the electricity demand curve that is modeled.

Modeling was done on the US energy economy using high-fidelity data available from the Energy Information Administration (EIA) from 2019-2022[c], and results were scaled to estimate actions needed for the global economy using a 6x scaling factor based on the 2019 energy consumption scalar between the U.S. and the world, according to IEA Energy Balances. This is a significant simplification and could be an area for improvement in future analyses, as global energy demands are different from the U.S. in their composition and expected to increase over time. This analysis was conducted on the U.S. due to availability of high-fidelity hourly data.

This plan considers onshore/offshore wind, solar, existing nuclear and hydro as sustainable electricity generation sources, and considers existing biomass as sustainable although it will likely be phased out over time. Additionally, this plan does not address sequestering carbon dioxide emitted over the past century of fossil fuel combustion, beyond the direct air capture required for synthetic fuel generation; any future implementation of such technologies would likely increase global energy demand.

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c US hourly time series data used as model inputs are available at https://www.eia.gov/opendata/browser/ for download.

译文：消除化石燃料的计划

在可持续能源产生的电气化经济中，与采矿、精炼和燃烧燃料发电有关的大部分上游损失都被消除了，与非电力最终用途有关的下游损失也被消除了。一些工业过程将需要更多的能源投入(例如生产绿色氢)，一些采矿和精炼活动需要增加(与对电池、太阳能电池板、风力涡轮机等金属需求增加有关)。

以下6个步骤展示了全面电气化经济和消除化石燃料使用所需的行动。这6个步骤详细说明了可持续能源经济的电力需求假设，并进行了电力需求曲线的建模。

根据国际能源署能源平衡，使用能源情报署(EIA) 提供的2019-2022[c]年高保真数据对美国能源经济进行了建模，并根据2019年美国和世界之间的能源消耗标量，使用6倍的比例因子对结果进行了缩放，以估计全球经济所需的行动。这是一个重要的简化，也可能是未来分析的一个改进领域，因为全球能源需求的构成与美国不同，并且预计会随着时间的推移而加剧。由于可以得到美国的高保真小时数据，故基于美国的能源情况建立了该模型。

该计划将陆上/海上风能、太阳能、现有的核能和水力发电视为可持续的发电来源，并认为现有的生物质能是可持续的，尽管它可能会随着时间的推移而逐步淘汰。此外，除了合成燃料生产所需的直接空气捕获之外，该计划没有解决过去一个世纪化石燃料燃烧所排放的二氧化碳的封存问题，因此未来任何此类技术的实施都可能增加全球能源需求。

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[c] 作为模型输入的美国每小时时间序列数据可在https://www.eia.gov/opendata/browser/下载。

03 我们的理解

建模估算的逻辑与过程：

现有能源经济所需化石燃料

全面电气化带来的效率提升

÷ 提升的效率倍数

可持续能源经济的电力需求

原文：1. Repower the Existing Grid with Renewables

The existing US hourly electricity demand is modeled as an inflexible baseline demand taken from the EIA[4]. Four US sub-regions (Texas, Pacific, Midwest, Eastern) are modeled to account for regional variations in demand, renewable resource availability, weather, and grid transmission constraints. This existing electrical demand is the baseline load that must be supported by sustainable generation and storage.

Globally, 65PWh/year of primary energy is supplied to the electricity sector, including 46PWh/year of fossil fuels; however only 26PWh/year of electricity is produced, due to inefficiencies transforming fossil fuels into electricity[d]. If the grid were instead renewably powered, only 26PWh/year of sustainable generation would be required.

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d Embedded in the 26 PWh/year is 3.5 PWh/year of useful heat, mostly produced in co-generation power stations, which generate heat and power electricity.

03 译文：1. 可再生能源供电

现有的美国每小时电力需求是根据EIA[4]的非柔性基线需求来建模的。考虑到需求、可再生资源可用性、天气和电网传输限制的区域差异，模型中包含了四个美国子区域(德克萨斯、太平洋、中西部、东部)。通过可持续发电和储能来满足现有电力需求这一基线负荷。

在全球范围内，每年向电力部门供应的一次能源为65PWh，其中化石燃料为46PWh，但由于化石燃料转化为电力的效率低，每年只能产生26PWh的电力[d]。如果电网采用可再生能源发电，每年只需要26PWh的可持续发电。

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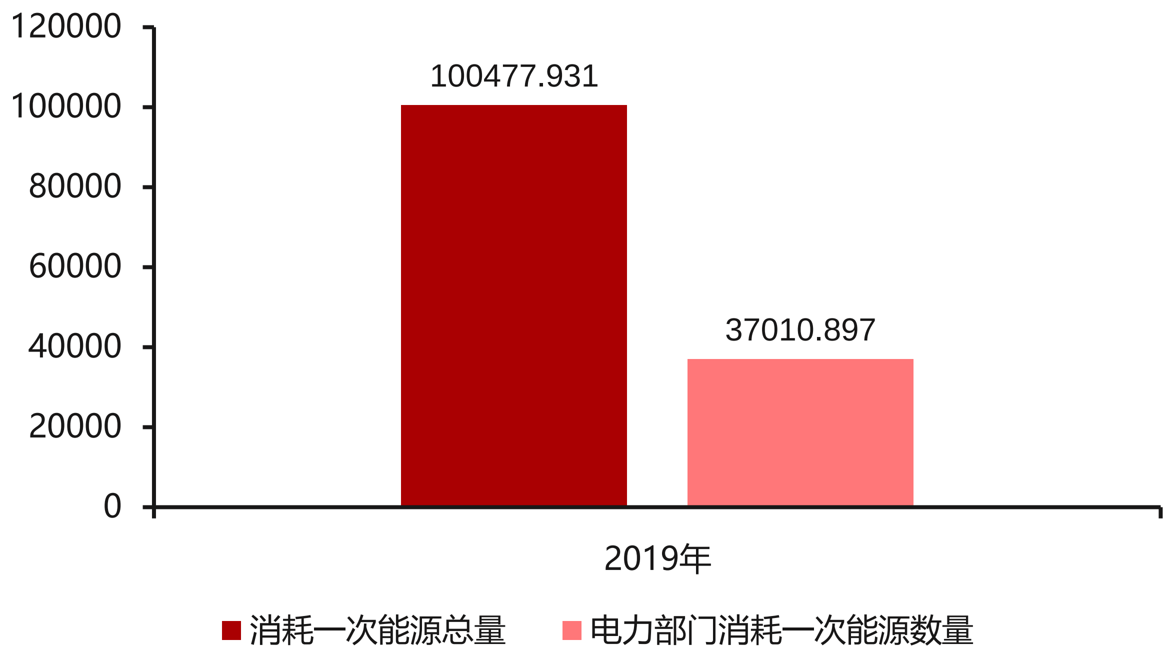
[d] 26 PWh/年中含有3.5 PWh/年的有用热，主要来自热电联产电站。

数据核算：根据EIA数据，2019年美国各部门消耗的一次能源数量为100477.931 Tbtu，其中电力部门消耗的一次能源数量为37010.897 Tbtu。按照6倍的比例因子缩放后，得到全球消耗的一次能源总量为176PWh/年，其中电力部门消耗的一次能源为65PWh/年。

图：2019年美国消耗一次能源总量及电力部门消耗一次能源（左轴：万亿 Btu）

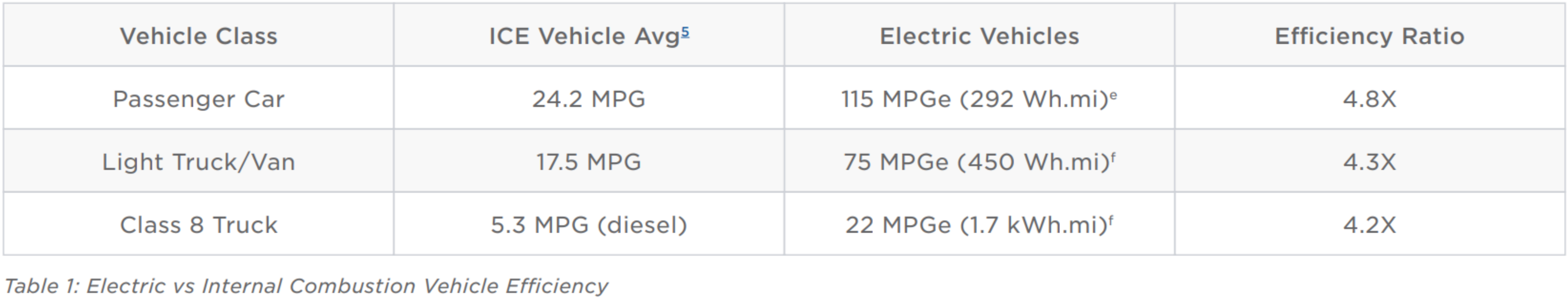


资料来源：EIA，浙商证券研究所

03

原文：2. Switch to Electric Vehicles

Electric vehicles are approximately 4x more efficient than internal combustion engine vehicles due to higher powertrain efficiency, regenerative braking capability, and optimized platform design. This ratio holds true across passenger vehicles, light duty trucks, and Class 8 semis as shown in the Table 1.



Vehicle Class	ICE Vehicle Avg[5]	Electric Vehicles	Efficiency Ratio
Passenger Car	24.2 MPG	115 MPGe (292 Wh.mi)[e]	4.8X
Light Truck/Van	17.5 MPG	75 MPGe (450 Wh.mi)[f]	4.3X
Class 8 Truck	5.3 MPG (diesel)	22 MPGe (1.7 kWh.mi)[f]	4.2X

Table 1: Electric vs Internal Combustion Vehicle Efficiency

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e Tesla’ s global fleet average energy efficiency including Model 3, Y, S and X.
f Tesla’ s internal estimate based on industry knowledge.

03

译文：2. 使用电动汽车

电动汽车具有更高的动力系统效率、回收制动能量及优化的平台设计，能源利用效率为内燃机汽车的4倍。下表对比了电动汽车和内燃机汽车在乘用车、轻型载货车及8级卡车三种车型上的效率。

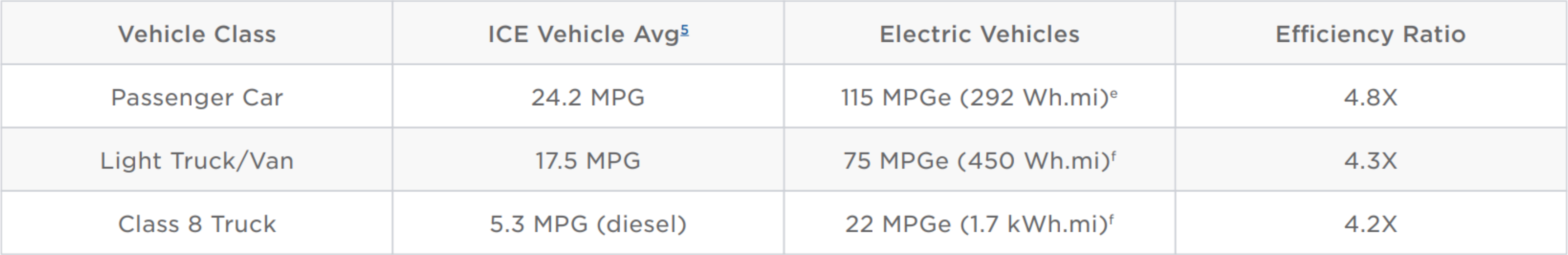

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Table 1: Electric vs Internal Combustion Vehicle Efficiency

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e 按照特斯拉Model 3, Y, S and X四种车型得到，其中Model 3为132 MPGe，Model Y为129 MPGe，Model X为120 MPGe，Model S为102 MPGe.

f 由特斯拉根据行业共识估计得到.

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

我们的理解

参数注解：

ICE：internal combustion engine，内燃机

MPG：miles per gasoline gallon，即每加仑汽油当量英里数

MPGe：miles per gallon equivalent，即等效每加仑汽油当量英里数

单位换算关系：

1L汽油热值=8.9kWh，

1加仑汽油=3.785L，

1加仑汽油热值=33.7kWh

03 原文：2. Switch to Electric Vehicles

As a specific example, Tesla's Model 3 energy consumption is 131MPGe vs. a Toyota Corolla with 34MPG[6,7], or 3.9x lower, and the ratio increases when accounting for upstream losses such as the energy consumption related extracting and refining fuel (See Figure 4).

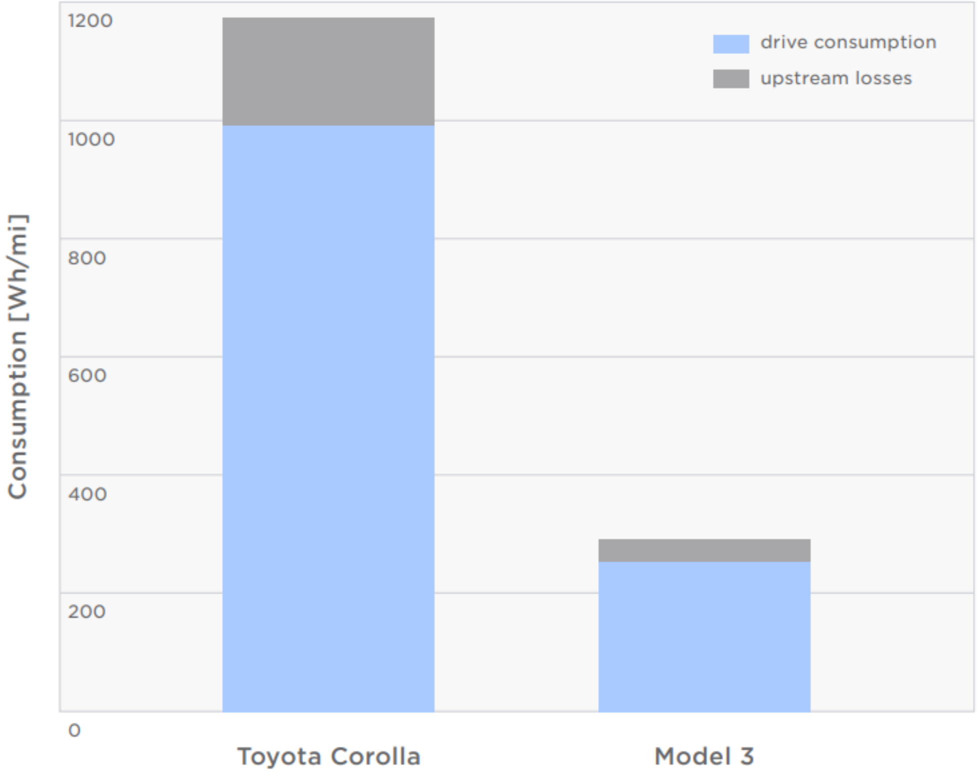


Figure 4: Comparison Tesla Model 3 vs. Toyota Corolla

03 译文：2. 使用电动汽车

以特斯拉Model 3和Toyota Corolla作为具体例子说明，Toyota Corolla的能量消耗为34MPGe，特斯拉Model 3的能量消耗为131MPGe[6,7]，是Toyota的3.9倍，如果考虑到上游化石能源在精炼和提纯的损耗，这一比值将更高。

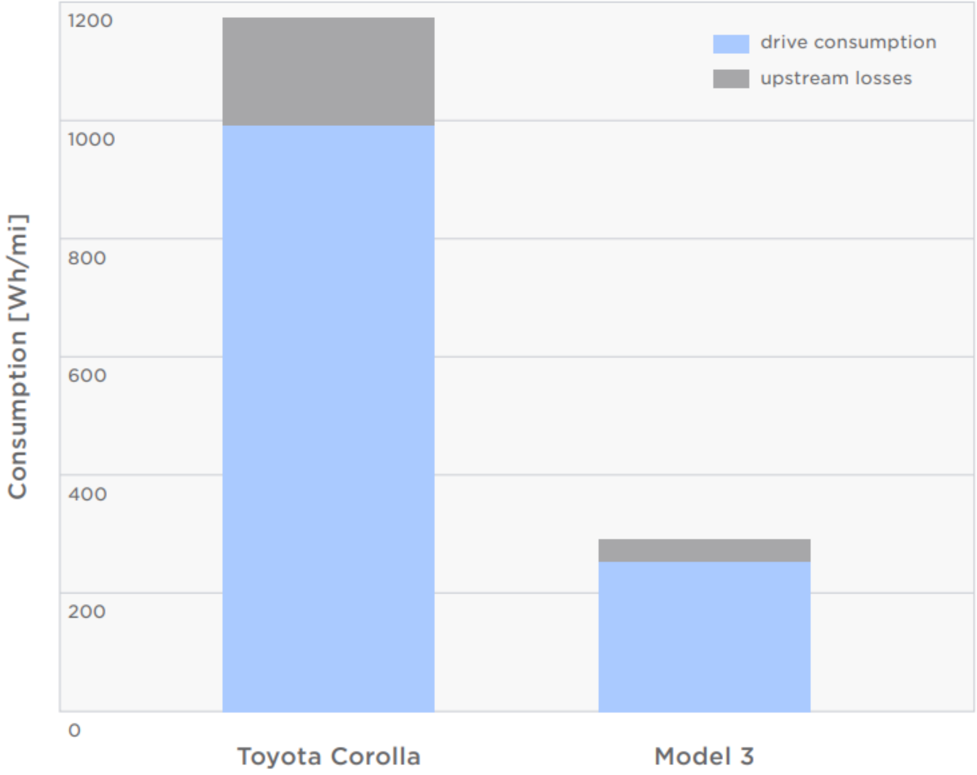
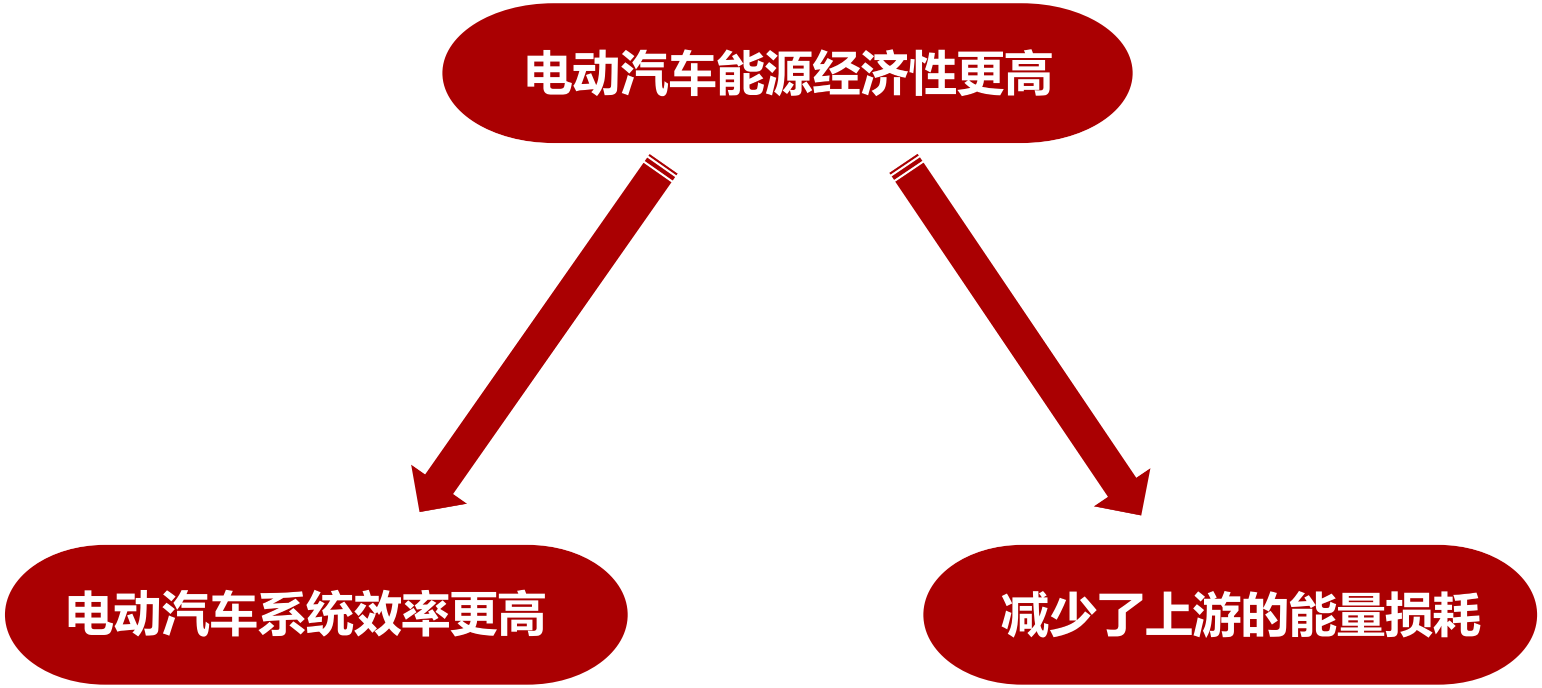


Figure 4: Comparison Tesla Model 3 vs. Toyota Corolla

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

03 我们的理解



电动汽车能源经济性更高

电动汽车系统效率更高

减少了上游的能量损耗

原文：2. Switch to Electric Vehicles

To establish the electricity demand of an electrified transportation sector, historical monthly US transportation petroleum usage, excluding aviation and ocean shipping, for each sub-region is scaled by the EV efficiency factor above (4x)[8]. Tesla’s hour by hour vehicle fleet charging behavior, split between inflexible and flexible portions, is assumed as the EV charging load curve in the 100% electrified transportation sector. Supercharging, commercial vehicle charging, and vehicles with <50% state of charge are considered inflexible demand. Home and workplace AC charging are flexible demand and modeled with a 72-hour energy conservation constraint, modeling the fact that most drivers have flexibility to charge when renewable resources are abundant.

On average, Tesla drivers charge once every 1.7 days from 60% SOC to 90% SOC, so EVs have sufficient range relative to typical daily mileage to optimize their charging around renewable power availability provided there is charging infrastructure at both homes and workplaces.

Global electrification of the transportation sector eliminates 28 PWh/year of fossil fuel use and, applying the 4x EV efficiency factor, creates ~7 PWh/year of additional electrical demand.

译文：2. 使用电动汽车

为了确定电气化运输部门的电力需求，将美国各子区域的历史月度运输用石油量（除去航空和海运）按上述电动汽车效率是内燃机汽车的4倍进行缩放[8]。假设将特斯拉每小时的车辆充电行为分为灵活负载和非灵活负载，作为100%电气化交通领域的电动汽车充电负荷曲线，其中超级充电、商用车辆充电和电量低于50%的车辆为非灵活负载；家庭和工作场所的交流充电是灵活负载，并以72小时节能约束为模型，模拟了大多数车主在可再生资源充足时具有充电灵活性的事实。

当电动汽车剩余容量为60%~90%时，平均每1.7天充电一次，因此只要在家庭和工作场所都有充电基础设施，电动汽车就有足够的续航里程来优化可再生能源的可用性。

全球交通运输行业的电气化消除了28PWh/年的化石燃料使用，按照4倍的电动汽车效率系数，每年产生约7PWh的额外电力需求。

03 我们的理解

数据核算：

假设：

1.全球汽车保有量为15亿辆，假设每辆车行驶50km/天；

2.转向电动汽车后，乘用车的MPGe为115；

3.计算得到全球电动车的电力需求为5PWh/年。

电动汽车的电力需求 = **全球电动汽车数量** × **日耗电量** × **365 天**

资料来源：前瞻产业研究院，IEA，浙商证券研究所

原文：3. Switch to Heat Pumps in Residential, Business & Industry

Heat pumps move heat from source to sink via the compression/expansion of an intermediate refrigerant[9]. With the appropriate selection of refrigerants, heat pump technology applies to space heating, water heating and laundry driers in residential and commercial buildings, in addition to many industrial processes.

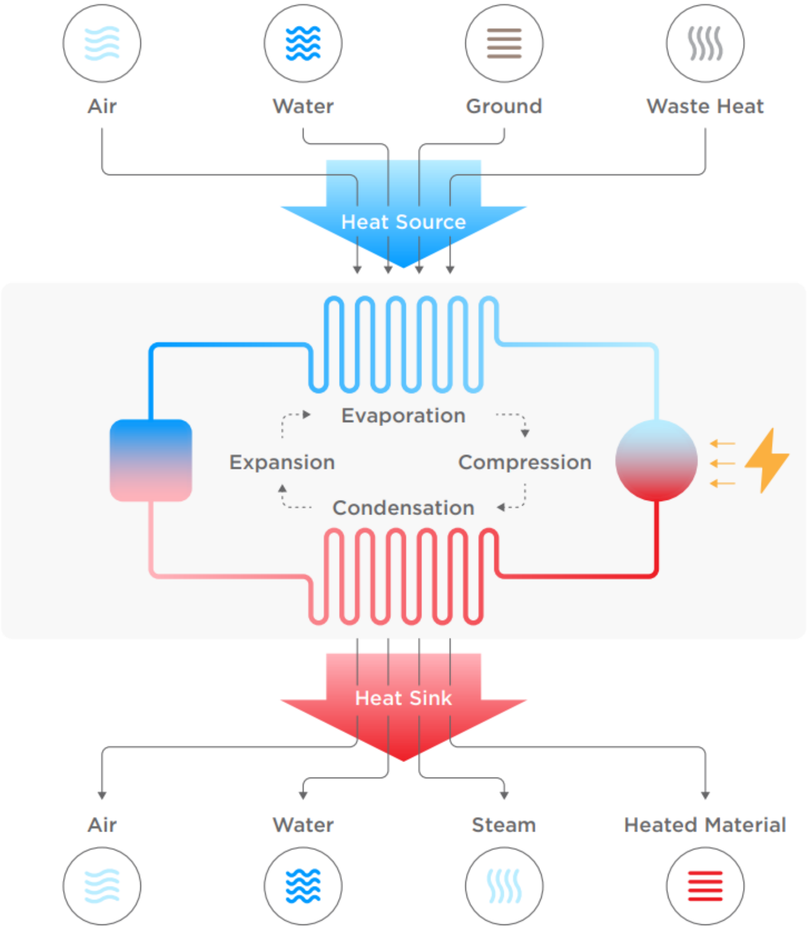


Figure 5: How Heat Pumps Work[10]

03 译文：3. 住宅、商业及工业中使用热泵

热泵通过中间制冷剂的压缩/膨胀将热量从热源转移到热汇[9]。随着制冷剂的适当选择，热泵技术适用于住宅和商业建筑的空间加热，水加热和洗衣烘干机，以及许多工业过程。

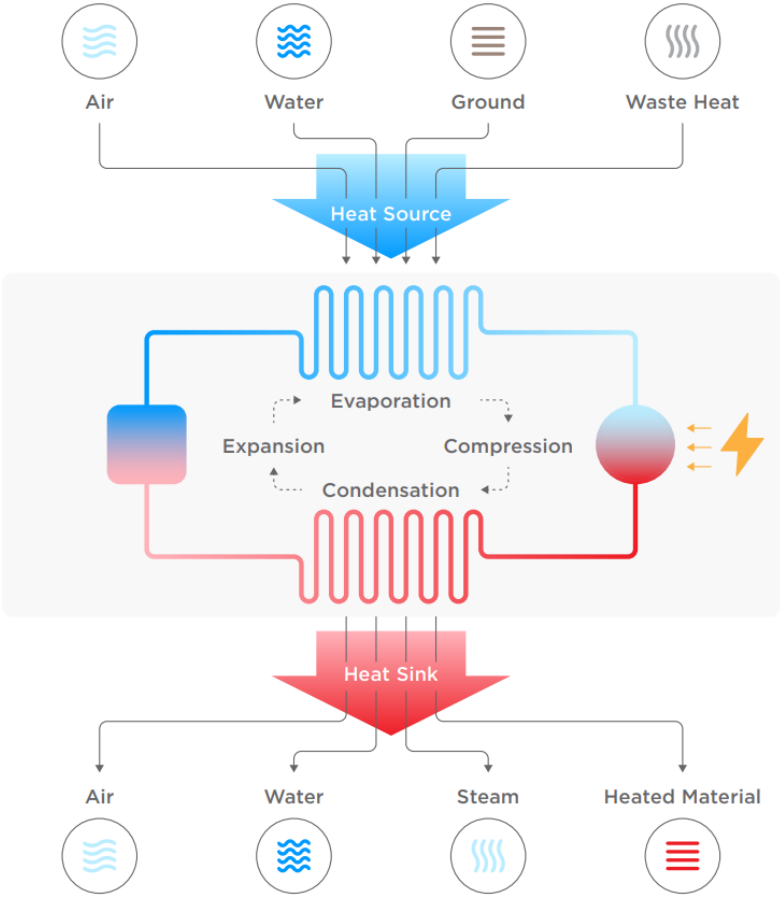


Figure 5: How Heat Pumps Work[10]

注：热汇，资源科学技术名词，指大气系统中从周围获得热量，并不断地消耗热量的地区。

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

03 我们的理解

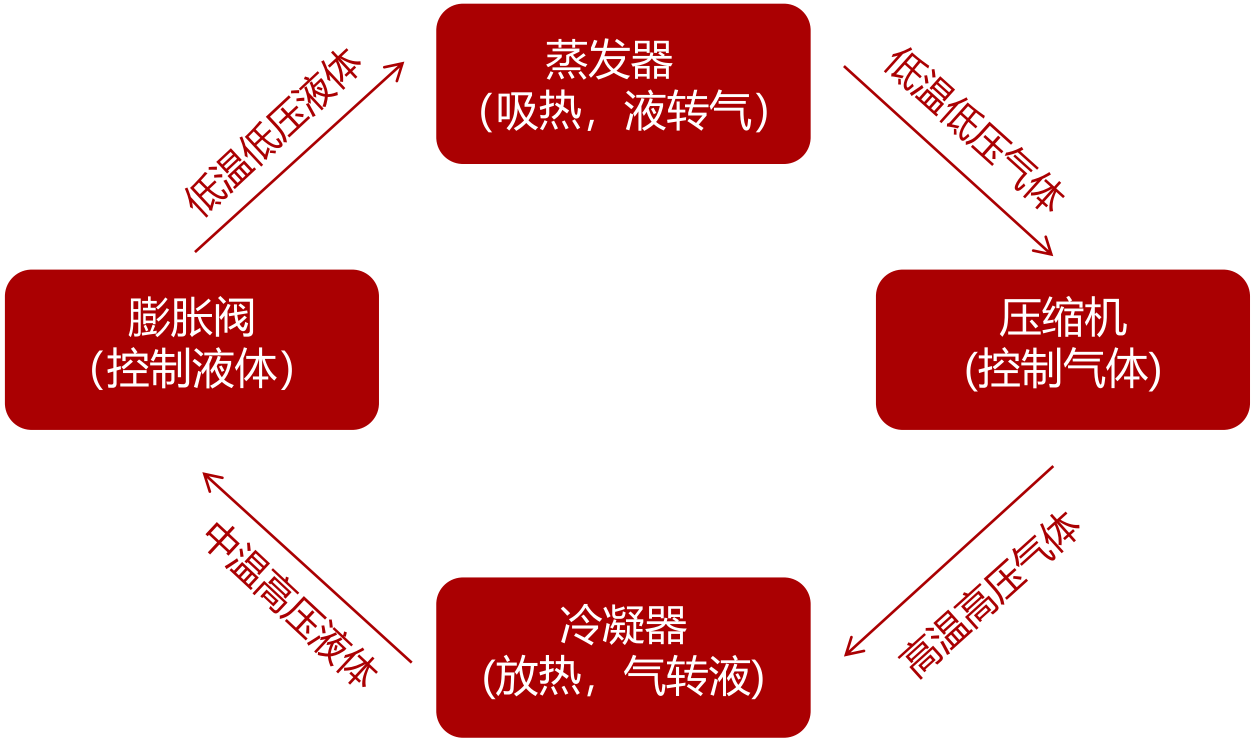
热泵工作原理：

热泵有四大关键部件：蒸发器、压缩机、冷凝器、膨胀阀。制冷剂从空气中吸热变成低温低压的气体，通过压缩机变为高温高压，在冷凝器中释放热量，自身变为液体流向膨胀阀，调节制冷剂的流量再次进入蒸发器，以此循环。

热泵的工作效率：

通常热泵输出的能量是其消耗电能/燃料能的3-4倍，比燃气锅炉更高效。

图：热泵的工作原理



蒸发器
（吸热，液转气）

低温低压气体

压缩机
(控制气体)

高温高压气体

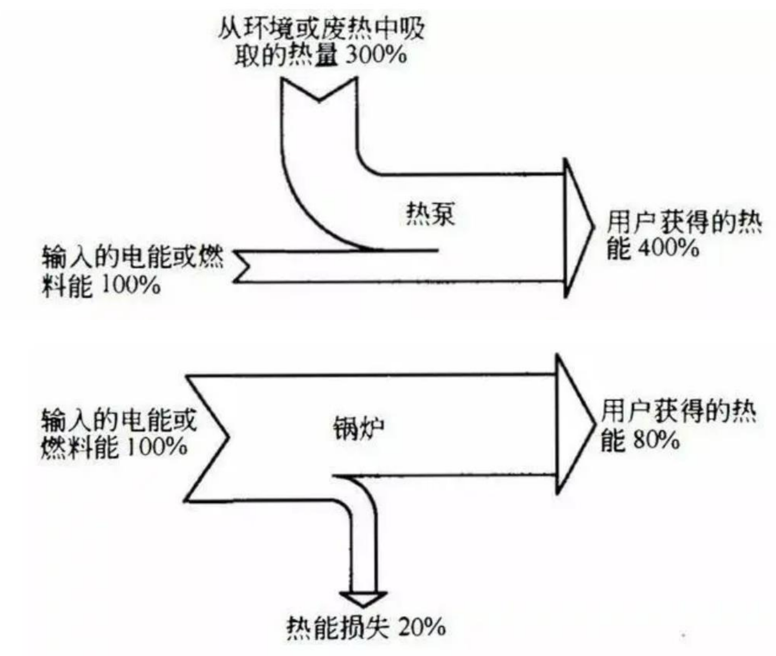
冷凝器
(放热，气转液)

中温高压液体

膨胀阀
(控制液体)

低温低压液体

图：热泵及锅炉的简化能流



资料来源：热泵市场，未来智库，浙商证券研究所

03 原文：3. Switch to Heat Pumps in Residential, Business & Industry

Air source heat pumps are the most suitable technology for retrofitting gas furnaces in existing homes, and can deliver 2.8 units of heat per unit of energy consumed based on a heating seasonal performance factor (HSPF) of 9.5 Btu/Wh, a typical efficiency rating for heat-pumps today[11]. Gas furnaces create heat by burning natural gas. They have an annual fuel utilization efficiency (AFUE) of ~90%[12]. Therefore, heat pumps use ~3x less energy than gas furnaces (2.8/0.9).

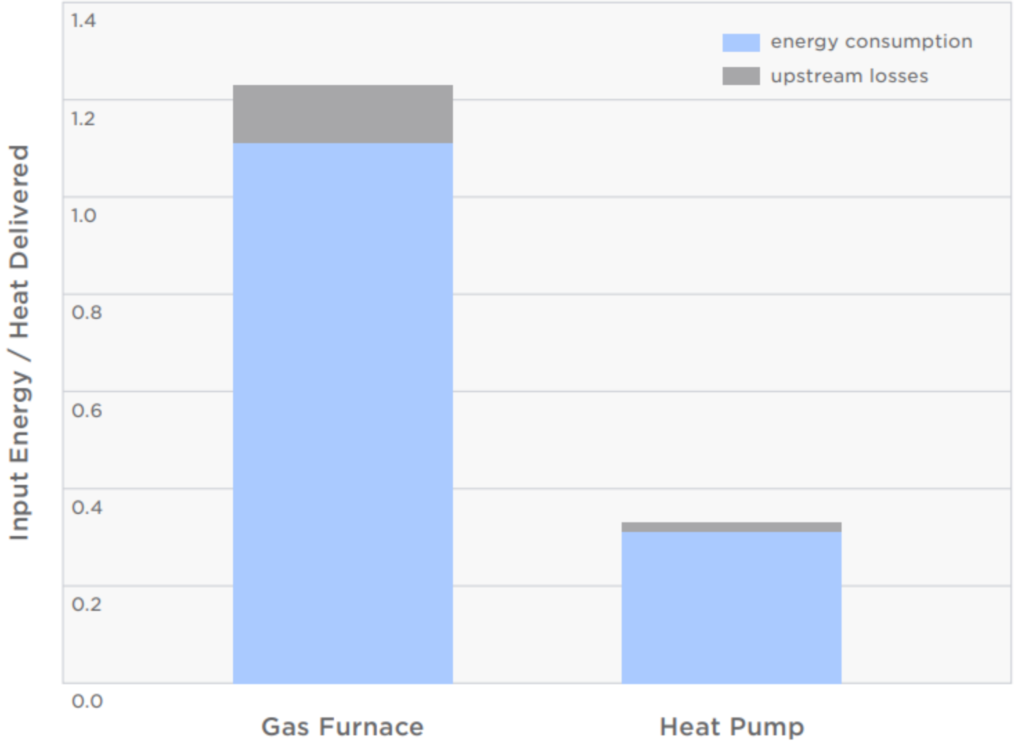


Figure 6: Efficiency improvement of space heating with heat pump vs gas furnace

03 译文：3. 住宅、商业及工业中使用热泵

空气源热泵是最适合改造现有家庭燃气炉的技术，根据9.5 Btu/Wh的供暖季节性能系数(HSPF)，每消耗单位能量可以提供2.8单位的热量，这是目前热泵常见的效率值[11]。而煤气炉通过燃烧天然气产生热量，其年燃料利用效率(AFUE)约为90%[12]。因此，热泵使用的能量比燃气炉少大约3倍(2.8/0.9)。

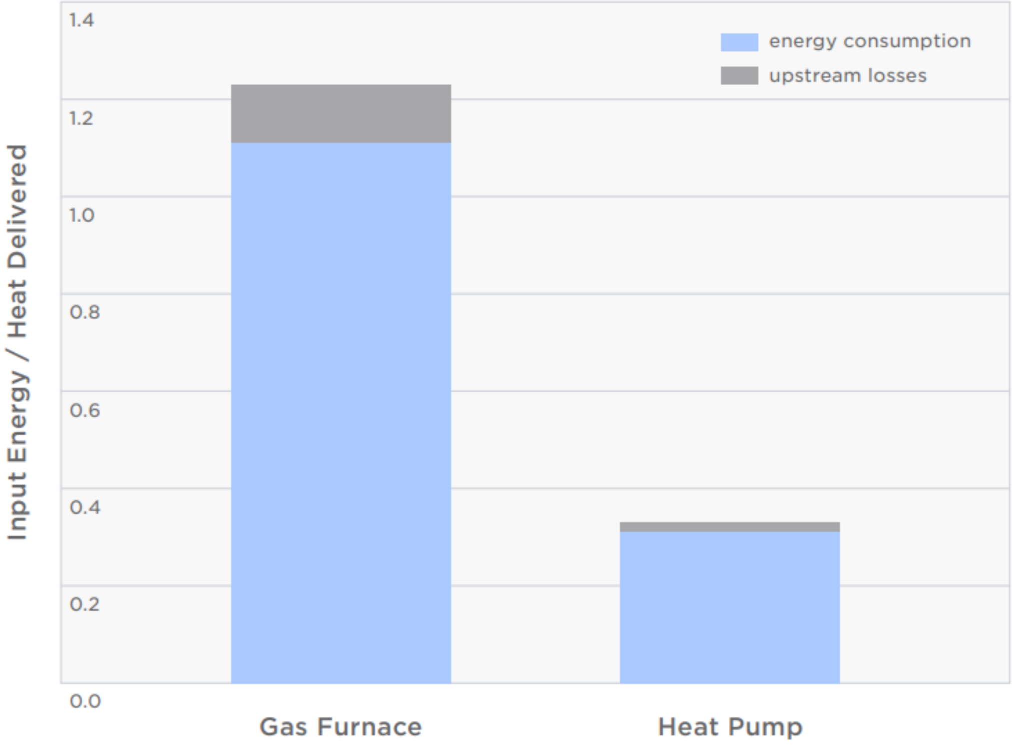


Figure 6: Efficiency improvement of space heating with heat pump vs gas furnace

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

我们的理解

参数注解：

- HSPF：季节供热性能系数，即供热季节热泵总的制热量 / 供热季节热泵总的输入能量
- AFUE：年燃料利用效率，即年输出热量/年消耗化石燃料。
- COP：制热性能系数，即压缩机的制热量与输入功率(消耗的电能or燃料能)的比值，COP越大，热泵系统的效率越高。
- HSPF和COP的换算：

1 Btu=1055.1 J

1 J=3600 Wh

1 Btu=0.293 Wh

03 原文：3. Switch to Heat Pumps in Residential, Business & Industry

Residential and Commercial Sectors

The EIA provides historical monthly US natural gas usage for the residential and commercial sectors in each sub-region[8]. The 3x heat-pump efficiency factor reduces the energy demand if all gas appliances are electrified. The hourly load factor of baseline electricity demand was applied to estimate the hourly electricity demand variation from heat pumps, effectively ascribing heating demand to those hours when homes are actively being heated or cooled. In summer, the residential/commercial demand peaks mid-afternoon when cooling loads are highest, in winter demand follows the well-known “duck-curve” which peaks in morning & evening.

Global electrification of residential and commercial appliances with heat pumps eliminates 18 PWh/year of fossil fuel and creates 6PWh/year of additional electrical demand.

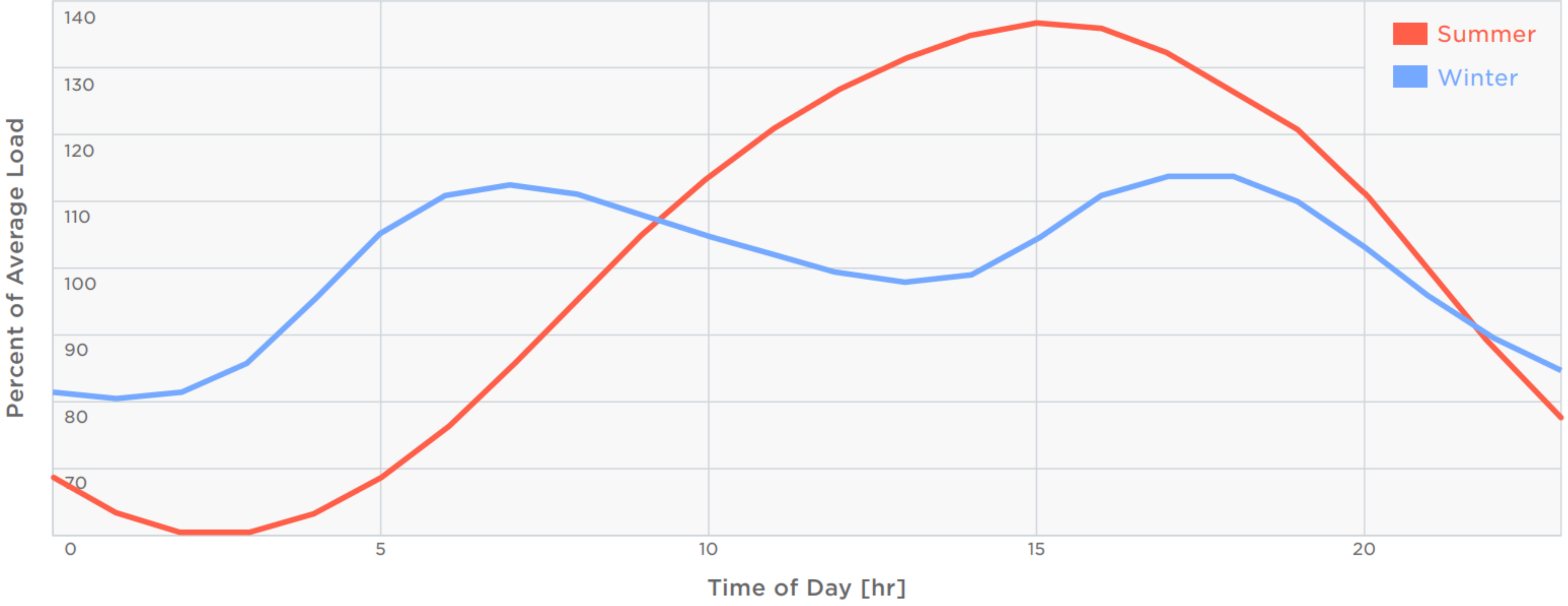


Figure 7: Residential & commercial heating & cooling load factor vs time of day

译文：3. 住宅、商业及工业中使用热泵

住宅和商业部门：

美国能源信息署提供了美国每个子区域的住宅和商业部门的月度天然气使用历史数据[8]。由于热泵效率为燃气炉的3倍，如果将所有燃气器具电气化，可减少能源需求。将基线电力需求的小时负荷系数作为估计热泵的小时电力需求变化，且供热制冷需求变化与家庭供暖制冷的时间变化高度一致。在夏季，住宅/商业的冷却负荷需求在下午达到峰值，在冬季，住宅/商业的供热负荷需求则遵循著名的“鸭子曲线”，在早晨和晚上达到峰值。

全球住宅/商业建筑使用热泵每年将减少18 PWh的化石燃料，以热泵效率为燃气炉的3倍计算，产生6PWh/年的电力需求。

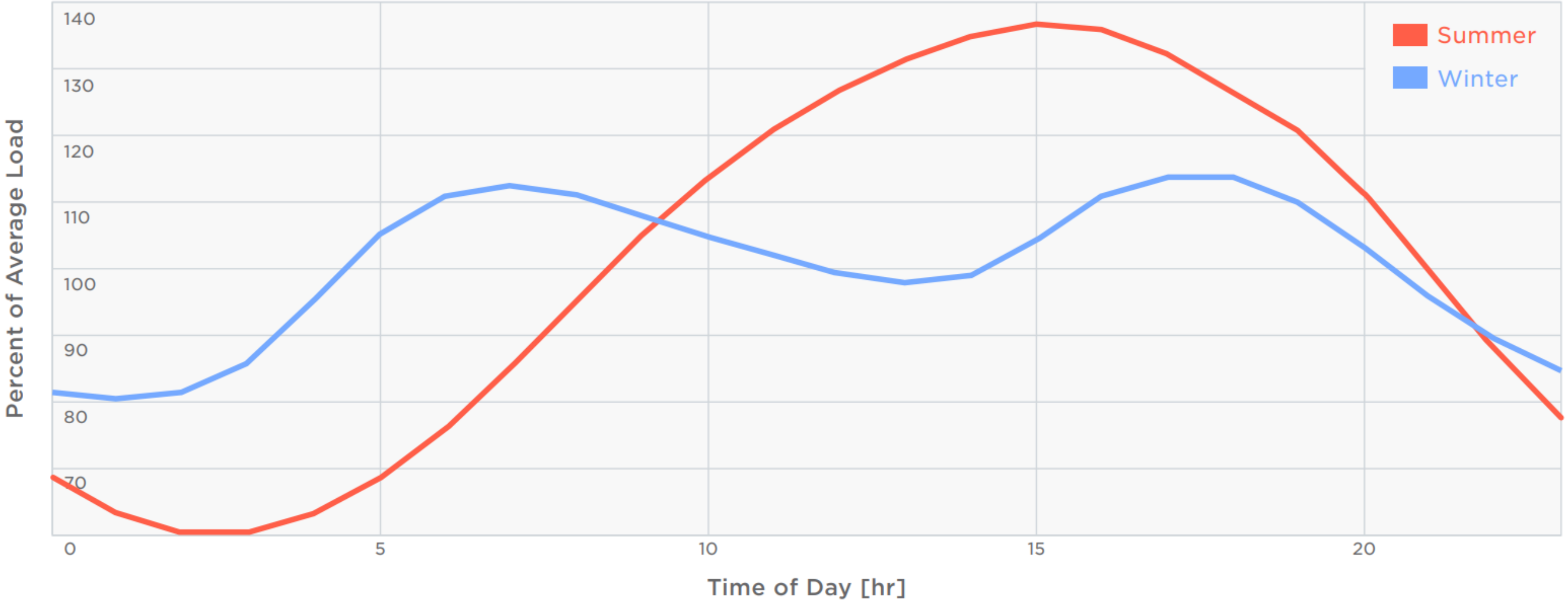


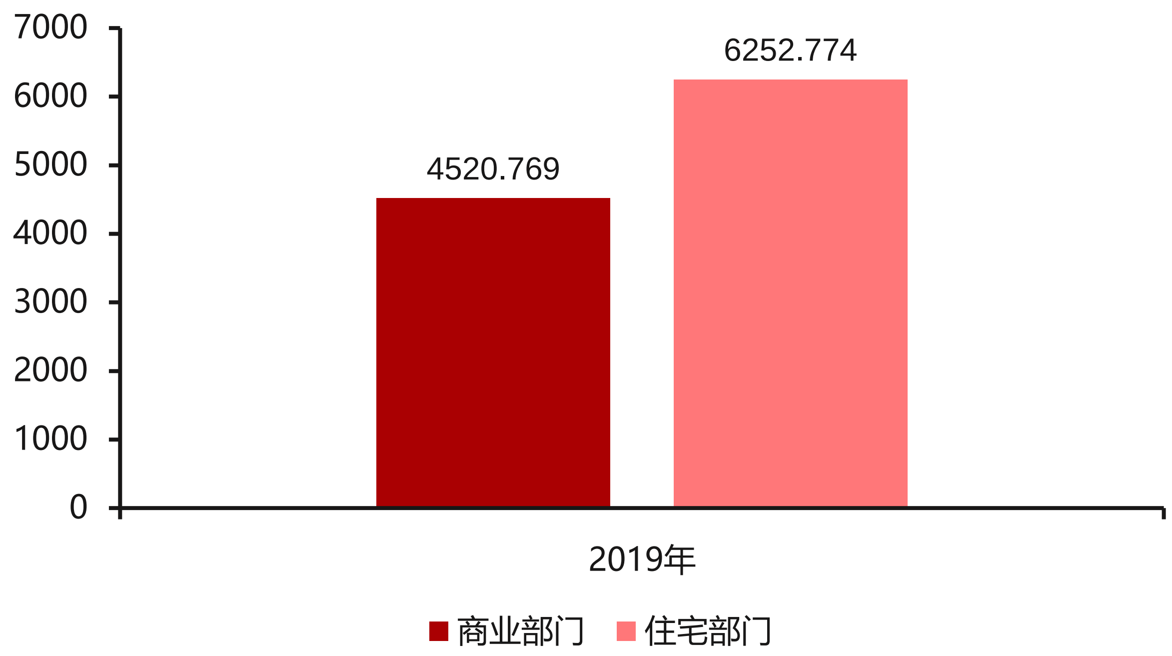
Figure 7: Residential & commercial heating & cooling load factor vs time of day

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

数据核算:

根据EIA数据，2019年美国商业和住宅消耗化石燃料数量为10773.543 TBtu，按照6倍的比例因子缩放后，得到全球商业和住宅消耗化石燃料数量为19PWh/年。

图：2019年美国商业和住宅消耗化石燃料数量（左轴：万亿 Btu）

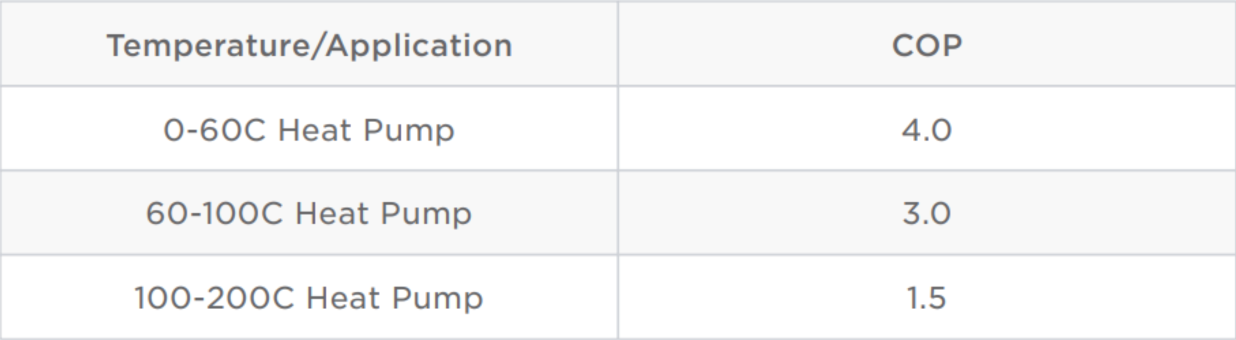


资料来源：EIA，浙商证券研究所

03 原文：3. Switch to Heat Pumps in Residential, Business & Industry

Industrial Sector

Industrial processes up to ~200C, such as food, paper, textile and wood industries can also benefit from the efficiency gains offered by heat pumps[13], although heat pump efficiency decreases with higher temperature differentials. Heat pump integration is nuanced and exact efficiencies depend heavily on the temperature of the heat source the system is drawing from (temperature rise is key in determining factor for heat pump efficiency), as such simplified assumptions for achievable COP by temperature range are used:



Temperature/Application	COP
0-60C Heat Pump	4.0
60-100C Heat Pump	3.0
100-200C Heat Pump	1.5

Table 2: Assumed Heat Pump Efficiency Improvements by Temperature

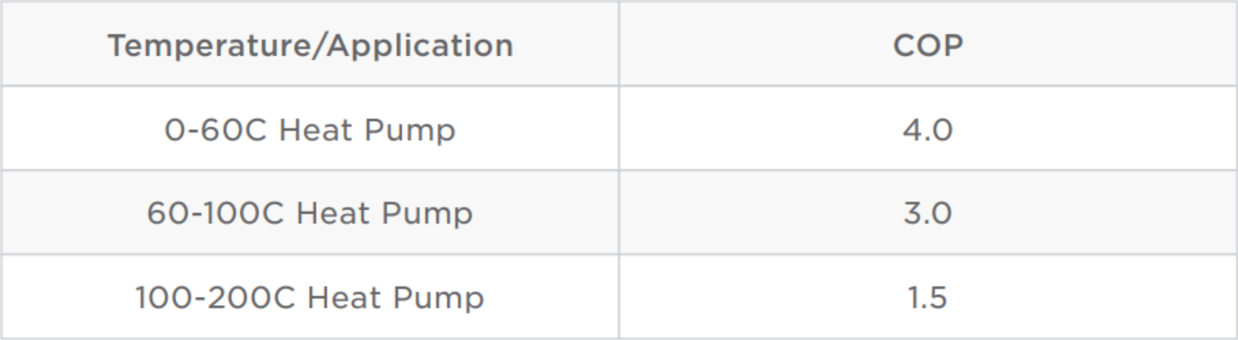
Based on the temperature make-up of industrial heat according to the IEA and the assumed heat pump efficiency by temperature in Table 2, the weighted industrial heat pump efficiency factor modeled is 2.2[14,15,16]. The EIA provides historical monthly fossil fuel usage for the industrial sector for each sub-region[8]. All industrial fossil fuel use, excluding embedded fossil fuels in products (rubber, lubricants, others) is assumed to be used for process heat. According to the IEA, 45% of process heat is below 200C, and when electrified with heat pumps requires 2.2x less input energy[16]. The added industrial heat-pump electrical demand was modeled as an inflexible, flat hourly demand.

Global electrification of industrial process heat <200C with heat pumps eliminates 12PWh/year of fossil fuels and creates 5PWh/year of additional electrical demand.

03 译文：3. 住宅、商业及工业中使用热泵

工业部门：

尽管热泵的效率随着温差的升高而降低，但使用热泵同样有益于温度高达200°C的工业过程，如食品、造纸、纺织和木材工业[13]。由于热泵的效率与系统所使用的热源温度高度相关，因此假设不同温度范围热泵的COP如下：



Temperature/Application	COP
0-60C Heat Pump	4.0
60-100C Heat Pump	3.0
100-200C Heat Pump	1.5

Table 2: Assumed Heat Pump Efficiency Improvements by Temperature

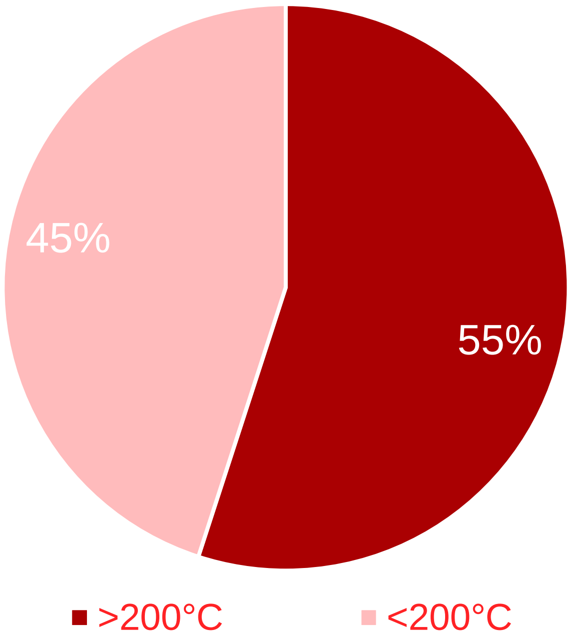
根据国际能源署(IEA)统计的工业过程的不同温度构成和上述按温度对热泵效率的假设，加权得到工业热泵效率为2.2[14,15,16]。EIA提供了美国各子区域工业部门对化石燃料的历史月度使用量[8]，且化石燃料均用于工业热过程，不包含橡胶、润滑剂等产品中含有的化石燃料的使用。根据IEA的数据，45%的工业过程热低于200摄氏度，如果使用热泵，则可减少2.2倍的输入能量[16]。在模型中，增加的工业热泵小时电力需求是非柔性且变化平坦的负载需求。全球低于200摄氏度的工业热过程使用热泵消除了12PWh/年的化石燃料，并创造了5PWh/年的额外电力需求。

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

数据核算：

根据EIA数据，2019年美国工业消耗化石燃料数量为20511.057 TBtu，其中200°C以下的工业过程占比45%，按照6倍的比例因子缩放后，得到全球200°C以下的工业过程消耗化石燃料数量为16PWh/年。

图：不同温度的工业过程占比



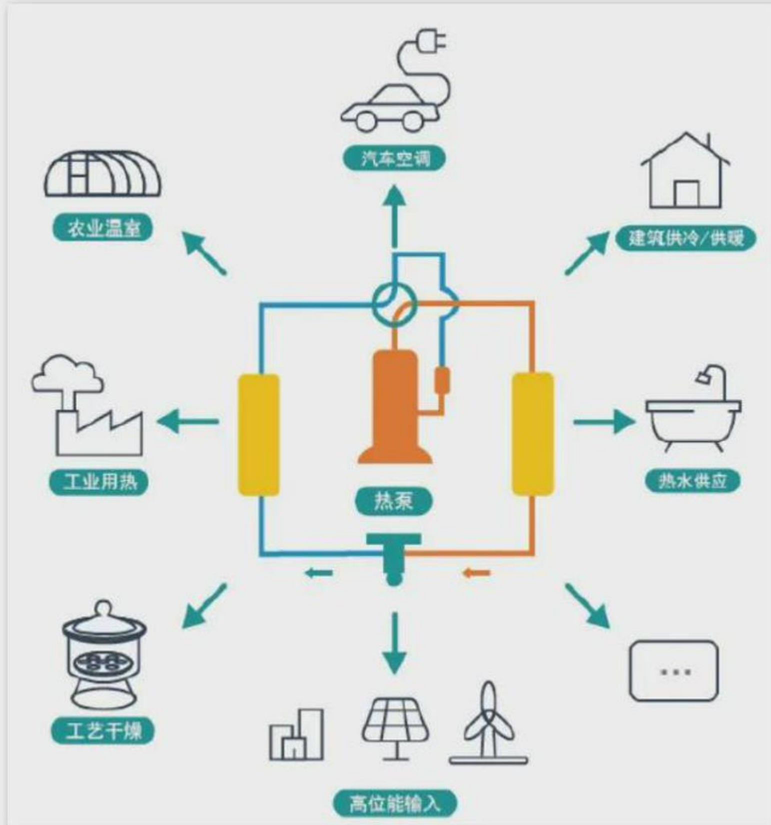
资料来源：EIA，浙商证券研究所

03 我们的理解

热泵应用场景：

- 住宅及商业建筑：热泵可为建筑供暖、供冷、除湿及提供热水；
- 工业：采用大型热泵用于输送热空气、水或蒸汽，或直接加热材料，输入温度比住宅应用更高，热源可来自工业过程、数据中心或废水的废热。

图：热泵的应用场景



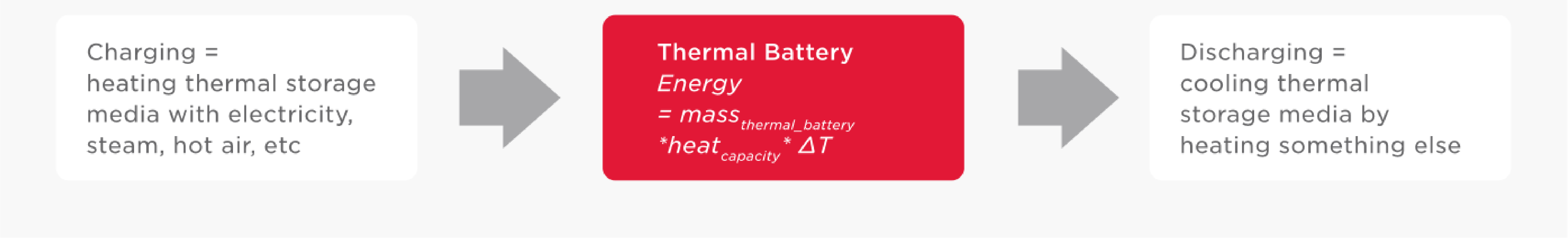
资料来源：《热泵助力碳中和白皮书》，浙商证券研究所

03 原文：4. Electrify High Temperature Heat Delivery and Hydrogen Production

Electrify High Heat Industrial Processes

Industrial processes that require high temperatures (>200C), account for the remaining 55% of fossil fuel use and require special consideration. This includes steel, chemical, fertilizer and cement production, among others. These high-temperature industrial processes can be serviced directly by electric resistance heating, electric arc furnaces or buffered through thermal storage to take advantage of low-cost renewable energy when it is available in excess. On-site thermal storage may be valuable to cost effectively accelerate industrial electrification (e.g., directly using the thermal storage media and radiative heating elements)[17,18].

Identify the optimal thermal storage media by temperature/application



Charging = heating thermal storage media with electricity, steam, hot air, etc

Thermal Battery

$Energy = mass_{thermal\_battery} * heat_{capacity} * \Delta T$

Discharging = cooling thermal storage media by heating something else

Figure 8: Thermal Storage Overview

03 译文：4. 高温传热和氢能的电气化

高热工业过程的电气化

除了低于200°C的工业过程，剩余55%的化石燃料则用于高于200°C的工业过程，如钢铁、化工、化肥和水泥生产等，需要单独考虑。这些工业过程所需的高温可以直接通过电阻加热或电弧炉提供，也可以通过储热系统在可再生能源过剩时将这种低成本的能量储存起来作为缓冲，在工业过程所需时为其供热。直接使用储热介质和辐射热元素实现就地储热对于加速工业过程电气化是经济有效的[17,18]。

根据温度/应用确定最佳的储热介质

输入：
通过电力，蒸汽，热空气等加热储热介质

热电池能量=
热电池质量*单位热容量*温度变化

输出：
通过加热其他物质冷却储热介质

原文：4. Electrify High Temperature Heat Delivery and Hydrogen Production

Delivering Heat to High Temperature Processes

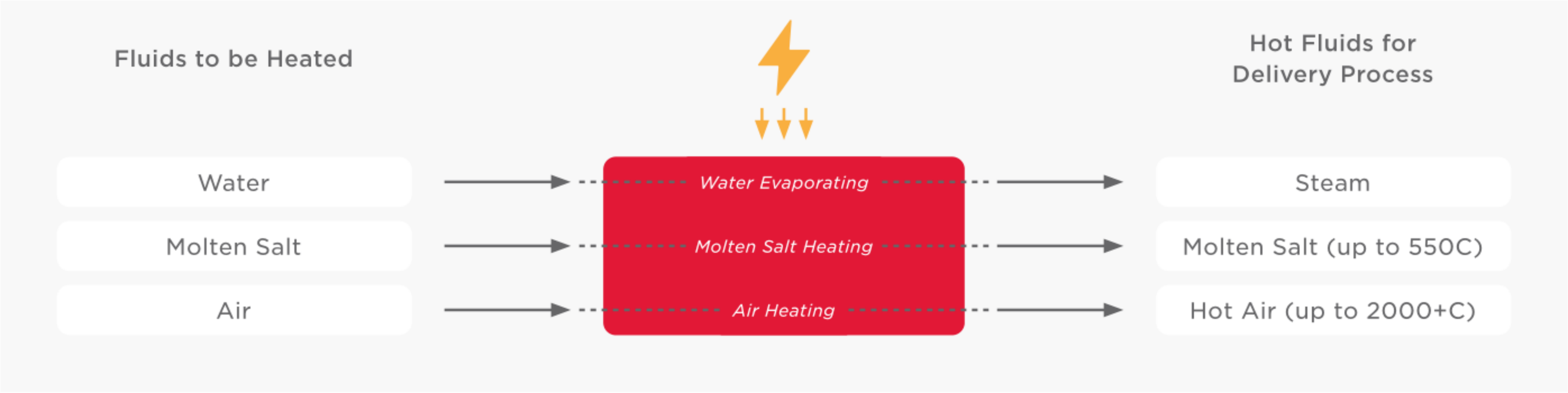


Figure 9A: Thermal Storage - Heat Delivery to Process via Heat Transfer Fluids

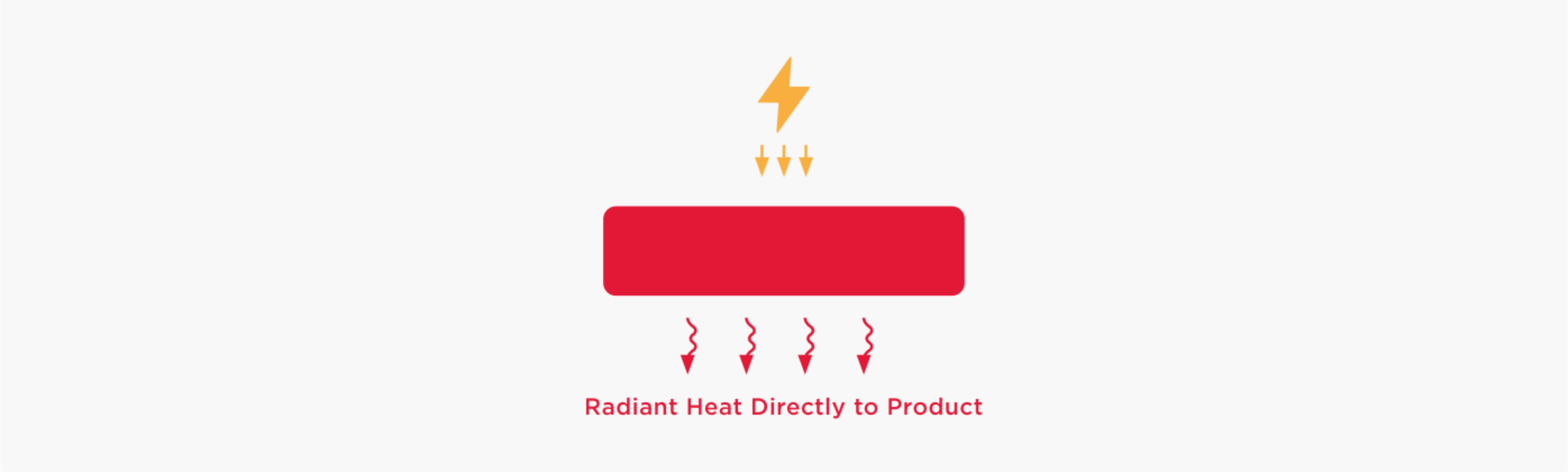
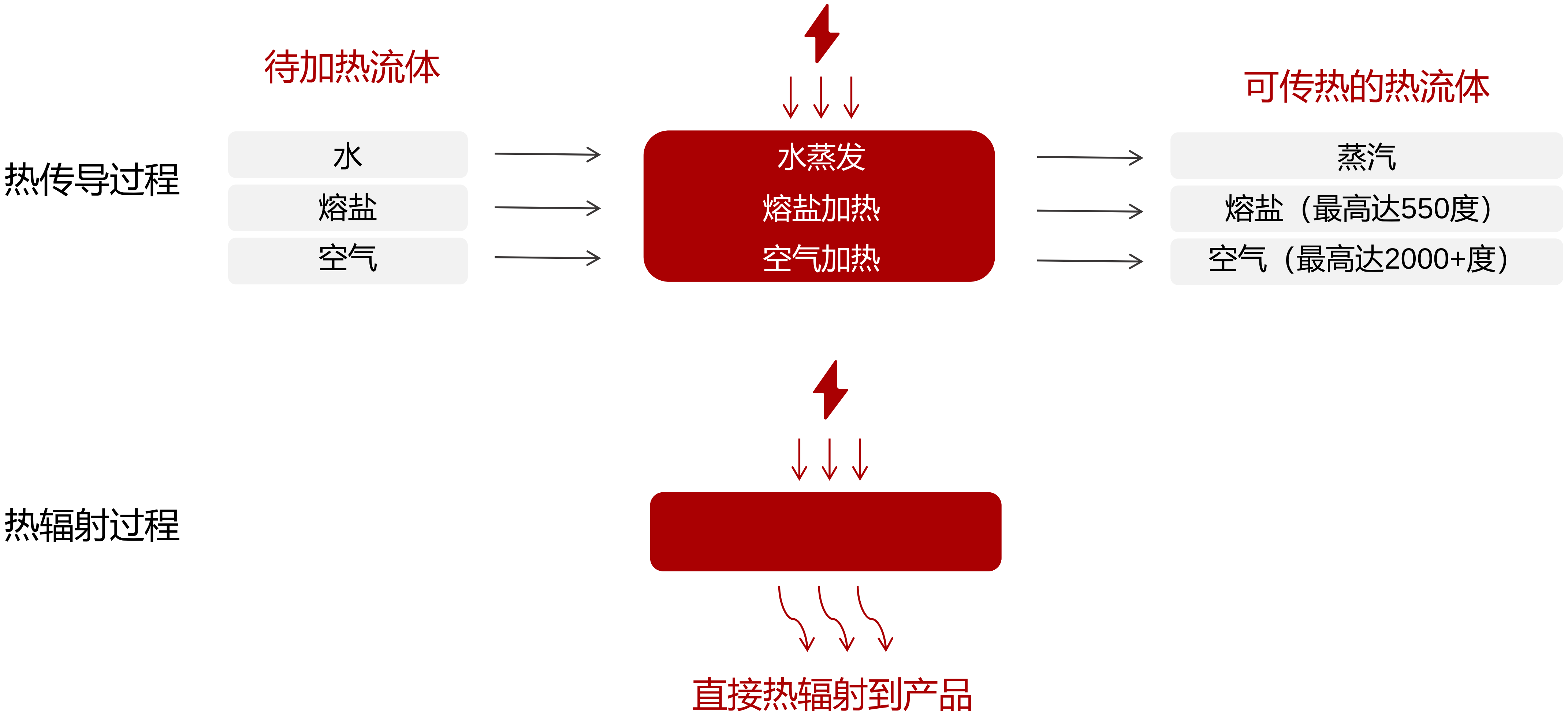


Figure 9B: Thermal Storage - Heat Delivery to Process via Direct Radiant Heating

03 译文：4. 高温传热和氢能的电气化

向高温过程传递热量：



热传导过程

待加热流体
水
熔盐
空气

水蒸发
熔盐加热
空气加热

可传热的热流体
蒸汽
熔盐（最高达550度）
空气（最高达2000+度）

热辐射过程

直接热辐射到产品

03 我们的理解

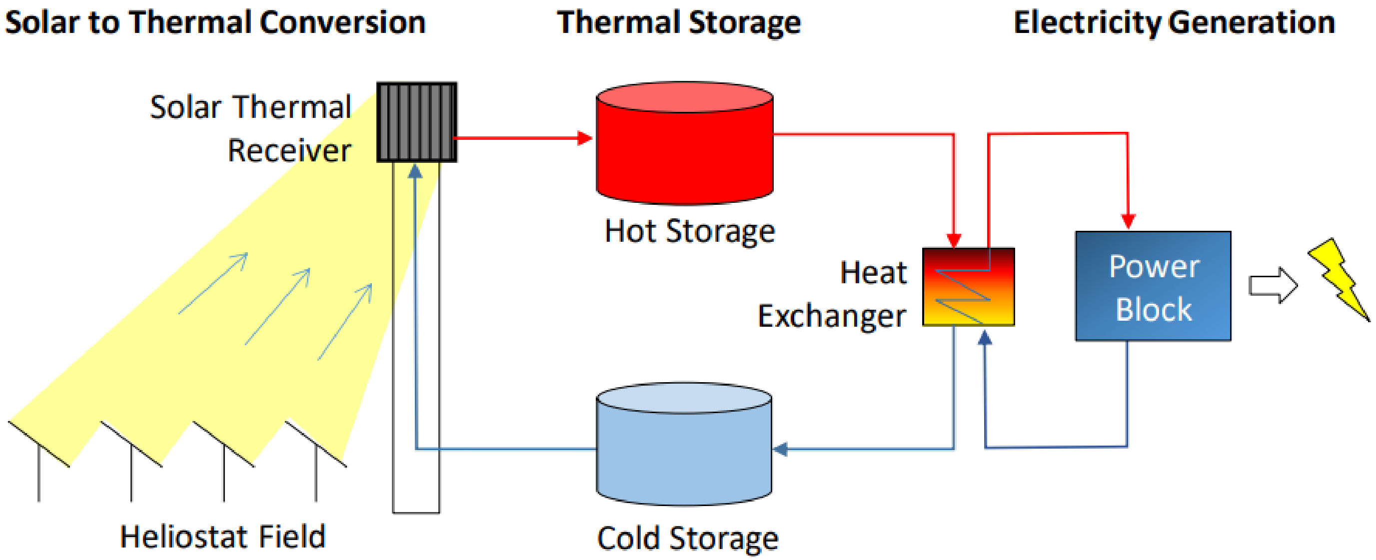
熔盐储热过程:

熔盐通过塔顶的太阳能接收器被加热到约565°C，随后流入热储罐中。当需要热能时，熔盐被输送到热交换器中，加热水产生蒸汽以带动涡轮机发电，同时熔盐冷却到约300度回到冷储罐中，然后再次进入太阳能接收器被加热。

常见熔盐体系：

Solar salt：二元共晶硝酸盐(60wt% $NaNO_3$-40wt% KNO_3)，熔点为221°C，在565°C下高温热稳定性较好；

Hitec：三元共晶硝酸盐(53wt% KNO_3-7wt% $NaNO_3$-40wt% $NaNO_2$)，熔点为142°C，在454°C下高温热稳定性较好；



资料来源：Sandia National Laboratories，浙商证券研究所

原文：4. Electrify High Temperature Heat Delivery and Hydrogen Production

Electric resistance heating, and electric arc furnaces, have similar efficiency to blast furnace heating, therefore will require a similar amount of renewable primary energy input. These high-temperature processes are modeled as an inflexible, flat demand.

Thermal storage is modeled as an energy buffer for high-temperature process heat in the industrial sector, with a round trip thermal efficiency of 95%. In regions with high solar installed capacity, thermal storage will tend to charge midday and discharge during the nights to meet continuous 24/7 industrial thermal needs. Figure 9 shows possible heat carriers and illustrates that several materials are candidates for providing process heat >1500C.

Global electrification of industrial process heat >200C eliminates 9PWh/year of fossil fuel fuels and creates 9PWh/year of additional electrical demand, as equal heat delivery efficiency is assumed.

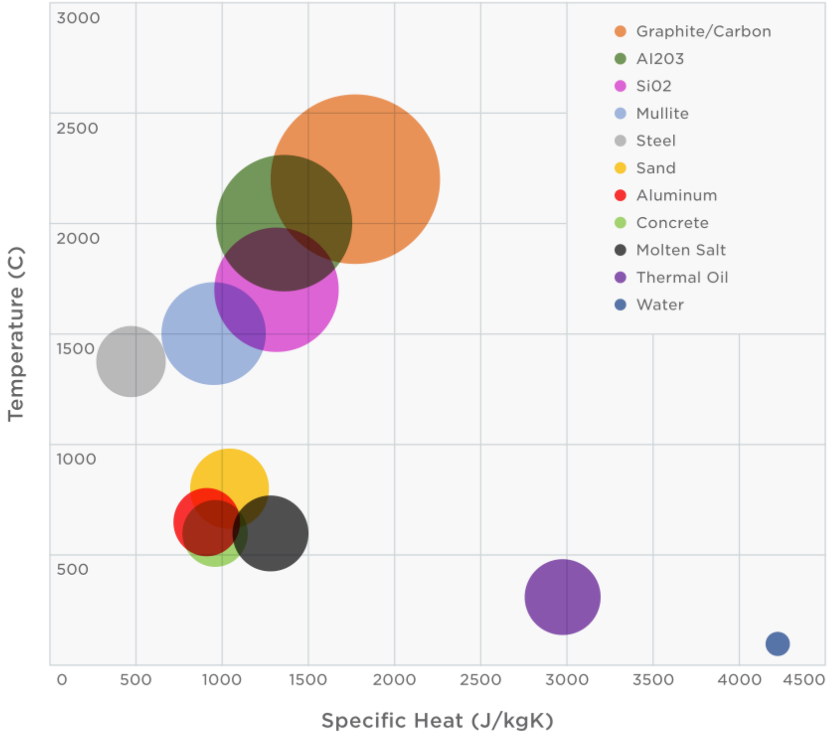


Figure 10: Thermal Storage - Heat Storage Media

03

译文：4. 高温传热和氢能的电气化

电阻加热和电弧炉与燃气炉加热的效率相近，因此对可再生一次能源的需求量相似，作为固定且平坦的需求建模。

储热系统被建模为工业部门高温过程热量的能量缓冲器，热效率为95%。在太阳能装机容量较大的地区，蓄热系统在中午充电，晚上放电，以满足24/7连续的工业热需求。下图列出了可能的热载体，其中几种材料可用于提供高于1500度的工艺热。

使用储热系统实现>200℃工业过程热的全球电气化，消除了9PWh/年的化石燃料，在传热效率相同的假设下，将创造9PWh/年的电力需求。

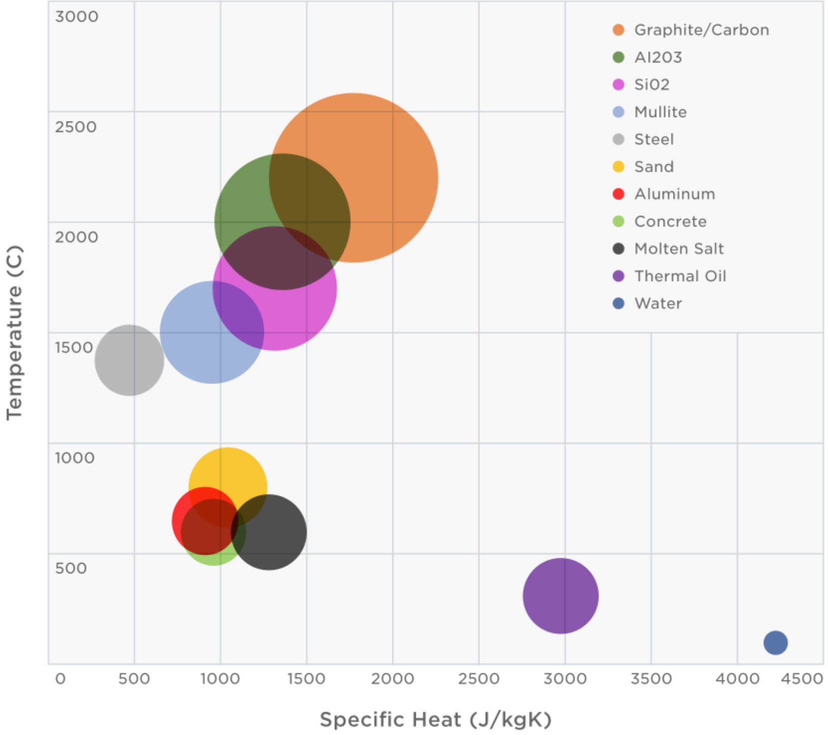


Figure 10: Thermal Storage - Heat Storage Media

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

碳作为储热介质的优势：

1.原材料成本低：碳块是最便宜的大体积储热材料，来源于其他工业过程的副产品。

2.产量丰富：用于金属工业的碳块年产量约为3000万吨/年，即使是现有供应链的一小部分，也足以建立每年TWh的储能能力。

3.优异的热性能和机械性能：碳的高温比热容比大多数传统储热材料高30%-70%，且具有高导电性、机械强度和循环寿命。

4.极端温度稳定性：碳是现存的热稳定性最好的材料之一，在3000°C以上仍保持固体状态，是钢铁熔化温度的2倍，较高的工作温度能实现巨大的能量密度，也意味着更小的占地面积。

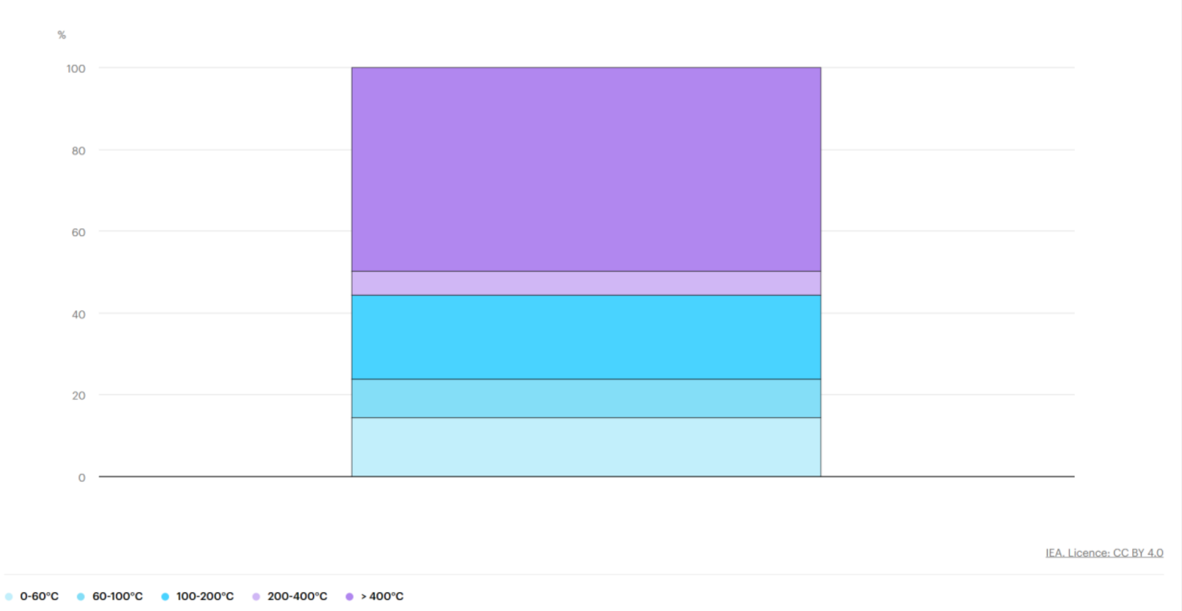
资料来源：Antora Energy，浙商证券研究所

数据核算：

根据EIA数据， 2019年工业消耗化石燃料数量为20511.057 TBtu，其中200°C以上的工业过程占比55%，按照6倍的比例因子缩放后，得到全球200°C以上的工业过程消耗化石燃料数量为20PWh/年。

同时，根据IEA提供的2018年全球按照温度划分的工业热需求，200°C以下的工业过程需47.8EJ，折算为13.3PWh；200°C以上的工业过程需60.1EJ，折算为16.7PWh。

图：2018年按照温度划分的工业热需求



资料来源：IEA，EIA，浙商证券研究所

原文：4. Electrify High Temperature Heat Delivery and Hydrogen Production

Sustainably Produce Hydrogen for Steel and Fertilizer

Today hydrogen is produced from coal, oil and natural gas, and is used in the refining of fossil fuels (notably diesel) and in various industrial applications (including steel and fertilizer production).

Green hydrogen can be produced via the electrolysis of water (high energy intensity, no carbon containing products consumed/produced) or via methane pyrolysis (lower energy intensity, produces a solid carbon-black byproduct that could be converted into useful carbon-based products)[g].

To conservatively estimate electricity demand for green hydrogen, the assumption is:

- No hydrogen will be needed for fossil fuel refining going forward
- Steel production will be converted to the Direct Reduced Iron process, requiring hydrogen as an input. Hydrogen demand to reduce iron ore (assumed to be Fe_3O_4) is based on the following reduction reaction:

Reduction by H_2

- $Fe_3O_4 + H_2 = 3FeO + H_2O$
- $FeO + H_2 = Fe + H_2O$

- All global hydrogen production will come from electrolysis

---

[g] Sustainable steel production may also be performed through molten oxide electrolysis, which requires heat and electricity, but does not require hydrogen as a reducing agent, and may be less energy intensive, but this benefit is beyond the scope of the analysis[19].

译文：4. 高温传热和氢能的电气化

用于钢铁和化肥的氢气的可持续生产

当前氢是从煤、石油和天然气中产生的，并用于精炼化石燃料(尤其是柴油)和各种工业过程(如生产钢铁和化肥)。

绿氢可以通过电解水(高能量密度，不消耗/生产含碳产品)或通过甲烷热解(低能量密度，产生的固体炭黑副产品可转化为有用的碳基产品)得到[g]。

为估计生产绿氢的保守电力需求，做出如下假设：

- 未来的化石燃料精炼不再需要氢气
- 钢铁生产将转变为直接还原铁工艺，使用氢气还原，还原铁矿石的方程式如下:

使用氢气还原：

- $Fe_3O_4 + H_2 = 3FeO + H_2O$
- $FeO + H_2 = Fe + H_2O$

- 全球所有的氢气都来自电解过程

---

[g] 可持续的钢铁生产也可以通过熔融氧化物电解进行，这需要热量和电力，但不需要氢作为还原剂，并且可能不那么耗能，但这种好处超出了分析的范围。

我们的理解

氢气制取方法：主要分为化石燃料制氢、工业副产制氢及可再生能源制氢，当前我国氢气主要采用化石燃料制取。

化石燃料精炼用氢：目前炼油企业采用的加氢工艺主要有加氢精制和加氢裂化两大类。

加氢精制：可将油品中的硫、氧、氮等有害杂质转变为相应的硫化氢、水、氨而除去，并使烯烃和二烯烃加氢饱和、芳烃部分加氢饱和，以改善油品的质量。主要用于各种来源的汽油、煤油、柴油、催化重整原料、润滑油、石蜡油的精制，喷气燃料中芳烃的部分加氢饱和，燃料油的加氢脱硫，渣油脱重金属及脱沥青预处理等。

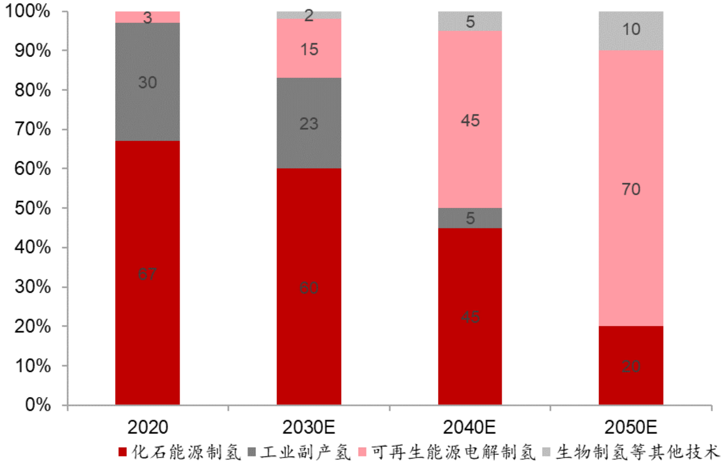
加氢裂化：主要用来生成高质量的轻质油品，如柴油、航煤、汽油等。

钢铁生产：碳冶金转向氢冶金

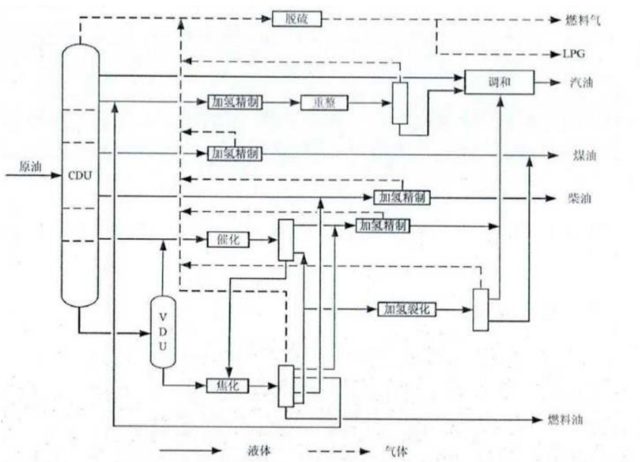
碳冶金：$2Fe_2O_3 + 3C = 4Fe + 3CO_2$

氢冶金：$Fe_3O_4 + 4H_2 = 3Fe + 4H_2O$

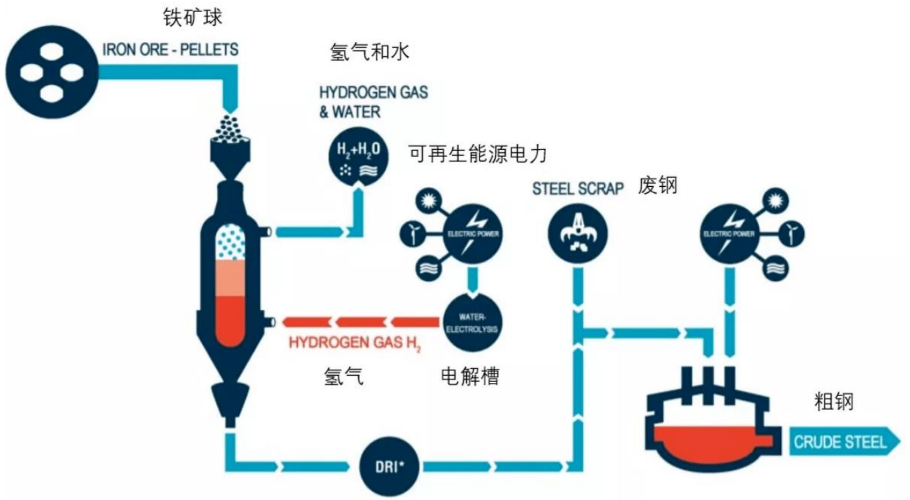
图：2020-2050氢气的主要来源



图：氢气在炼油中的应用



图：氢气用于生产钢铁



资料来源：中商情报网，《炼油企业氢气系统优化研究及应用》，界面新闻，浙商证券研究所

原文：4. Electrify High Temperature Heat Delivery and Hydrogen Production

These simplified assumptions for industrial demand, result in a global demand of 150Mt/yr of green hydrogen, and sourcing this from electrolysis requires an estimated ~7.2PWh/year of sustainably generated electricity[h,20,21].

The electrical demand for hydrogen production is modeled as a flexible load with annual production constraints, with hydrogen storage potential modeled in the form of underground gas storage facilities (like natural gas is stored today) with maximum resource constraints. Underground gas storage facilities used today for natural gas storage can be retrofitted for hydrogen storage; the modeled U.S. hydrogen storage requires ~30% of existing U.S. underground gas storage facilities[22,23]. Note that some storage facilities, such as salt caverns, are not evenly geographically dispersed which may present challenges, and there may be better alternative storage solutions.

Global sustainable green hydrogen eliminates 6 PWh/year of fossil fuel energy use, and 2 PWh/year of non-energy use[i,24]*. The fossil fuels are replaced by 7PWh/year of additional electrical demand.*

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[h] Adjusted current demand for hydrogen, removing demand related to oil refining, as that will not be required. Assumed all of the hydrogen produced from coal and natural gas today is replaced. Then, the energy required to produce the hydrogen from coal and natural gas, compared to electrolysis, is calculated.

[i] According to the IEA, 85% of natural gas non-energy consumption is consumed by fertilizer and methanol production

译文：4. 高温传热和氢能的电气化

通过对工业用氢的简化假设，得到全球对绿氢的需求为1.5亿吨/年，每年需要约7.2PWh的可再生电力电解得到[h,20,21]。

将产氢的电力需求建模为具有年度生产约束的柔性负载，储氢潜力建模为具有最大资源约束的地下储气设施(即目前天然气储存)的形式。目前用于天然气储存的地下储气设施可以改造为储氢设施，模型中美国氢气储存需要约30%现有美国地下天然气储存设施[22,23]，但由于储存设施如盐穴在地理上并非均匀分布，会为储氢带来挑战，可能存在更好的其他存储解决方案。

可持续绿氢消除了全球6PWh/年的化石燃料在能源领域的应用和2PWh/年的非能源应用[i,24]，创造了每年7PWh的额外电力需求。

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[h] 调整了目前对氢气的需求，取消了与炼油相关的需求，因为这将不再需要。假设今天所有由煤和天然气产生的氢都被取代。然后，计算从煤和天然气中生产氢气所需的能量，并将其与电解相比较。

[i] 根据国际能源署的数据，85%的天然气非能源消耗被化肥和甲醇生产所消耗。

数据核算：

1.假设简化中工业生产用氢只包含了钢铁生产:

（当前氢气的工业应用：精炼石油、合成氨和甲醇、冶炼金属等；未来氢冶金是主要的下游应用）

2.对生产钢铁所需的还原剂绿氢的电力需求估算：

2022年全球钢产量：18.785亿吨，生产1吨生铁需要氢气1000标准立方米，即89.3kg，则生产18.785亿吨生铁需要氢气1.67亿吨，当前电解1kg氢气耗电量为48KWh，则产生电力需求8.0PWh。

3.使用绿氢替代煤炭作为生产钢铁的还原剂能消除的化石燃料数量：

生产1吨生铁需要400kg煤炭，1吨煤炭约产8141KWh的电力，则生产18.785亿吨生铁需6.1PWh化石燃料。

4.根据EIA数据， 2019年美国消耗非燃烧用的天然气1.158744QBtu，按照6倍的比例因子缩放后，得到全球消耗非燃烧用的天然气2.0PWh。

资料来源：世界钢铁协会，EIA，日本钢铁协会，特斯拉，浙商证券研究所

原文: 5. Sustainably Fuel Planes & Boats

Both continental and intercontinental ocean shipping can be electrified by optimizing design speed and routes to enable smaller batteries with more frequent charge stops on long routes. According to the IEA, ocean shipping consumes 3.2PWh/year globally. By applying an estimated 1.5x electrification efficiency advantage, a fully-electrified global shipping fleet will consume 2.1PWh/year of electricity[25].

Short distance flights can also be electrified through optimized aircraft design and flight trajectory at today's battery energy densities[26]. Longer distance flights, estimated as 80% of air travel energy consumption (85B gallons/year of jet fuel globally), can be powered by synthetic fuels generated from excess renewable electricity leveraging the Fischer-Tropsch process, which uses a mixture of carbon monoxide (CO) and hydrogen (H_2) to synthesize a wide variety of liquid hydrocarbons, and has been demonstrated as a viable pathway for synthetic jet fuel synthesis[27]. This requires an additional 5PWh/year of electricity, with:

- H_2 generated from electrolysis[21]
- CO_2 captured via direct air capture[28, 29]
- CO produced via electrolysis of CO_2

Carbon and hydrogen for synthetic fuels may also be sourced from biomass. More efficient and cost-effective methods for synthetic fuel generation may become available in time, and higher energy density batteries will enable longer-distance aircraft to be electrified thus decreasing the need for synthetic fuels.

The electrical demand for synthetic fuel production was modeled as a flexible demand with an annual energy constraint. Storage of synthetic fuel is possible with conventional fuel storage technologies, a 1:1 volume ratio is assumed. The electrical demand for ocean shipping was modeled as a constant hourly demand.

Global sustainable synthetic fuel and electricity for boats and planes eliminates 7PWh/year of fossil fuels, and creates 7PWh/year of additional global electrical demand.

译文：5. 可持续燃料飞机和船只

通过优化设计速度和路线，大陆和洲际远洋运输的电气化可以通过在长途航线上使用容量更小的电池但更频繁地停靠充电来实现。根据IEA的数据，全球远洋运输消耗电力3.2PWh/年。如果电气化后能源利用效率是原来的1.5倍，则全球船队的完全电气化将消耗2.1PWh/年的电力[25]。

在今天的电池能量密度下，通过优化飞机设计和飞行轨迹，短途飞行也可以实现电气化[26]。全球每年消耗的航空燃料为850亿加仑，其中长途飞行消耗了其中的80%。长途飞行可以通过利用费托工艺从多余的可再生电力中产生的合成燃料来提供动力，该工艺使用CO和H_2混合物合成各种液态碳氢化合物，并已经被证实是合成航空燃料的可行途径[27]，且需要额外的5PWh/年的电力，包括:

- 电解产生的H_2[21]
- 通过直接空气捕获CO_2[28,29]
- 通过电解CO_2产生的CO

用于合成燃料的碳和氢也可以来自生物质。更高效、更具成本效益的合成燃料生产方法迟早会出现，而更高能量密度的电池将使长途飞行实现电气化，从而减少对合成燃料的需求。

将合成燃料的电力需求建模为具有年度能源约束的柔性需求，远洋运输的电力需求被建模为一个恒定的小时需求。假设使用可持续法合成的燃料与传统方法合成的燃料体积比为1：1，可使用传统的燃料储存技术。

全球船舶和飞机燃料的可持续合成及电气化消除了7PWh/年的化石燃料，并创造了7PWh/年的额外全球电力需求。

03 我们的理解

船只电气化：电池

数据核算：电力需求=化石燃料产生的电力/效率比例因子；

飞机电气化：绿氢+CO合成航空煤油

数据核算：电力需求=电解氢气所需的电力，$(2n+1)H_2+nCO=C_nH_{2n+2}+nH_2O$

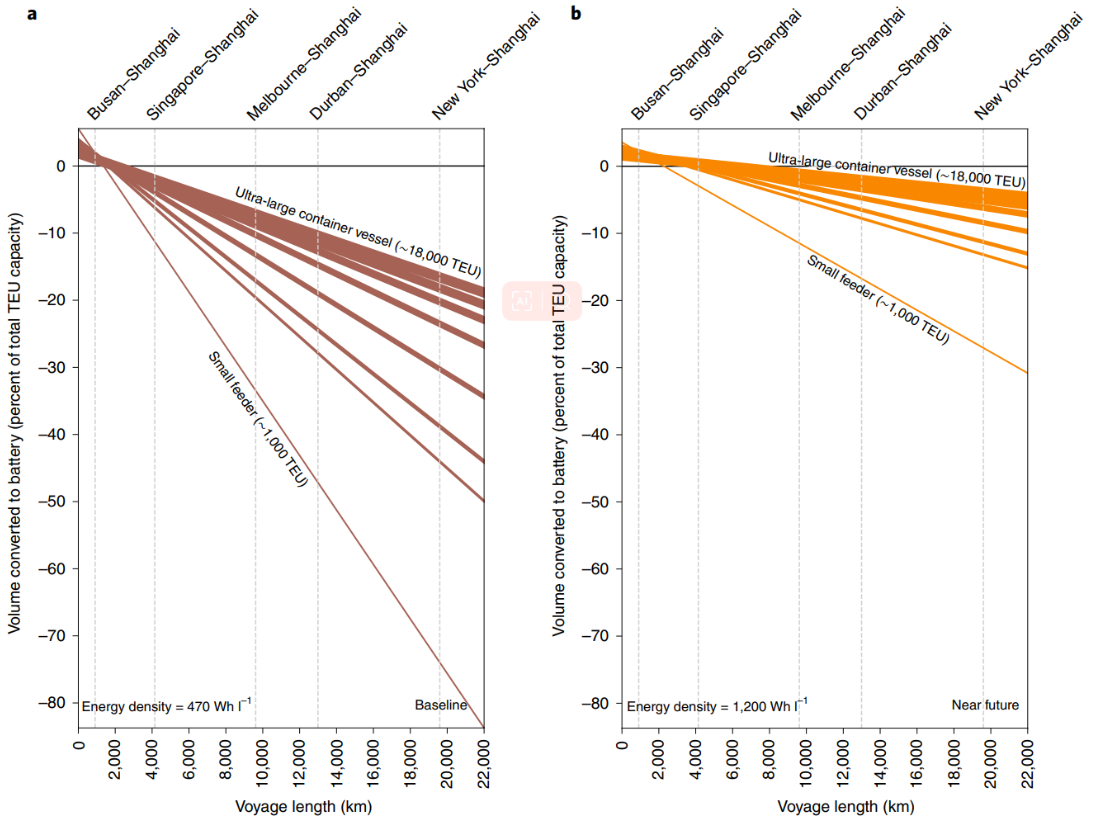
03 我们的理解

动力电池重量 vs 船舶重量：

电动船的关键技术限制是电池系统和电动机与内燃机船发电机和燃料储存的相对体积、重量大小。

1）假设一艘航程5000km的巴拿马型货船装配5GWh的磷酸铁锂电池，能量密度为260Wh/kg，则电池重量为2万吨，会增加1m的吃水深度；该货船载重5-8万吨，按照3：1的载重比，自重约为2万吨。

2) 图：不同载重和航程下船舶电气化后电池体系与原有内燃机体系的体积大小关系



左图描述了不同载重的船舶在不同航程下，电气化后电池体系与原有内燃机体系的体积大小，其中a图假设船舶装配的锂电池体积能量密度为470Wh/L，b图假设锂电池体积能量密度为1200Wh/L。

a图中，当小型巴拿马货船的航程低于3000km时，电池体系的体积小于现有内燃机和燃料罐所需体积。但当航程达到20000km时，电池将占据船载重的32%。

b图中根据船舶的载重不同，对应航程在2000-5000km内电池体系的体积小于现有内燃机和燃料罐所需体积。

结论：电池体系占货船总载重的比例随着电池能量密度提升、航程减少、运载能力增大而减小。

资料来源：《Rapid battery cost declines accelerate the prospects of all-electric interregional container shipping》，浙商证券研究所

03 我们的理解

电动船成本 vs 油船成本：

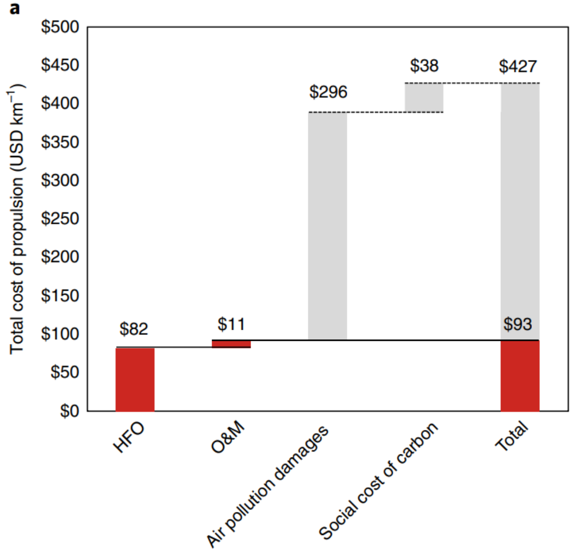
建模假设：

1）货船种类：新型巴拿马货船，载重7650TEU，平均航程1565km。

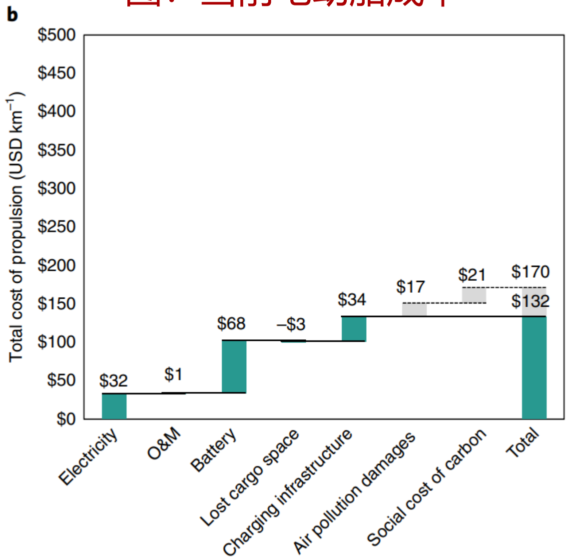
2）油船：使用极低硫燃油(0.5%硫含量)，考虑燃料、运维、空气污染物排放成本。

3）电动船：考虑电力、运维、空气污染物排放、电池组的原始和更换成本、减少的载货量机会成本、充电设备成本。

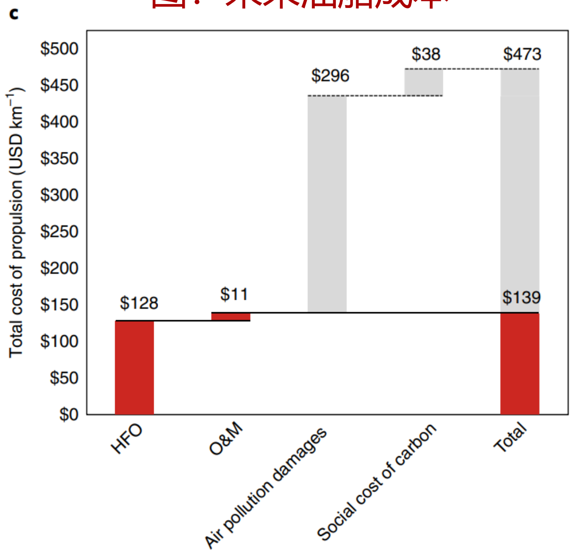
图：当前油船成本



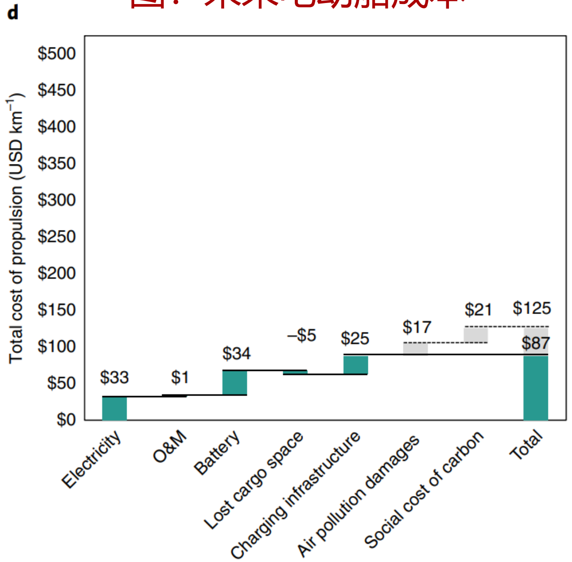
图：当前电动船成本



图：未来油船成本



图：未来电动船成本



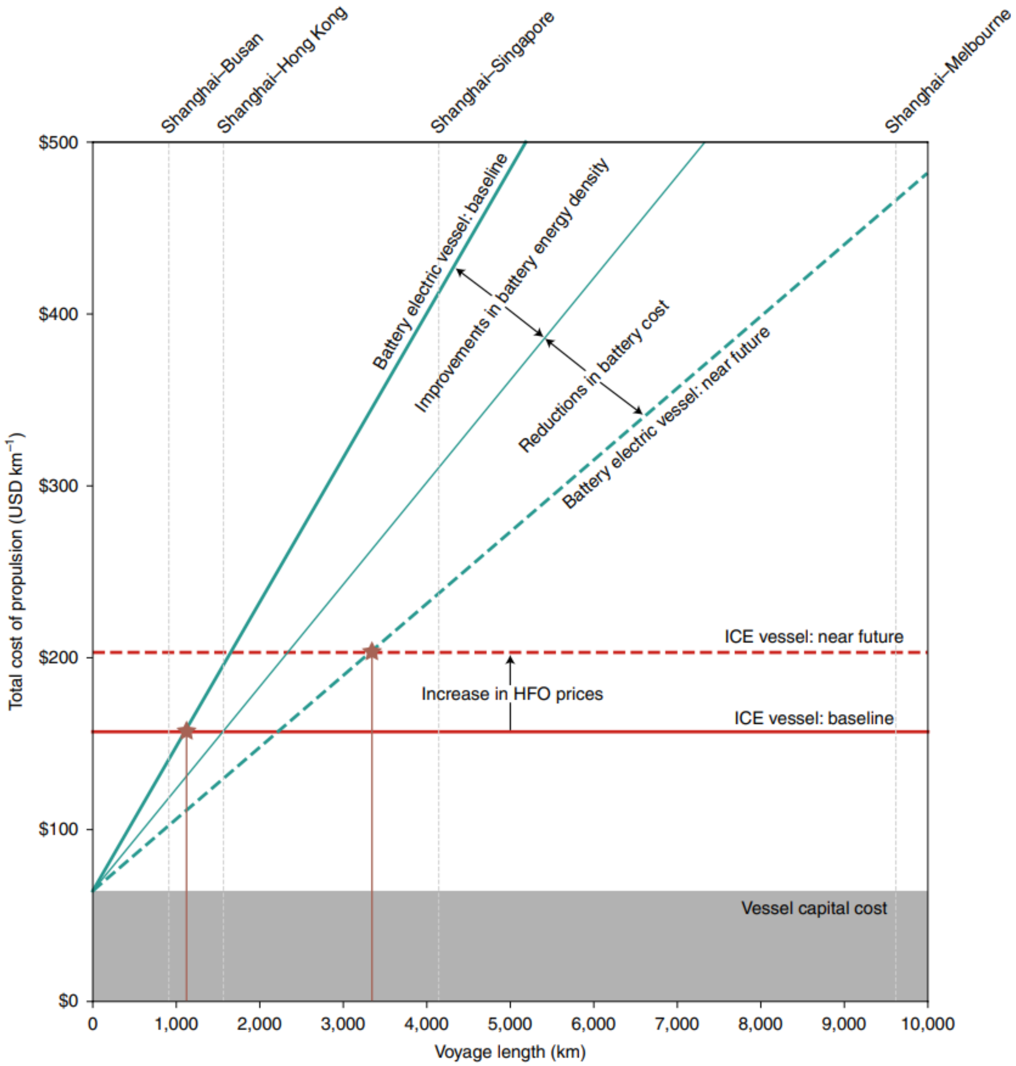
当前：假设电池成本为$100/kWh，体积能量密度为470Wh/L，充电设施利用率为50%，电价为$0.035/kWh，油船成本为$0.048/kWh；若不考虑空气污染成本，当前电动船成本比油船成本高$39/km。

未来：假设电池成本为$50/kWh，体积能量密度为1200Wh/L，充电设施利用率为70%，电价为$0.035/kWh，油船成本为$0.075/kWh(考虑每吨CO$_2$排放税价为$100)；若不考虑空气污染成本，则电动船成本比油船成本低$52/km。

资料来源：《Rapid battery cost declines accelerate the prospects of all-electric interregional container shipping》，浙商证券研究所

03 我们的理解

图：电动船和油船的单位成本对比



左图描述了在不包括环境成本时，当前和未来电动船和油船的TCP，其中红线代表油船，绿线代表电动船，实线代表当前情景，虚线代表未来情景。

在当前情境下，当航程小于1000km时，电动船具有成本优势；未来情境下，考虑油船成本上升及电池能量密度提升、成本下降，当航程小于3300km时，电动船具有成本优势。

电池电动船与内燃机船在更远航程上的成本平价的主要限制因素是电池成本。若使一艘续航里程为10000公里的电动船具有成本效益，对应的电池价格需降低到$20/kWh。

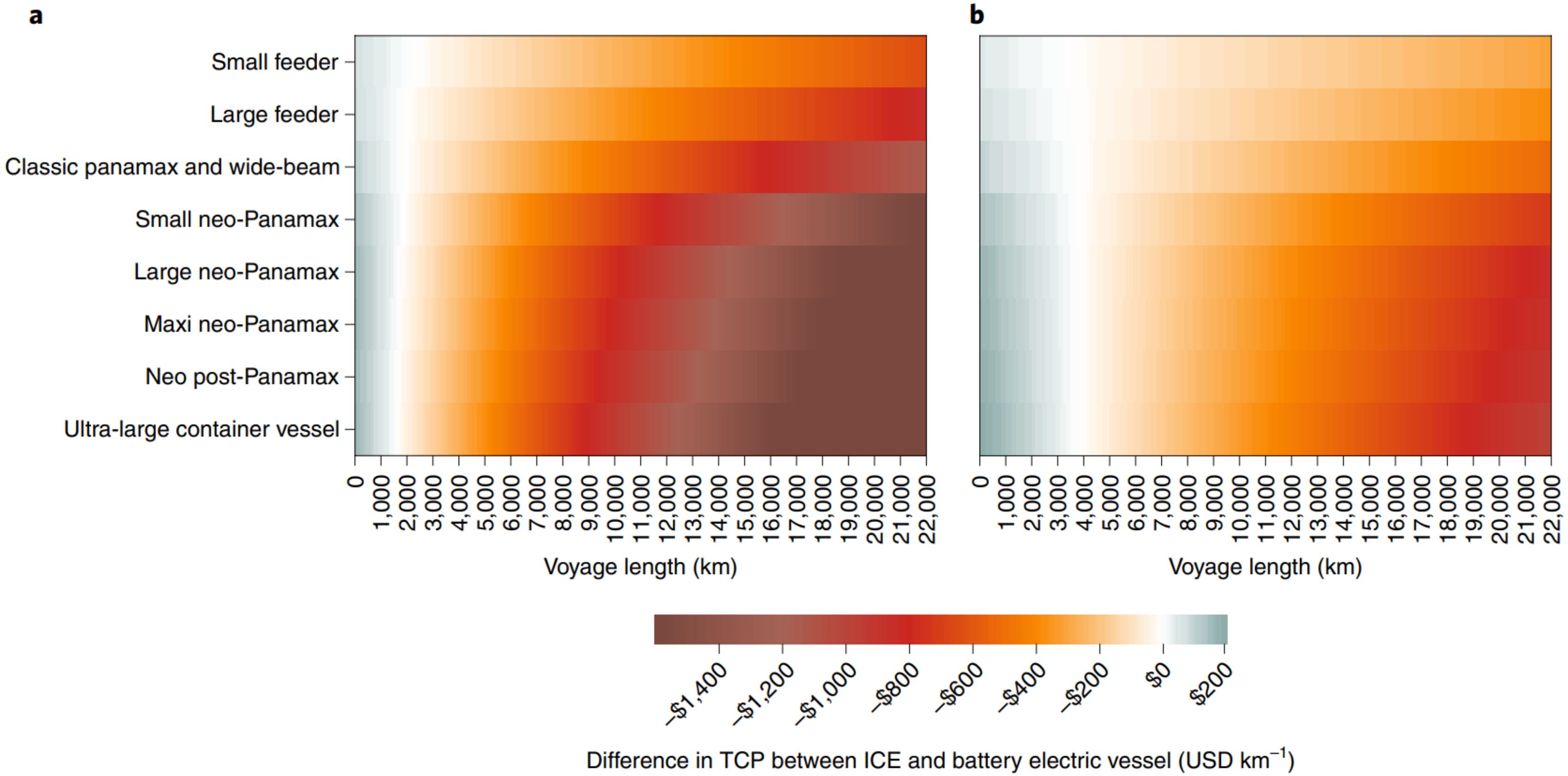
资料来源：《Rapid battery cost declines accelerate the prospects of all-electric interregional container shipping》，浙商证券研究所

我们的理解

下图描述了在不包括环境成本时，当前(a)和未来(b)情境下八种不同载货量的电动船和油船在0-22000km航程内的TCP，差值为正表示电动船具有成本优势。

当货船载重量增加、航程变长，电动船的成本劣势变得明显，表明在中短途区域内逐步使用电动航船存在一定的经济效益，而要实现大型远航船舶成本经济的电气化则存在挑战。

图：不同类型及不同航程下电动船和油船的成本差异

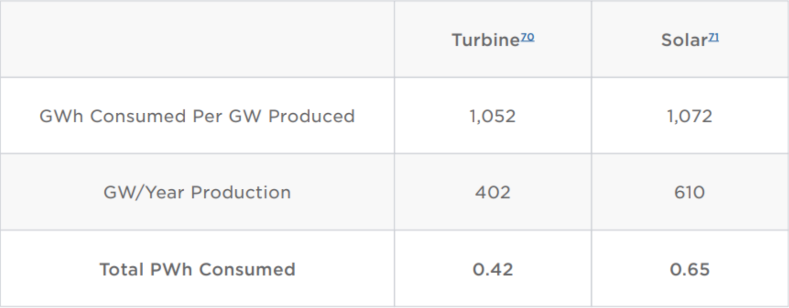


资料来源：《Rapid battery cost declines accelerate the prospects of all-electric interregional container shipping》，浙商证券研究所

原文: 6. Manufacture the Sustainable Energy Economy

Additional electricity is required to build the generation and storage portfolio - solar panels, wind turbines and batteries - required for the sustainable energy economy. This electricity demand was modeled as an incremental, inflexible, flat hourly demand in the industrial sector. More details can be found in the Appendix: Build the Sustainable Energy Economy - Energy Intensity.

Manufacturing the batteries, solar panels, and wind turbines in the sustainable energy economy itself requires 4PWh/year of sustainable power. To arrive at power demand, the energy intensity of manufacturing is estimated as shown in the figures below:



	Turbine[70]	Solar[71]
GWh Consumed Per GW Produced	1,052	1,072
GW/Year Production	402	610
Total PWh Consumed	**0.42**	**0.65**

Table 20: Annual Energy Intensity of Wind Turbine and Solar Panel Production

	High Ni[gg]	LFP[gg]	Ni/Mn Based[gg]	Thermal[72,ff]
GWh Consumed Per GW Produced	312	190	342	125
GW/Year Production	3,481	7,715	292	2,070
Total PWh Consumed	**1.09**	**1.47**	**0.10**	**0.26**

Table 21: Annual Energy Intensity of Battery Production

[ff] Energy intensity of graphite is used as a proxy for thermal batteries
[gg] Internal estimate

03 译文：6. 构建可持续能源经济

建立可持续能源经济所需的发电和储能组合(太阳能电池板、风力涡轮机和电池)需要额外的电力。这种电力需求被建模为工业部门不灵活、固定的增量小时需求。详情请参阅附录：建立可持续能源经济-能量密度。

在可持续能源经济中，制造电池、太阳能电池板和风力涡轮机本身需要4PWh/年的可持续电力。为了计算电力需求，制造业的能量密度估计如下图所示:

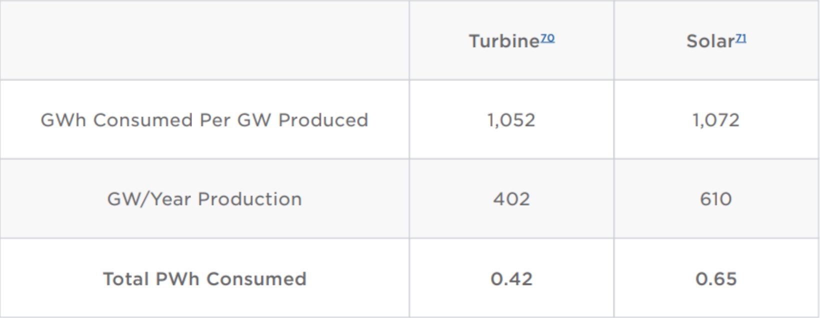


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Table 21: Annual Energy Intensity of Battery Production

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ff 热电池的能量密度以石墨作为参考
gg 内部估计

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

我们的理解

能源下游应用	采用的技术	消除化石燃料/PWh	可再生电力需求/PWh
电网	可再生能源供电	46	26
使用电动汽车	电池	28	7
住宅和商业建筑	热泵	18	6
工业热(<200C)	热泵	12	5
工业热(>200C)	储热系统	9	9
工业用氢	电解水制氢	8	7
飞机使用可持续燃料	绿氢+CO	7	7
船舶使用可持续燃料	电池		
构建可持续经济能源	发电-储能	/	4

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

04

对可持续能源经济建模

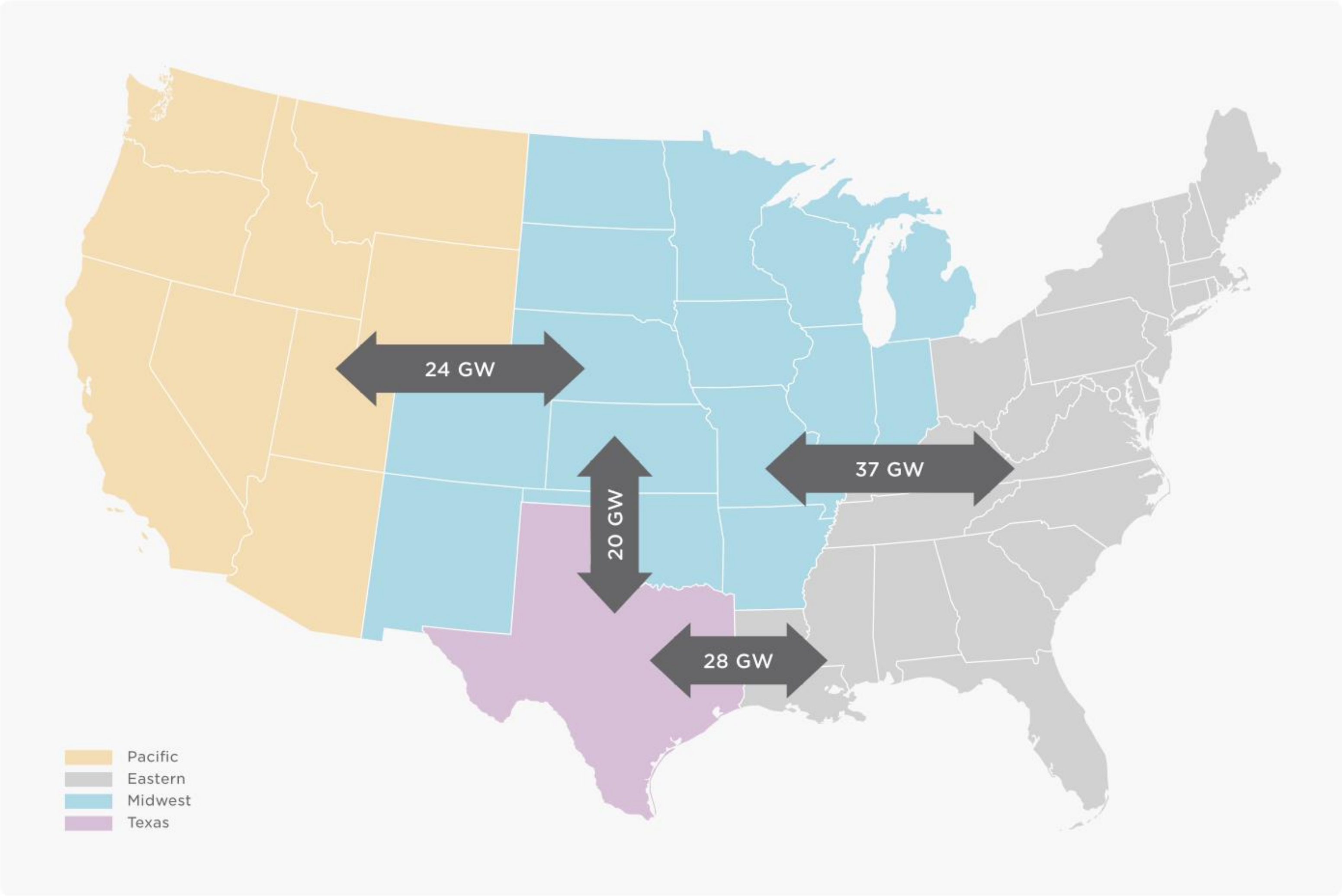
美国完全可持续能源经济模型

发电及储能技术评估

最佳的发电-储能组合

原文：Modeling the Fully Sustainable Energy Economy

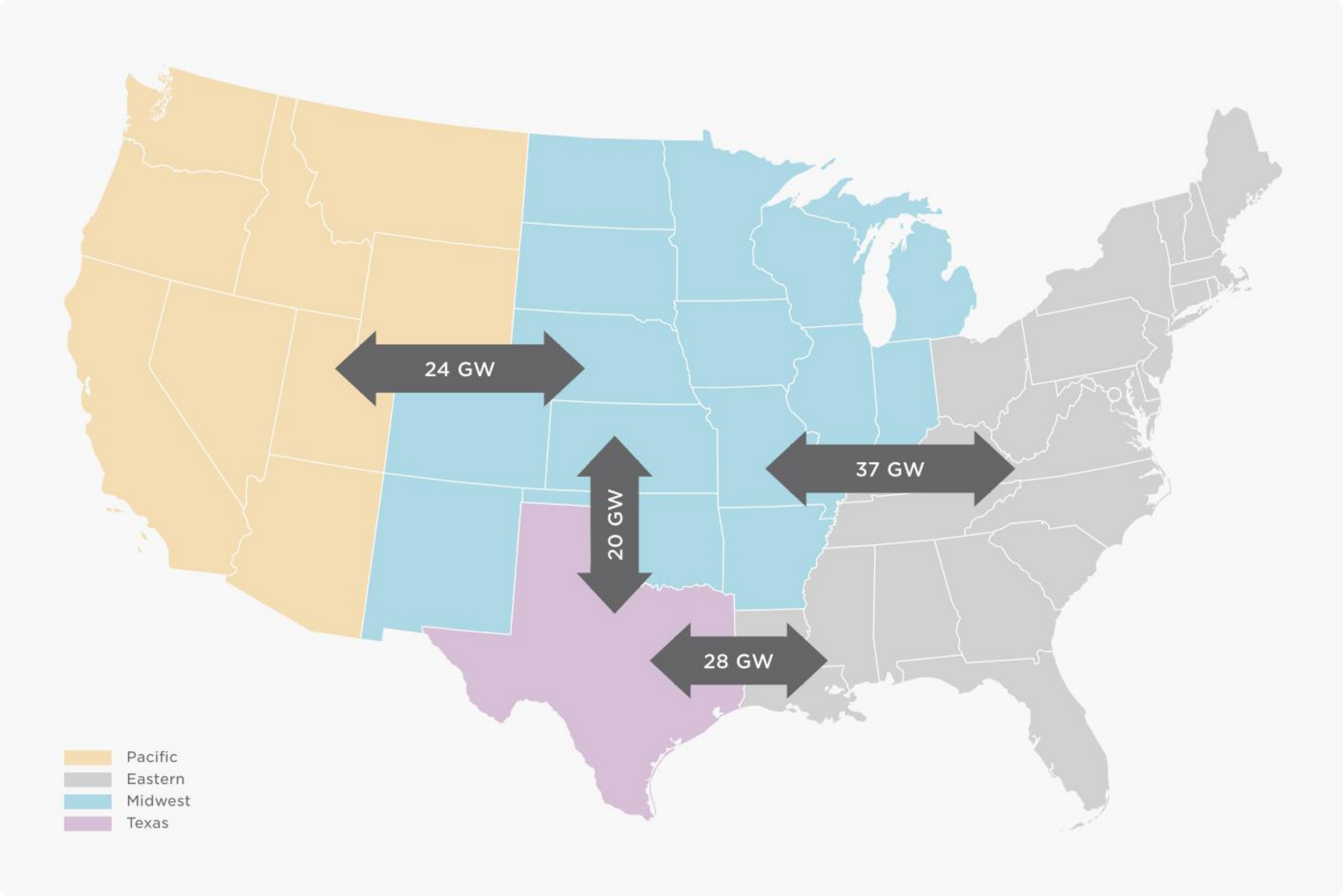
Modeled Regions and Grid Interconnections



Map 1: US Modeled Regions and Interconnections

译文：对完全可持续能源经济建模

建模中的各区域及电网



Map 1: US Modeled Regions and Interconnections

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

原文：Modeling the Fully Sustainable Energy Economy

These 6 steps create a U.S. electrical demand to be fulfilled with sustainable generation and storage. To do so, the generation and storage portfolio is established using an hourly cost-optimal integrated capacity expansion and dispatch model[j]. The model is split between four sub-regions of the US with transmission constraints modeled between regions and run over four weather-years (2019-2022) to capture a range of weather conditions[k]. Interregional transmission limits are estimated based on the current line capacity ratings on major transmission paths published by North American Electricity Reliability Council (NERC) Regional Entities (SERC[30], WECC[31], ERCOT[32]). Figure 11 shows the fully electrified economy energy demand for the full US.

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[j] Convex optimization models that can determine optimal capacity expansion and resource dispatch are widely used within the industry. For instance, by utilities or system operators to plan their systems (e.g., generation and grid investments required to meet their expected load), or to assess the impact of specific energy policies on the energy system. This model builds the least-cost generation and storage portfolio to meet demand every hour of the four-year period analyzed and dispatches that portfolio every hour to meet demand. The capacity expansion and dispatch decisions are optimized in one step, which ensures the portfolio is optimal over the period analyzed, storage value is fully reflected and the impact of weather variability modeled. Other analyses typically model capacity expansion and portfolio dispatch as two separate steps. The capacity expansion decisions are made first (e.g. how much generation and storage is estimated to be the least-cost portfolio over the time horizon), followed by separate dispatch modeling of the portfolio mix (e.g. how much generation and storage should be dispatched in each hour to meet demand with sufficient operating reserves). The two-stage approach produces pseudo-optimal results, but allows more computationally intensive models at each stage.

[k] The model is constrained to meet a 15% operating reserve margin every hour to ensure this generation and storage portfolio is robust to a range of weather and system conditions beyond those explicitely modeled.

译文：对完全可持续能源经济建模

通过这6个步骤创造了美国的电力需求，且可以通过可持续的发电和储能来满足。为此，采用每小时成本最优的集成容量扩张和调度模型建立发电和储能组合[j]。该模型分为美国的四个子区域，在不同区域之间建立传输约束模型，并在2019-2022年运行以捕捉一系列天气条件[k]。区域间输电限制是根据北美电力可靠性委员会(NERC)区域实体(SERC[30]，WECC[31]，ERCOT[32])公布的主要输电路径的当前线路容量额定值估计的。P75页的图显示了整个美国完全电气化经济的能源需求。

---

[j] 凸优化模型可以确定最优的容量扩张和资源分配，在业界得到了广泛的应用。例如，由公用事业公司或系统运营商来规划他们的系统(例如满足其预期负荷的发电和电网投资)，或评估特定能源政策对能源系统的影响。该模型建立了成本最低的发电和储能组合，以满足所分析的四年期间每小时的需求，并在每个小时调度该组合以满足需求。容量扩展和调度决策是一步优化的，这确保了在分析期间的投资组合是最优的，储能价值得到充分反映，并对天气变化的影响进行建模。其他分析通常将容量扩展和投资组合调度建模为两个独立的步骤。首先做出容量扩展决策(例如在一段时间内估计多少发电和储能是成本最低的投资组合)，然后对投资组合进行单独的调度建模(例如每小时应调度多少发电和储能以满足有充足运营储备的需求)。这种两步法将产生伪最优结果，但在每个阶段可以允许更多的计算密集型模型。

[k] 在已明确的建模条件之外，该模型必须满足每小时15%的运行储备余量，以确保发电和储能组合能够适应各种天气和系统条件。

原文：Modeling the Fully Sustainable Energy Economy

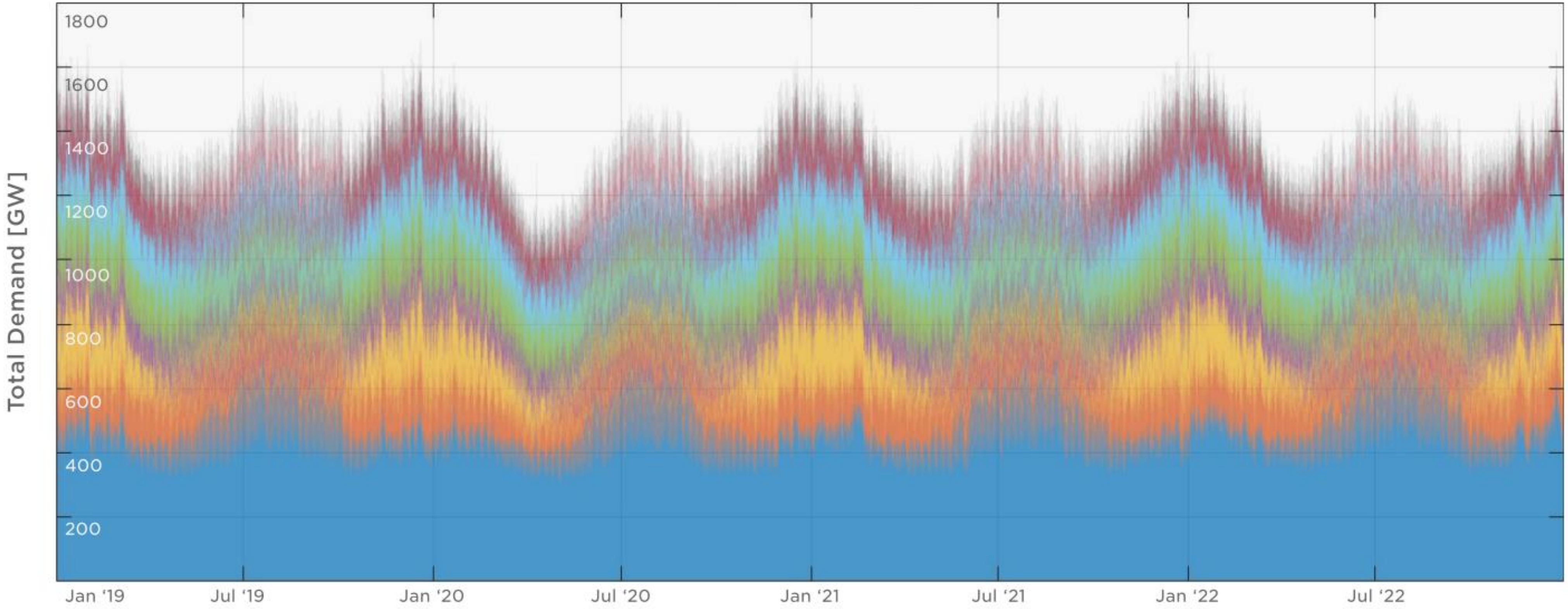


Figure 11: US Fully Electrified Hourly Demand

04 译文：对完全可持续能源经济建模

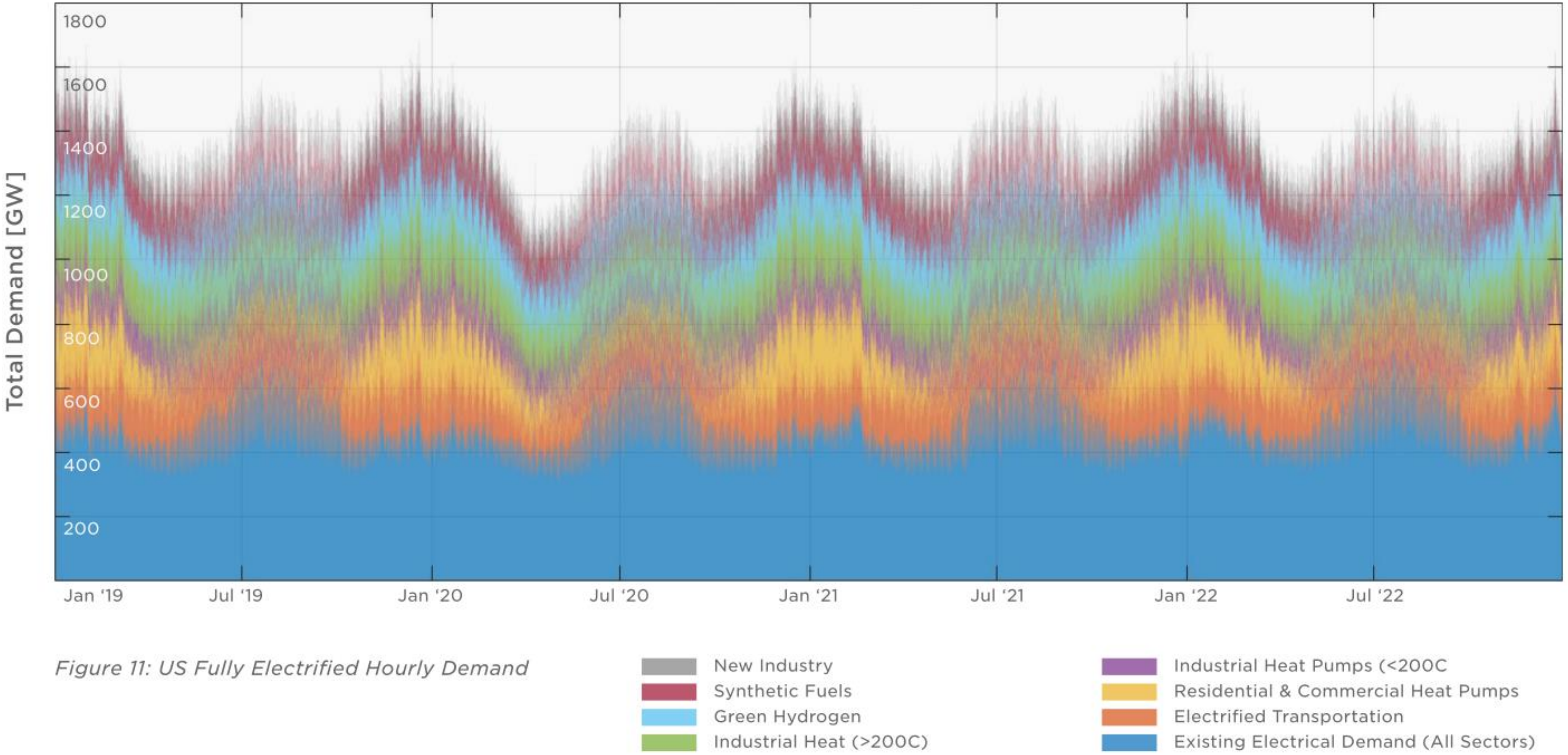


Figure 11: US Fully Electrified Hourly Demand

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

04 原文：Modeling the Fully Sustainable Energy Economy

Wind and solar resources for each region are modeled with their respective hourly capacity factor (i.e., how much electricity is produced hourly per MW of installed capacity), its interconnection cost and the maximum capacity available for the model to build. The wind and solar hourly capacity factors specific to each region were estimated using historical wind/solar generation taken from EIA in each region, thus capturing differences in resource potential due to regional weather patterns[l,m]. Capacity factors were scaled to represent forward looking trends based on the recent Princeton Net-Zero America study[33]. Figure 12 shows the hourly capacity factor for wind & solar versus time for the full US. Table 3 shows the average capacity factor and demand for each region of the US.

---

[l] EIA does not report offshore wind production for the period analyzed given the limited existing offshore wind installed capacity. The offshore wind generation profile was estimated by scaling the historical onshore wind generation profile to the offshore wind capacity factor estimated by the Princeton Net-Zero America study.

[m] Each region is modeled with two onshore wind and two solar resources with different capacity factor, interconnection cost and maximum potential. This accounts for the fact that the most economic sites are typically built first and subsequent projects typically have lower capacity factors and/or higher interconnection cost as they may be farther located from demand centers requiring more transmission or in locations with higher cost land.

04 译文：对完全可持续能源经济建模

每个地区的风能和太阳能资源是根据各自的小时容量系数(即每兆瓦装机容量每小时产生多少电力)、电网互连成本和模型可构建的最大容量进行建模。利用EIA发布的历史风能/太阳能发电量估计了每个地区特有的风能和太阳能小时发电量系数，从而捕捉到了由于区域天气模式造成的资源潜力差异[l,m]。根据普林斯顿大学最近的美国净零排放研究[33]，对产能因素进行了缩放，以预测未来趋势。P79页的图显示了整个美国风能和太阳能的小时容量系数与时间的关系，P79页的表列出了美国每个地区的平均容量系数和需求。

---

[l] 鉴于现有海上风电装机容量有限，EIA没有报告所分析期间的海上风电产量。通过将历史陆上风力发电剖面与普林斯顿净零美国研究估计的海上风电容量因子进行换算，估算出海上风力发电曲线。

[m] 每个区域都用两种不同容量系数、电网互连成本和最大容量潜力的陆上风能和太阳能资源建模。这解释了这样一个事实，即最经济的站点通常是首先建造的，而随后的项目可能因为位于离需要更多输电需求中心更远的地方或土地成本更高的地方而通常具有较低的容量系数和较高的互连成本。

04 原文：Modeling the Fully Sustainable Energy Economy

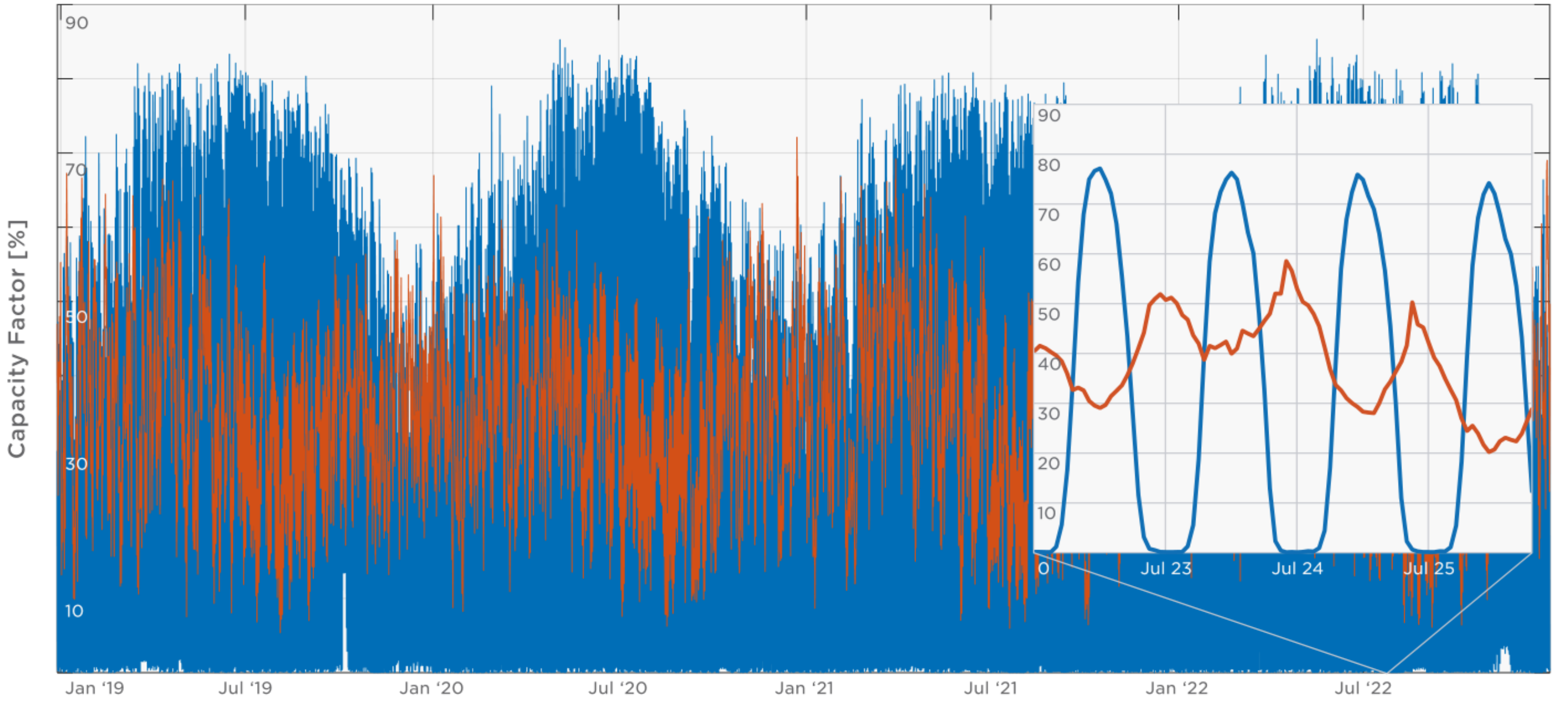


Figure 12: US Historical Hourly Renewable Capacity Factor

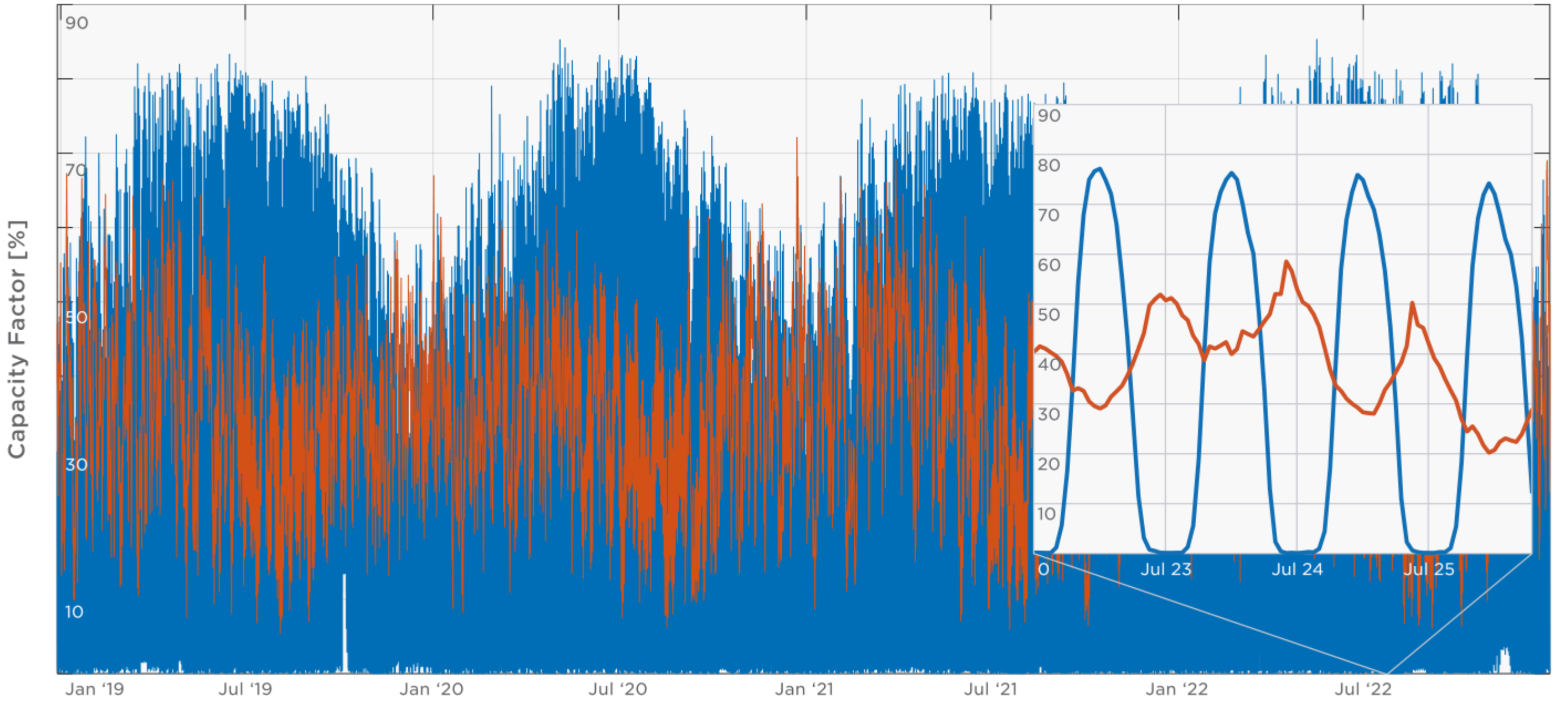
Solar Resources 🟦 Wind Resources 🟧

Region	Wind CF	Solar CF	Demand [PWh/yr]
East	29%	22%	4.6
Midwest	40%	27%	3.6
Pacific	36%	27%	1.9
Texas	37%	23%	1.6
Full U.S.	34%	24%	11.6

Table 3: Wind and solar average historical capacity factor, and fully electrified economy demand by region

04

译文：对完全可持续能源经济建模



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Texas	37%	23%	1.6
Full U.S.	34%	24%	11.6

Table 3: Wind and solar average historical capacity factor, and fully electrified economy demand by region

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

原文：Modeling the Fully Sustainable Energy Economy

The model builds generation and storage based on resource-specific cost and performance attributes, and a global objective of minimizing the levelized cost of energy[n]. The model assumes increased inter-regional transmission capacities[o].

To provide reliable year-round power, it is economically optimal to deploy excess solar and wind capacity, which leads to curtailment. Curtailment will happen when (1) solar and/or wind generation is higher than the electricity demand in a region, (2) storage is full and (3) there is no available transmission capacity to transmit the excess generation to other regions. There is an economic tradeoff between building excess renewable generation capacity, building grid storage, or expanding transmission capability. That tradeoff may evolve as grid storage technologies mature, but with the assumptions modeled, the optimal generation and storage portfolio resulted in 32% curtailment.

---

[n] Costs considered in the objective function: levelized capex of new generation and storage with a 5% discount rate, fixed and variable operational and maintenance (O&M) costs.

[o] 37 GW of transmission capacity is modeled between the Midwest and the East, 28 GW between T exas and the East, 24 GW between Pacific and the Midwest and 20 GW between T exas and the Midwest. This corresponds to ~3% of the modeled combined regional peak load. E.g., the peak load of the combined East and Midwest regions was ~1.2 TW , and the transmission capacity between Midwest and the East modeled as 37 GW . Currently, the transmission capacity is <1% of the combined regional peak loads (with transmission to/from T exas the lowest). Higher transmission capacities generally reduce the total generation and storage buildout, but there is an economic tradeoff between building more transmission and building more generation plus storage.

04 译文：对完全可持续能源经济建模

该模型基于特定资源的成本、性能属性以及最小化能源平均成本的全球目标来构建发电和储能组合[n]。该模型假定了区域间输电能力也会增加[o]。

为了提供可靠的全年电力，部署过剩的太阳能和风能是经济上最优的，但这也导致了弃电现象：(1)当太阳能和/或风能发电量高于一个地区的电力需求，(2)达到储能容量最大值，(3)没有可用的输电能力将多余的发电量传输到其他地区时。在建设过剩的可再生能源发电能力、电网储能或扩大输电能力之间存在经济权衡。随着电网储能技术的成熟，这种权衡可能会发生变化，但根据建模的假设，最佳发电和存储组合将导致32%的弃电。

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[n] 目标函数中考虑的成本：以5%的贴现率平衡新一代和存储的资本支出，固定和可变的运营和维护成本。

[o] 中西部和东部之间的输电容量为37GW，德克萨斯州和东部之间的输电容量为28GW，太平洋和中西部之间的输电容量为24GW，德克萨斯州和中西部之间的输电容量为20GW，各区域输电容量量相当于模型综合区域峰值负荷的~3%。例如，东部和中西部合并地区的峰值负荷为~1.2 TW，中西部和东部之间的输电容量为37GW。目前，输电容量小于区域峰值负荷总和的1%(其中德克萨斯州的输电量最低)。更高的输电容量通常会减少总发电量和储能的建设，但在建设更多的输电和建设更多的发电加储能之间存在经济权衡。

04 原文：Modeling the Fully Sustainable Energy Economy

For context, curtailment already exists in markets with high renewable energy penetration. In 2020, 19% of the wind generation in Scotland was curtailed, and in 2022, 6% of solar generation in California (CAISO) was curtailed due to operational constraints, such as thermal generators’ inability to ramp down below their minimum operating level, or local congestion on the transmission system[34,35].

The sustainable energy economy will have an abundance of inexpensive energy for consumers able to use it during periods of excess, which will impact how and when energy is used.

In Figure 12 below, hourly dispatch is depicted across a sample of fall days, showing the role of each generation and storage resource in balancing supply and demand, as well as the concentration of economic curtailment in the middle of the day when solar is abundant.

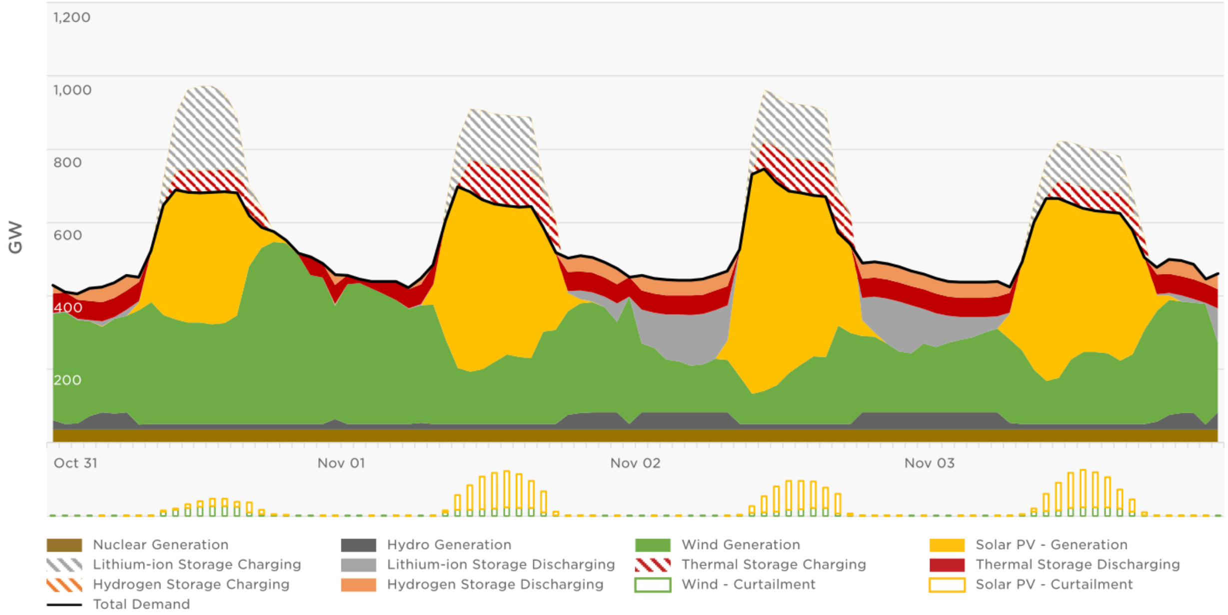


Figure 13: Hourly generation in 2019 in US Eastern region (excluding imports/exports)

04 译文：对完全可持续能源经济建模

在可再生能源普及率高的市场，弃电现象已经存在。2020年，苏格兰19%的风力发电量被弃，2022年，加州(CAISO)由于运行限制的原因如火力发电机无法降至最低运行水平以下，或者输电系统的局部拥堵，导致6%的太阳能发电量被弃[34,35]。

可持续能源经济将为消费者在能源过剩时提供丰富的廉价能源，这将会影响能源的使用方式和时间。

下图展示了秋季的每小时调度情况，显示了每一发电和储能资源在平衡供需方面的作用，以及在太阳能充足的正午存在集中的经济性缩减现象。

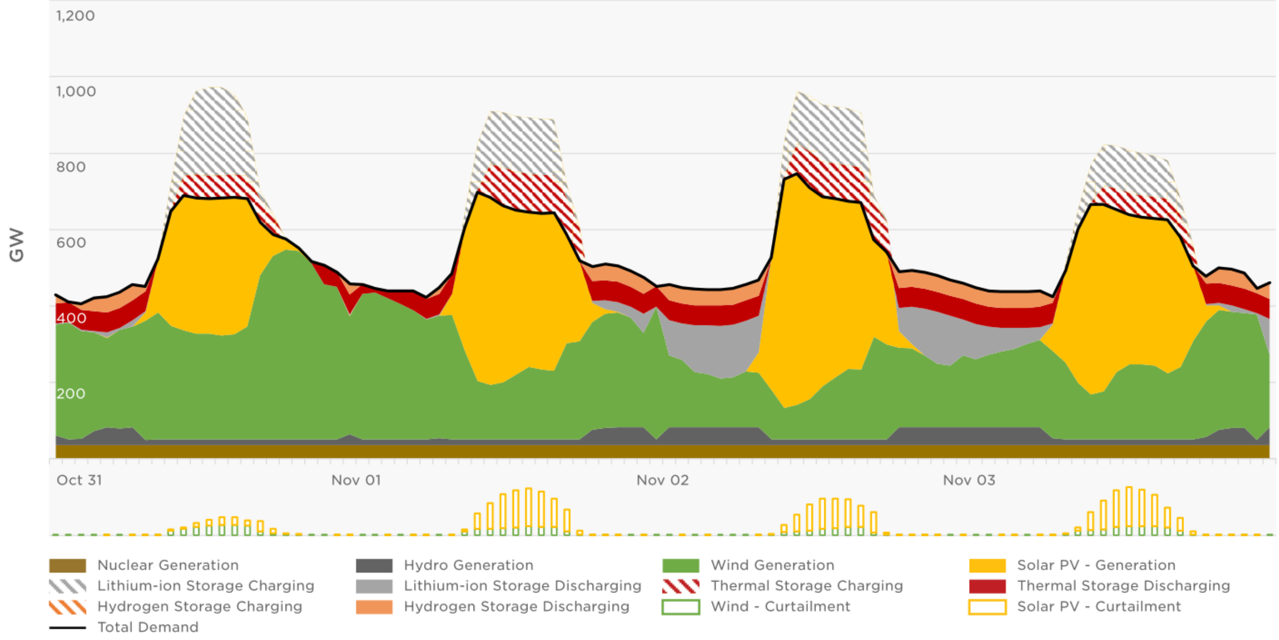


Figure 13: Hourly generation in 2019 in US Eastern region (excluding imports/exports)

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

原文：Modeling the Fully Sustainable Energy Economy

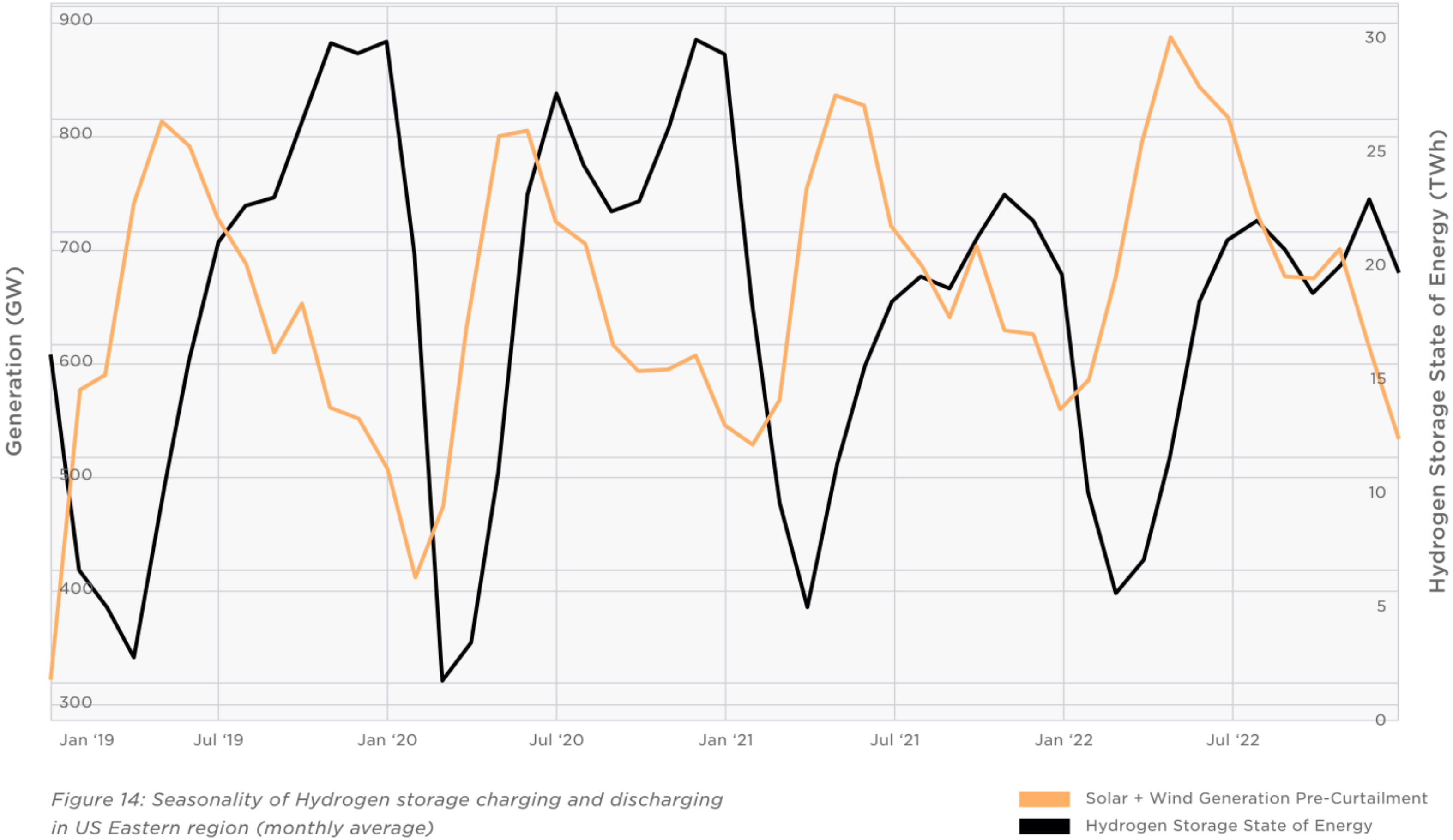


Figure 14: Seasonality of Hydrogen storage charging and discharging in US Eastern region (monthly average)

In Figure 14, hydrogen storage is generally filled during the shoulder months (spring and fall) when electricity demand is lower as heating and cooling seasons are over, and solar and wind generation is relatively high. Similarly, as excess generation declines in summer and winter months, hydrogen reservoirs decline providing inter-seasonal hydrogen storage.

04 译文：对完全可持续能源经济建模

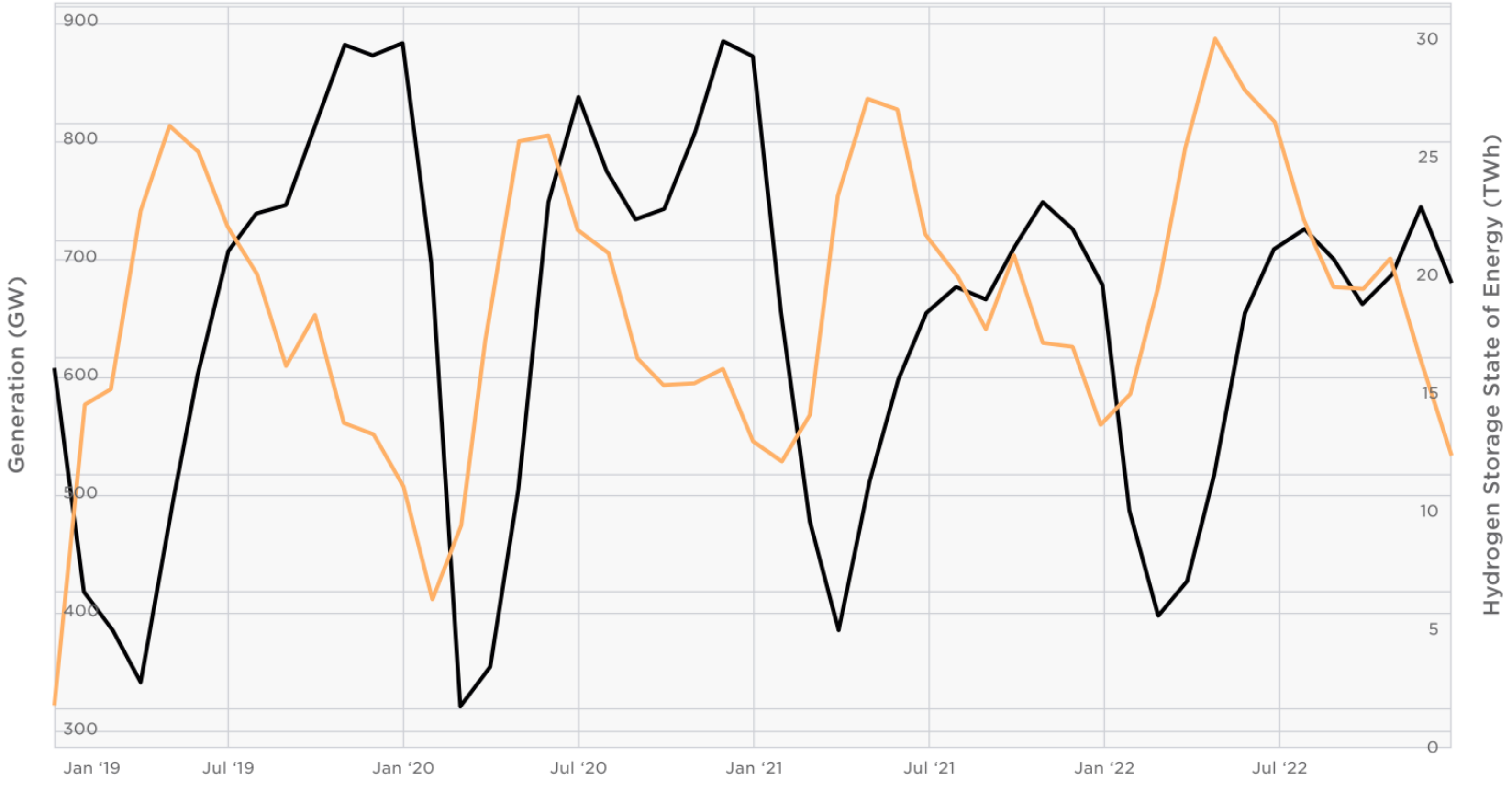


Figure 14: Seasonality of Hydrogen storage charging and discharging in US Eastern region (monthly average)

🟧 Solar + Wind Generation Pre-Curtailment
⬛ Hydrogen Storage State of Energy

在上图中，储氢通常在肩部月份（春季和秋季）进行，此时随着供暖和制冷季节的结束，电力需求较低，太阳能和风能发电量相对较高。同样，随着夏季和冬季过剩发电量的下降，跨季节储氢量也在减少。

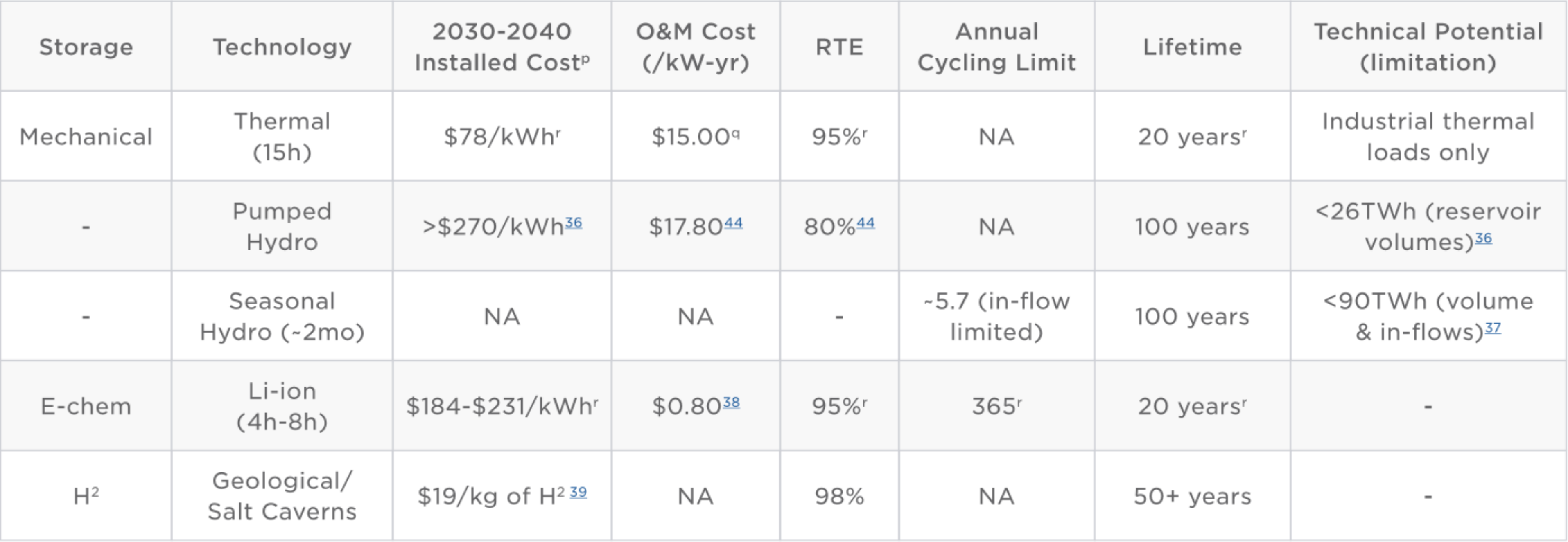
资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

04

原文：Energy Storage Technologies Evaluated

浙商证券股份有限公司
ZHESHANG SECURITIES CO.LTD

For stationary applications, the energy storage technologies in Table 4 below, which are currently deployed at scale, are considered. Li-ion means $LiFePO_4$/Graphite lithium-ion batteries. A range of conservative future installed costs are listed for lithium ion given the volatility in commodities prices (especially lithium). While there are other emerging technologies such as metal-air (Fe <-> Fe_2O_3 redox couple) and Na-ion, these are not commercially deployed and therefore not considered.



Storage	Technology	2030-2040 Installed Cost[p]	O&M Cost (/kW-yr)	RTE	Annual Cycling Limit	Lifetime	Technical Potential (limitation)
Mechanical	Thermal (15h)	$78/kWh[r]	$15.00[q]	95%[r]	NA	20 years[r]	Industrial thermal loads only
-	Pumped Hydro	>$270/kWh[36]	$17.80[44]	80%[44]	NA	100 years	<26TWh (reservoir volumes)[36]
-	Seasonal Hydro (~2mo)	NA	NA	-	~5.7 (in-flow limited)	100 years	<90TWh (volume & in-flows)[37]
E-chem	Li-ion (4h-8h)	$184-$231/kWh[r]	$0.80[38]	95%[r]	365[r]	20 years[r]	-
H^2	Geological/ Salt Caverns	$19/kg of H^2 [39]	NA	98%	NA	50+ years	-

Table 4: Energy Storage Technologies Evaluated

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p This includes the storage equipment cost, balance of system, interconnection and installation cost.

q Efficiency for the electricity to thermal conversion. The model does not include generating electricity from heat.

r Internal estimate.

04 译文：储能技术评估

对于固定应用，下表中考虑了目前大规模部署的储能技术。Li-ion是指$LiFePO_4$/石墨锂离子电池。考虑到大宗商品价格(尤其是锂)的波动，本文列出了未来锂离子电池的保守安装成本范围。虽然当前还有其他新兴技术，如金属-空气电池(Fe <-> Fe_2O_3氧化还原对)和钠离子电池，但这些技术尚未商业化部署，因此不予考虑。

Storage	Technology	2030-2040 Installed Cost[p]	O&M Cost (/kW-yr)	RTE	Annual Cycling Limit	Lifetime	Technical Potential (limitation)
Mechanical	Thermal (15h)	$78/kWh[r]	$15.00[q]	95%[r]	NA	20 years[r]	Industrial thermal loads only
-	Pumped Hydro	>$270/kWh[36]	$17.80[44]	80%[44]	NA	100 years	<26TWh (reservoir volumes)[36]
-	Seasonal Hydro (~2mo)	NA	NA	-	~5.7 (in-flow limited)	100 years	<90TWh (volume & in-flows)[37]
E-chem	Li-ion (4h-8h)	$184-$231/kWh[r]	$0.80[38]	95%[r]	365[r]	20 years[r]	-
H^2	Geological/ Salt Caverns	$19/kg of H^2 [39]	NA	98%	NA	50+ years	-

Table 4: Energy Storage Technologies Evaluated

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p 这包括存储设备成本、系统平衡成本、互连成本和安装成本。
q 电能到热能转换的效率。该模型不包括利用热能发电。
r 内部估计。

我们的理解

储能种类	技术	2030-2040安装成本	运维成本(元/kW-年)	系统循环效率	年循环次数	使用寿命	技术局限
机械储能	热储能 (储能时长15h)	\$78/kWh	\$15.00	95%	/	20年	仅限于工业热负荷
	抽水蓄能	>\$270/kWh	\$17.80	80%	/	100年	<26TWh (水库体积有限)
	季节性水力发电 (储能时长约2个月)	/	/	/	~5.7 (受水流限制)	100年	<90TWh (水库体积&水流限制)
电化学储能	锂离子电池 (储能时长4-8h)	\$184-231/kWh	\$0.80	95%	365	20年	/
氢能	地质/盐穴储氢	\$19/kg of H_2	/	98%	/	50+年	/

综合5种储能技术，机械储能在技术上存在局限，而氢能在制氢、储氢及运氢等环节均需要取得突破，技术成熟度有待进一步提高，因此技术成熟度高、应用场景广泛的锂离子电池储能技术为当前储能的最优解。

04

原文：Generation Technologies Evaluated

The Table below details all the generation technologies considered in the sustainable energy economy. Installed costs were taken from studies for 2030-2040 from NREL and the Princeton Net-Zero America study.

Generation	2030-2040 Installed Cost	O&M Cost (/kW-yr)	Capacity Factor	Lifetime	Model Constraint	US Technical Potential (limitation)
Solar	\$752/kW[44] + interconnection[40]	\$15.97[41]	23-28%[40]	30 years[44]	Technical potential per region/resource class[40]	<153 TW (available land)[42]
Onshore Wind	\$855/kW[44] + interconnection[40]	\$27.57[41]	36-52%[40]	30 years[s]	Technical potential per region/resource class[40]	<11 TW (available land)[42]
Offshore Wind	\$2,401/kW[44] + interconnection[40]	\$76.51[44]	48-49%[40]	30 years[s]	Technical potential per region/resource class[40] Technology only available in East region	<1 TW[43,45]
Hydro	\$4,200/kW[44] to \$7,000/kW	\$61.41[44]	NA	100 years	152 GW Exogenously Built	<152 GW (river flow rates)[46]
Nuclear	\$10,500/kW[t]	\$127.35[41]	Modeling Output	<80 years	No New Nuclear	NA (deployment pace)
Geothermal	\$5,616/kW[44]	\$99.32[44]	>95%[47]	30 years[44]	No New Build	<100 GW[u]

Table 5: Generation Technologies Evaluated

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r Internal estimate.

s Assumed lifetime improvement. The NREL 2019 Cost of Wind Energy Review estimates wind cost with 25-year lifetime as reference and creates sensitivities with 30-year lifetime

t Assumed 50% higher capex than the EIA Cost and Performance Characteristics of New Generating Technologies

u Excluding Deep Enhanced Geothermal System Resources

04

译文：发电技术评估

下表详细介绍了可持续能源经济中考虑的所有发电技术。安装成本来自NREL对2030-2040的研究和普林斯顿净零美国研究。

Generation	2030-2040 Installed Cost	O&M Cost (/kW-yr)	Capacity Factor	Lifetime	Model Constraint	US Technical Potential (limitation)
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Geothermal	$5,616/kW[44]	$99.32[44]	>95%[47]	30 years[44]	No New Build	<100 GW[u]

Table 5: Generation Technologies Evaluated

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r 内部评估

s 假设寿命改善。NREL以25年的使用寿命为参考估计了风能成本，并创造了30年使用寿命的敏感度。

t 假设资本支出比EIA发布的《新发电技术的成本及性能》高50%。

u 不包括深层强化地热系统资源。

我们的理解

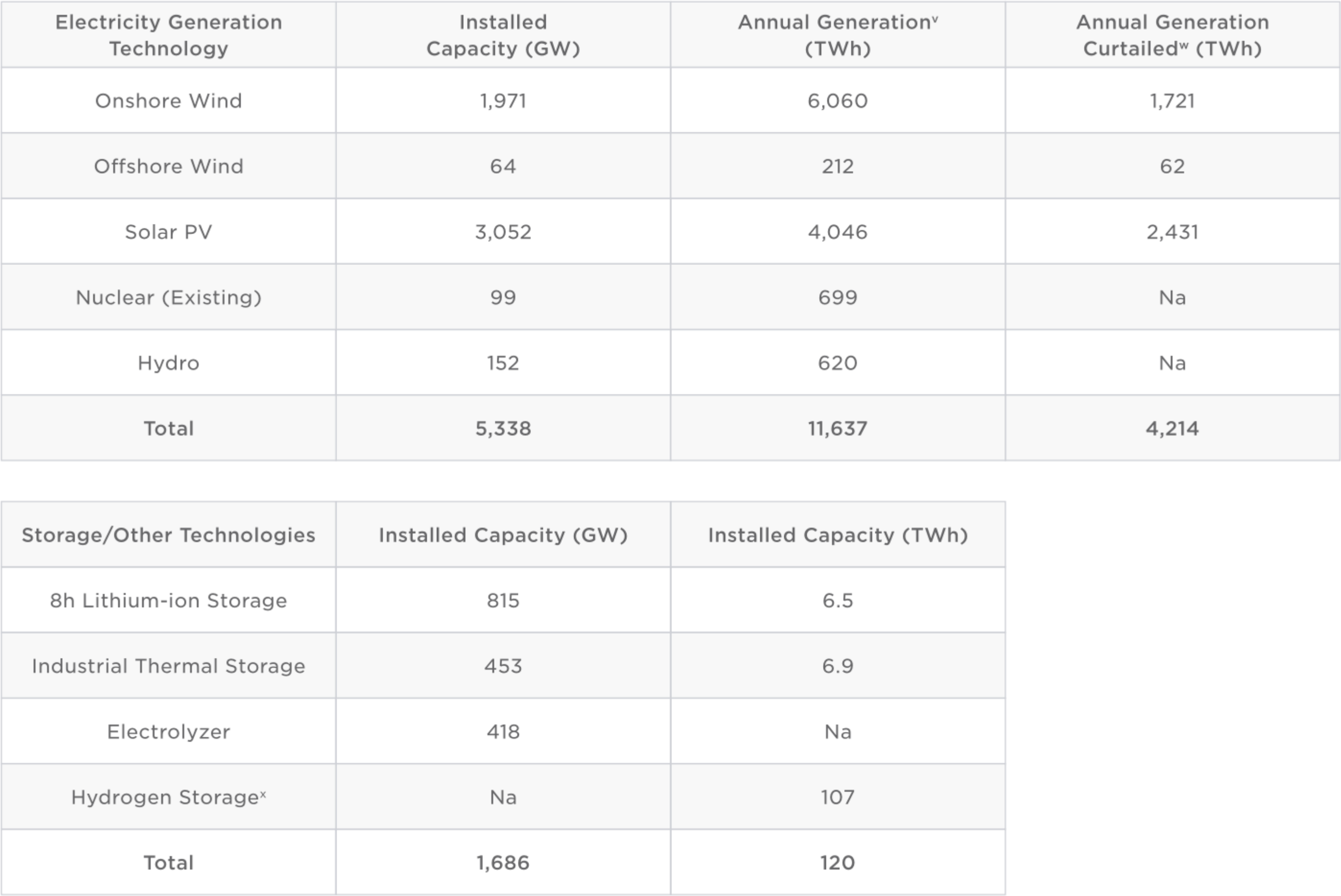
发电技术	2030-2040 安装成本	运维成本 (元/kW-年)	容量系数	使用寿命	模型约束	美国的技术限制
太阳能	$752/kW+ 电网互联成本	$15.97	23-28%	30年	每个地区/可用资源种类的技术潜力	<153TW (可用土地范围内)
陆地风能	$855/kW+ 电网互联成本	$27.57	36-52%	30年	每个地区/可用资源种类的技术潜力	<11TW (可用土地范围内)
海上风能	$2401/kW+ 电网互联成本	$76.51	48-49%	30年	每个地区/可用资源种类的技术潜力；仅在东部地区可用	<1TW
水力发电	$4200/kW~ $7000/kW	$61.41	NA	100年	额外建造152GW	<152GW (受河流流速限制)
核能	$10500/kW	$127.35	模型输出	<80年	无新建核能	受部署速度限制
地热能	$5616/kW	$99.32	>95%	30年	无新建部分	<100GW

综合6种发电技术，太阳能发电具有成本优势，且在美国可用土地范围内能达到的安装功率上限相对较高。

注：容量因子即年实际发电量/额定发电量

原文：US Only Model Results – Meeting New Electrification Demand

For the US, the optimal generation and storage portfolio to meet the electricity demand, each hour, for the years modeled is shown in the Table below.



Electricity Generation Technology	Installed Capacity (GW)	Annual Generation[v] (TWh)	Annual Generation Curtailed[w] (TWh)
Onshore Wind	1,971	6,060	1,721
Offshore Wind	64	212	62
Solar PV	3,052	4,046	2,431
Nuclear (Existing)	99	699	Na
Hydro	152	620	Na
Total	**5,338**	**11,637**	**4,214**

Storage/Other Technologies	Installed Capacity (GW)	Installed Capacity (TWh)
8h Lithium-ion Storage	815	6.5
Industrial Thermal Storage	453	6.9
Electrolyzer	418	Na
Hydrogen Storage[x]	Na	107
Total	**1,686**	**120**

Table 6: Model Results for US only

---

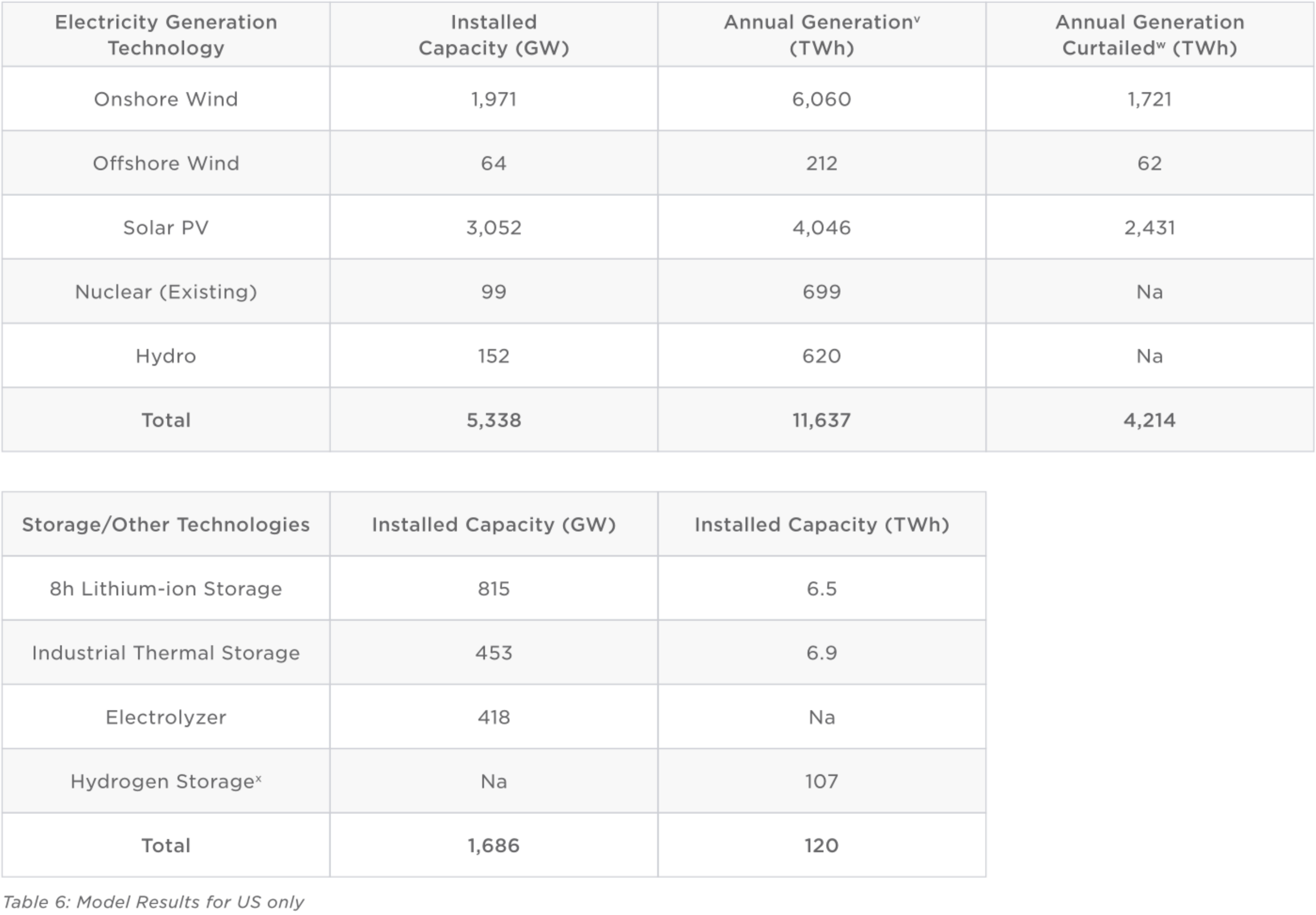
v After accounting for curtailment.

w The model curtails wind/solar generation when the electricity supply is higher than the electricity demand and battery/thermal/hydrogen storage are full already. Curtailed wind/solar generation is generation that isn't consumed by end-uses.

x 17.8 TWh of jet fuel derived from H2 are stored with current infrastructure

04 译文：仅包含美国的模型结果-满足新的电气化需求

对于美国来说，模拟年份中满足每小时电力需求的最佳发电和储能组合如下表所示。



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Hydrogen Storage[x]	Na	107
Total	**1,686**	**120**

Table 6: Model Results for US only

---

v 在考虑削减后。
w 当电力供应高于电力需求并且电池/热/氢存储已经满时，该模型会减少风能/太阳能发电。减少的风能/太阳能发电是指不被终端用户消耗的发电。
x 17.8 TWh的H_2喷气燃料使用现有基础设施储存。

原文：Model Results

In addition, 1.2 TWh of distributed stationary batteries are added based on incremental deployments of distributed stationary storage alongside rooftop solar at residential and commercial buildings. This includes storage deployments at 15 million single-family homes48 with rooftop solar, industrial storage paired with 43GW[49,50] of commercial rooftop solar, and storage replacement of at least 200GW[51] of existing backup generator capacityy. Distributed storage deployments are exogenous to the model outputs given deployment driven by factors not fully reflected in a least-cost model framework, including end-user resiliency and self-sufficiency when storage is paired with rooftop solar.

---

y Solar and storage is deployed at less than one-third of suitable residential buildings designated by NREL. Four hours of storage is assumed for C&I deployment and for backup generator substitution.

译文：模型结果

此外，基于未来将增加住宅和商业建筑屋顶分布式太阳能储能系统的部署，增加了1.2 TWh的分布式固定电池，包括了在1500万户带屋顶太阳能的单户家庭中部署储能、与43GW[49,50]商用屋顶太阳能配对的工业储能，以及替换至少200GW[51]现有的备用发电机容量。分布式储能部署是模型输出的外生因素，因为能源部署并非完全由最低成本模型框架中的因素驱动，如与屋顶太阳能发电配对时，对储能的部署需考虑终端用户使用能源的弹性和自给自足。

---

y 在NREL指定的合适住宅建筑中，只有不到三分之一部署了太阳能和储能系统。假定用于C&I部署和备用发电机替换的存储时间为4小时。

04

原文：World Model Results – Meeting New Electrification Demand

Applying the 6 steps to the world’s energy flow would displace all 125PWh/year of fossil fuels used for energy use and replace them with 66PWh/year of sustainably generated electricity[z]. An additional 4PWh/year of new industry is needed to manufacture the required batteries, solar panels and wind turbines (assumptions can be found in ***Appendix: Build the Sustainable Energy Economy – Energy Intensity***).

The global generation and storage portfolio to meet the electricity demand was calculated by scaling the US resource mix by 6x. As noted above, this is a significant simplification and could be an area for improvement in future analyses, as global energy demands are different from the U.S. in their composition and expected to increase over time. This analysis was conducted on the U.S. due to availability of high-fidelity hourly data.

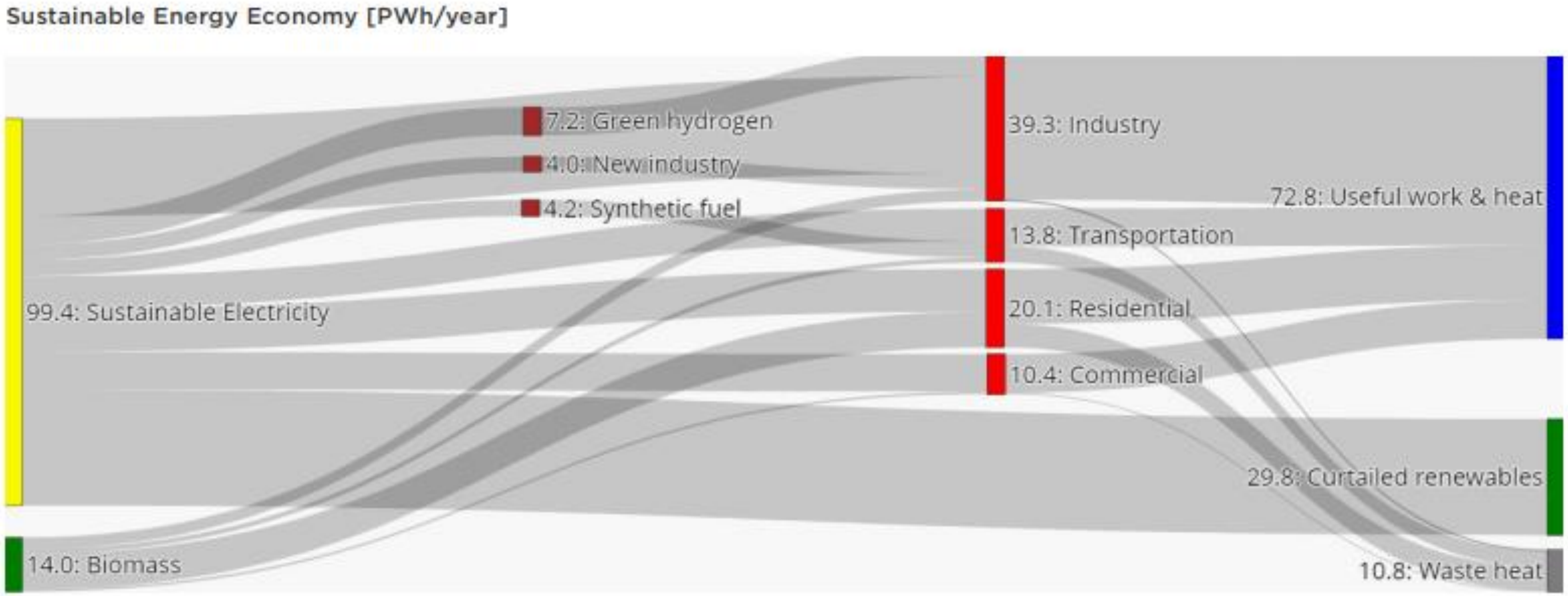

Figure 15: Sustainable Energy Economy, Global Energy Flow by Sector, IEA & Tesla analysis

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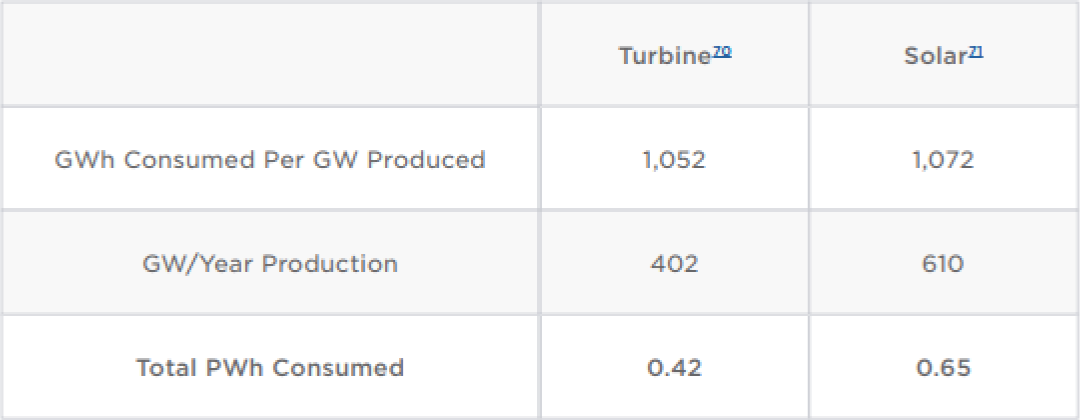
[z] Remaining ~9PWh/year of fossil fuels are consumed through non-energy uses

04

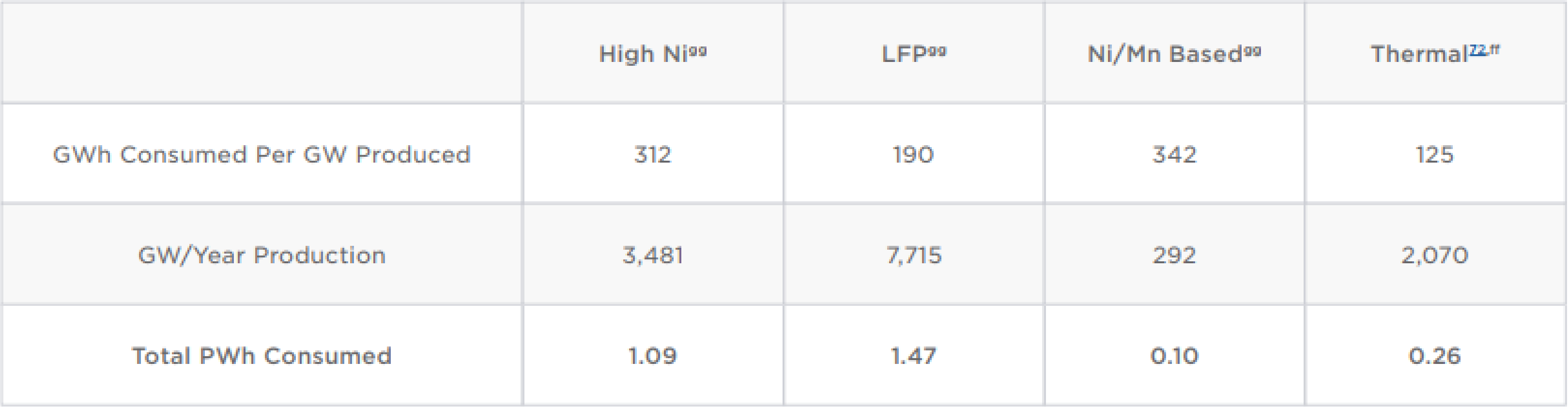
原文：Appendix: Energy Intensity

Manufacturing the batteries, solar panels, and wind turbines in the sustainable energy economy itself requires 4PWh/year of sustainable power. To arrive at power demand, the energy intensity of manufacturing is estimated as shown in the figures below:



	Turbine[70]	Solar[71]
GWh Consumed Per GW Produced	1,052	1,072
GW/Year Production	402	610
Total PWh Consumed	0.42	0.65

Table 20: Annual Energy Intensity of Wind Turbine and Solar Panel Production



	High Ni[gg]	LFP[gg]	Ni/Mn Based[gg]	Thermal[72,ff]
GWh Consumed Per GW Produced	312	190	342	125
GW/Year Production	3,481	7,715	292	2,070
Total PWh Consumed	1.09	1.47	0.10	0.26

Table 21: Annual Energy Intensity of Battery Production

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ff Energy intensity of graphite is used as a proxy for thermal batteries
gg Internal estimate

04 译文：世界模型结果——满足新的电气化需求

- □ 采用上文所述6个步骤，将用 **66PWh/年**的可再生能源发电取代**125PWh/年**的化石能源发电；
- □ 每年因此需额外增加**4PWh**的新产业用于制造电池、太阳能电池板和风力涡轮机；
- □ 仍保留原化石燃料消耗结构中非能源用途消耗：大约**9PWh/年**；
- □ 全球的发电与存储组合是通过将美国的资源组合扩大**6倍**进行计算。

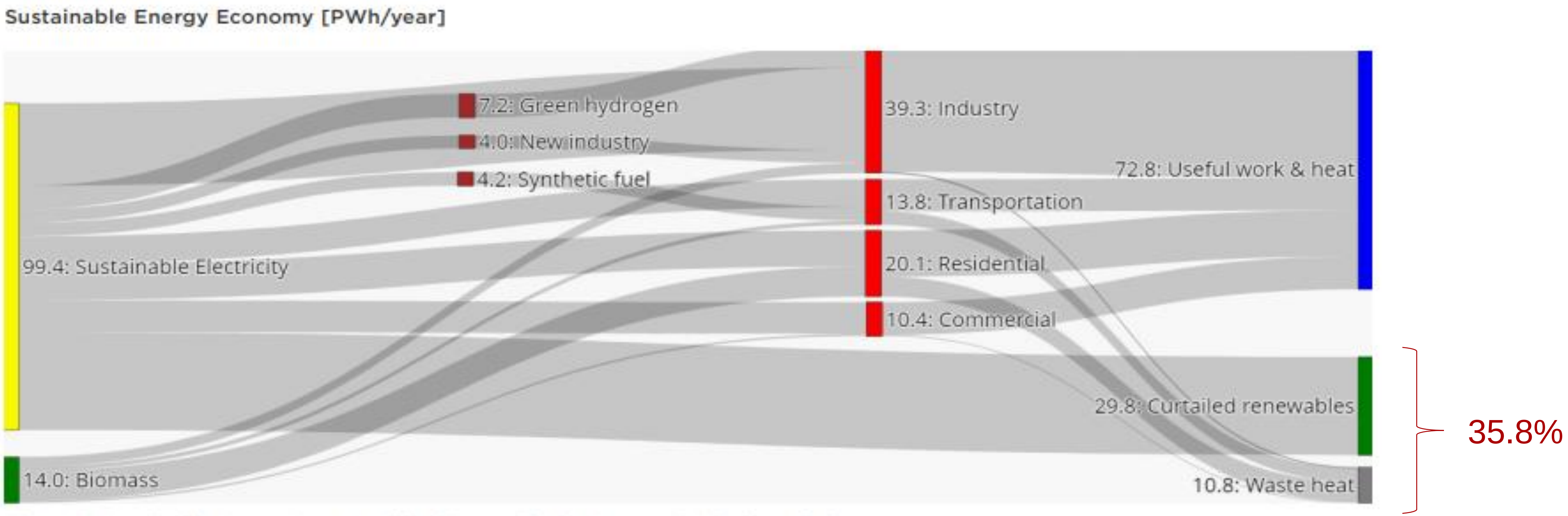


Figure 15: Sustainable Energy Economy, Global Energy Flow by Sector, IEA & Tesla analysis

资料来源： Tesla-《Master Plan Part 3》，浙商证券研究所

04 译文：附录—能量密度

风电&光伏年耗能数据

	风电涡轮机	太阳能面板
耗能密度GWh/GW	1052	1072
装机容量GW/年	402	610
总耗能（PWh）	0.42	0.65

电池年耗能数据

	高镍	LFP	Ni/Mn电池	热电池
耗能密度GWh/GWh	312	190	342	125
电池容量GWh/年	3481	7715	292	2070
总耗能（PWh）	1.09	1.47	0.10	0.26

4 PWh

还需要每年约4PWh的耗能来制造所需的电池、太阳能电池板、风电涡轮机

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

04 我们的理解：可再生能源经济更为高效

- □ **66PWh/年**的可再生能源 ═ **125PWh/年**的化石能源
- □保留约**9PWh/年**非能源用途化石燃料需求；
- □美国的发电储能组合✖ **6** ≈ 满足全球需求的发电与储能组合。

- ✓ 可再生能源更为**高效**；
- ✓ 化石燃料仍不可完全被取代；
- ✓ 资源禀赋与发展水平差异限制了对全球可再生经济的精确建模求解。

04 原文：Batteries for Transportation

Vehicles

Today there are 1.4B vehicles globally and annual passenger vehicle production of ~85M vehicles, according to OICA. Based on pack size assumptions, the vehicle fleet will require 112 TWh of batteries[aa]. Autonomy has potential to reduce the global fleet, and annual production required, through improved vehicle utilization.

Standard-range vehicles can utilize the lower energy density chemistries (LFP), whereas long-range vehicles require higher energy density chemistries (high nickel). Cathode assignment to vehicle segment is listed in the table below. High Nickel refers to low to zero cobalt Nickel Manganese cathodes currently in production, under development at Tesla, Tesla’s suppliers and in research groups.

Vehicle Type	Tesla Equivalent	Cathode	Pack Size (kWh)	Vehicle Sales	Global Fleet	Global Fleet (TWh)
Compact	[TBD]	LFP	53	42M	686M	36
Midsized	Model 3/Y	LFP	75	24M	380M	28
Commercial/ Passenger Vans	[TBD]	High Nickel	100	10M	163M	16
Large Sedans, SUVs & Trucks	Model S/X, Cybertruck	High Nickel	100	9M	149M	15
Bus	[TBD]	LFP	300	1M	5M	2
Short Range Heavy Truck	Semi Light	LFP	500	1M	6.7M	3
Long Range Heavy Truck	Semi Heavy	High Nickel	800	2M	13.3M	11
Total	-	-	-	89M	1,403M	112

Table 7: Vehicle Fleet Breakdown

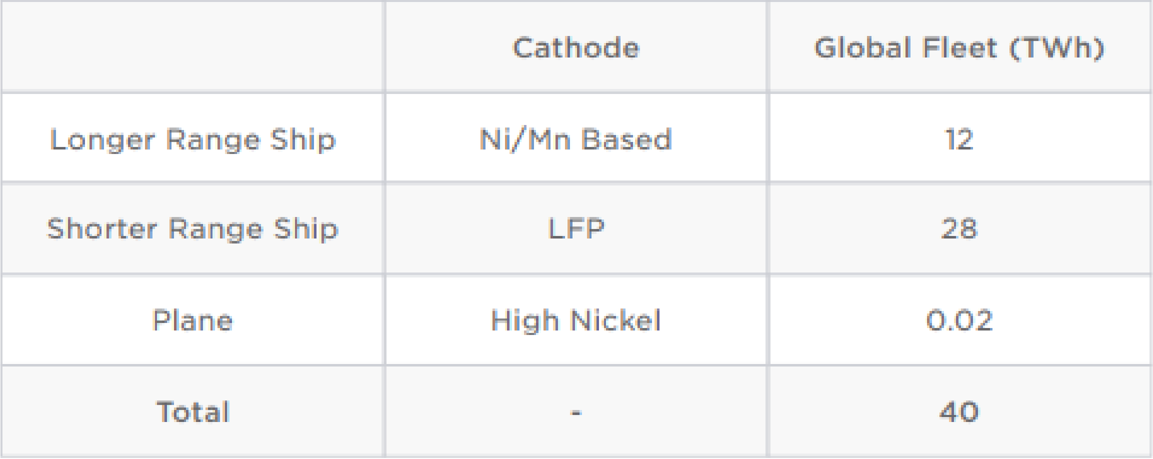
[aa] To approximate the battery storage required to displace 100% of road vehicles, the global fleet size, pack size (kWh)/ Global passenger fleet size and annual production (~85M vehicles/year) is based on data from OICA. The number of vehicles by segment is estimated based on S&P Global sales data. For buses and trucks, the US-to-global fleet scalar of ~5x is used as global data was unavailable

04 原文：Batteries for Transportation

Ships and Planes

With 2.1PWh of annual demand, if ships charge ~70 times per year on average, and charge to 75% of capacity each time, then 40TWh of batteries are needed to electrify the ocean fleet. The assumption is 33% of the fleet will require a higher density Nickel and Manganese based cathode, and 67% of the fleet will only require a lower energy density LFP cathode. For aviation, if 20% of the ~15,000 narrow body plane fleet is electrified with 7MWh packs, then 0.02TWh of batteries will be required.

These are conservative estimates and likely fewer batteries will be needed.



	Cathode	Global Fleet (TWh)
Longer Range Ship	Ni/Mn Based	12
Shorter Range Ship	LFP	28
Plane	High Nickel	0.02
Total	-	40

Table 8: Electric Ship and Plane Fleet Breakdown

04 译文：车用电池

根据OICA的数据，如今全球有14亿辆汽车，年乘用车产量约为8500万辆。根据电池组尺寸假设，车队将需要 112 TWh 的电池。自动驾驶有可能通过提高车辆利用率来减少全球车队和所需的年产量。

标准范围车辆可以使用较低的能量密度化学物质（LFP），而远程车辆则需要更高的能量密度化学物质（高镍）。下表列出了车辆段的正极分配。高镍是指特斯拉、特斯拉供应商和研究小组目前正在生产、正在开发的低至零钴镍锰正极。

车用电池能量测算

车型	Tesla 车型	正极	Pack Size (kWh)	销量/万辆/年	保有量/万辆	能量/TWh
紧凑型	[TBD]	LFP	53	4200	68600	36
中型	Model 3/Y	LFP	75	2400	38000	28
商用/客车	[TBD]	High Nickel	100	1000	16300	16
大型轿车，SUV和卡车	Model S/X, Cybertruck	High Nickel	100	900	14900	15
公共汽车	[TBD]	LFP	300	100	500	2
短程重型卡车	Semi Light	LFP	500	100	670	3
远程重型卡车	Semi Heavy	High Nickel	800	200	1330	11
合计	-	-	-	8900	140300	112

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aa 为了近似取代100%道路车辆所需的电池存储，全球车队规模，包装规模（kWh）/全球客运车队规模和年产量（~85M辆/年）基于OICA的数据。按细分市场划分的车辆数量是根据标普全球的销售数据估算的。对于公共汽车和卡车，由于全球数据不可用，因此使用~5倍的美国到全球车队标量。

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

04 译文：飞机&船舶电池

在年需求量为2.1PWh的情况下，如果船舶平均每年充电约70次，每次充电至75%的容量，则需要**40TWh**的电池为船舶舰队供电。假设33%的船队需要更高密度的镍和锰基正极，67%的船队只需要更低能量密度的LFP正极。对于航空业，如果约15000架窄体机队中有20%使用7MWh的电池组进行电气化，那么将需要**0.02TWh**的电池。这些都是保守估计，可能需要更少的电池。

电动船舶舰队/机队电池需求细分

	正极	全球规模需求/TWh
远程船舶	镍/锰基	12
短程船舶	磷酸铁锂	28
飞机	高镍	0.02
合计	-	40

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

04 我们的理解：运输电池市场无比广阔

测算逻辑

全球车队规模（分车型） × **车用电池容量（分类别）** = **全球车用电池容量需求**

14亿辆汽车全部电气化对应着112TWh的车用电池容量需求！

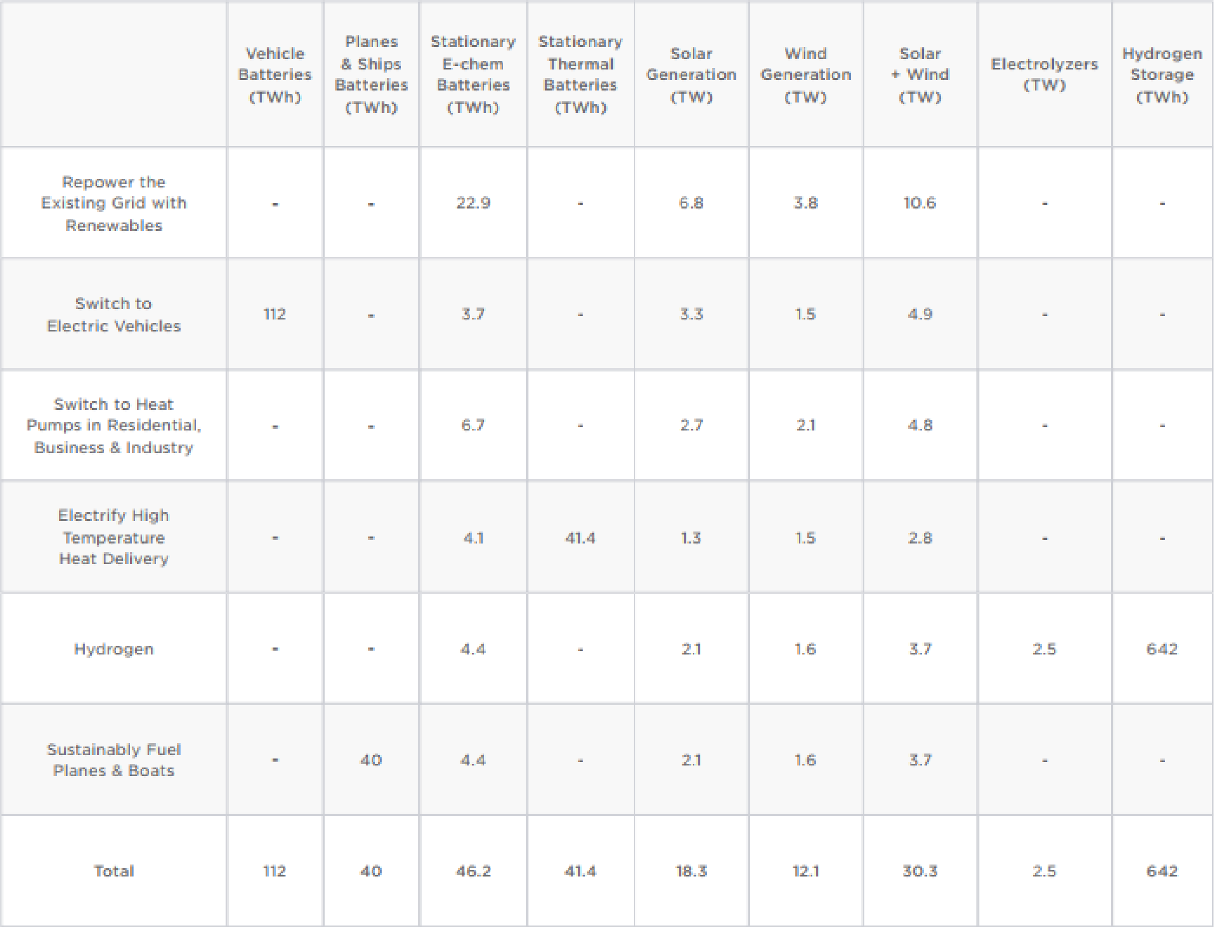
全球飞机/船舶规模 × **电气化替代比例** = **飞机/船舶电池容量需求**

若电气化替代顺利，全球飞机/船舶市场有约40TWh电池容量需求

Global Electric Fleet

04 原文：World Model Results – Electrification &Transportation Batteries

Table 9 summarizes the generation and storage portfolio to meet the global electricity demand and the transportation storage required based on the vehicle, ship and plane assumptions. Explanation of how the generation and storage portfolios were allocated to end-uses can be found ***in Appendix: Generation and storage allocation to end-uses.***



	Vehicle Batteries (TWh)	Planes & Ships Batteries (TWh)	Stationary E-chem Batteries (TWh)	Stationary Thermal Batteries (TWh)	Solar Generation (TW)	Wind Generation (TW)	Solar + Wind (TW)	Electrolyzers (TW)	Hydrogen Storage (TWh)
Repower the Existing Grid with Renewables	-	-	22.9	-	6.8	3.8	10.6	-	-
Switch to Electric Vehicles	112	-	3.7	-	3.3	1.5	4.9	-	-
Switch to Heat Pumps in Residential, Business & Industry	-	-	6.7	-	2.7	2.1	4.8	-	-
Electrify High Temperature Heat Delivery	-	-	4.1	41.4	1.3	1.5	2.8	-	-
Hydrogen	-	-	4.4	-	2.1	1.6	3.7	2.5	642
Sustainably Fuel Planes & Boats	-	40	4.4	-	2.1	1.6	3.7	-	-
Total	112	40	46.2	41.4	18.3	12.1	30.3	2.5	642

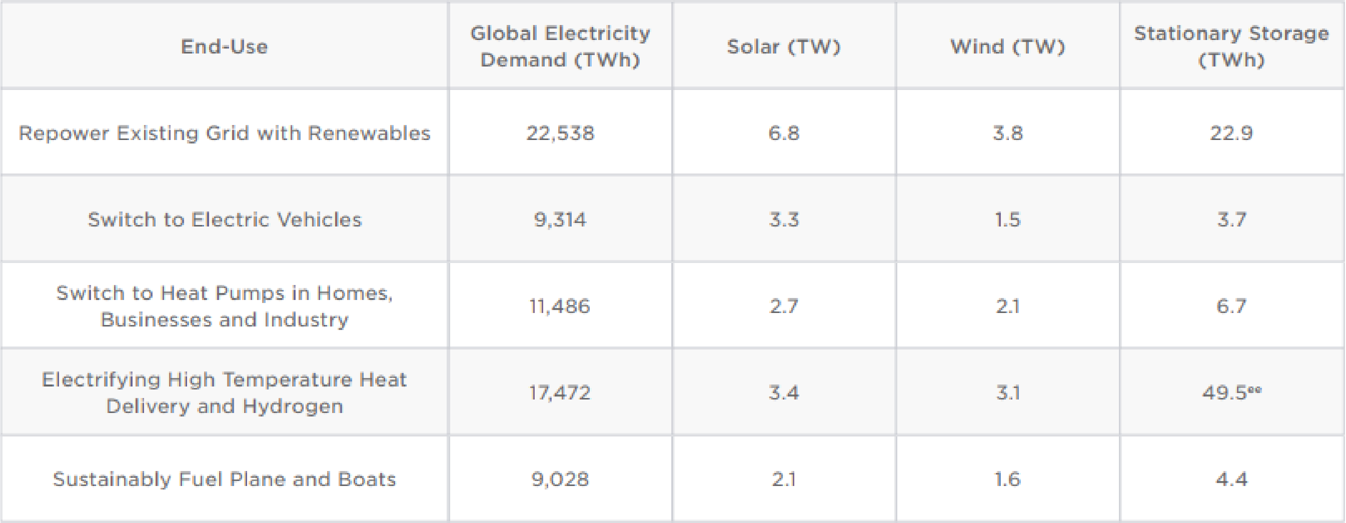
Table 9: Generation and Storage Portfolio to Meet the Global Electricity Demand & Transportation Batteries

04 原文：Appendix: Generation & Storage Allocation to End-Uses

In this analysis, generation and storage needs are estimated at the system level, i.e., answering the question: how much wind/solar and storage is required to reach a sustainable energy economy. The model does not explicitly calculate the required generation and storage to electrify each end-use separately. As an illustration, the allocation of the total system needs to each end-use is calculated using the output from the capacity expansion model.

To do so, the coincidence between the hourly demand profile and the solar and wind generation, after curtailment, is calculated for each end-use. Wind and solar installed capacity is allocated to each end-use based on their annual weighted average coincidence factor. For instance, 12% of the annual wind generation coincided with the EV charging demand. As the model output indicated the need for 15.2 TW of wind, 12% of that total was allocated to EV charging or about 1.9 TW. The same methodology was applied to allocate battery storage capacity to each end-use, by matching storage discharges to end-use demand. Generally, end-uses with the least flexibility to shift the demand, such as residential heating, are allocated more storage than end-uses like industrial high-grade heat where the availability of thermal storage is assumed.

This allocation methodology is a directional illustrative estimate of the impact of each end-use on the total solar/wind and storage requirement, as the need from each end-use is interrelated and cannot fully be separated from each other.



End-Use	Global Electricity Demand (TWh)	Solar (TW)	Wind (TW)	Stationary Storage (TWh)
Repower Existing Grid with Renewables	22,538	6.8	3.8	22.9
Switch to Electric Vehicles	9,314	3.3	1.5	3.7
Switch to Heat Pumps in Homes, Businesses and Industry	11,486	2.7	2.1	6.7
Electrifying High Temperature Heat Delivery and Hydrogen	17,472	3.4	3.1	49.5[ee]
Sustainably Fuel Plane and Boats	9,028	2.1	1.6	4.4

[ee] Including 8 TWh of stationary electricity storage, excluding h2 storage.

译文：全球建模结果——电气化&运输电池

发电和储存组合，以满足全球电力需求以及基于车辆、船舶和飞机假设所需的运输储存

	汽车电池/TWh	飞机&船舶电池/TWh	固定式电化学电池/TWh	固定式热电池/TWh	光伏发电/TW	风力发电/TW	光伏+风能发电/TW	电解槽/TW	储氢/TWh
用可再生能源改善现有电网	-	-	22.9	-	6.8	3.8	10.6	-	-
转向电动车	112	-	3.7	-	3.3	1.5	4.9	-	-
在住宅、商业和工业中改用热泵	-	-	6.7	-	2.7	2.1	4.8	-	-
电气化高温热传递过程	-	-	4.1	41.4	1.3	1.5	2.8	-	-
制氢/储氢	-	-	4.4	-	2.1	1.6	3.7	2.5	642
可再生能源飞机&船舶	-	40	4.4	-	2.1	1.6	3.7	-	-
合计	112	40	46.2	41.4	18.3	12.1	30.3	2.5	642

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

04 译文：附录：发电&储能终端用途分配

在这个分析中，系统层面上估计了发电和储能需求，也就是回答了这个问题：需要多少风能/太阳能和储能才能达到可持续的能源经济。该模型并没有明确计算电气化每个最终用途所需的发电和储能量。作为示例，将总体系统需求分配到每个最终用途上是**通过使用容量扩展模型的输出来计算**的。

为此，计算了每个最终用途的小时需求曲线和风能/太阳能发电量之间的巧合度，以及进行了削减后的量。根据年加权平均巧合系数，将风能和太阳能装机容量分配给每个最终用途。例如，12%的年风能发电量与电动汽车充电需求相吻合。由于模型输出显示需要15.2 TW的风能，因此这个总量的12%被分配给电动汽车充电，大约为1.9 TW。相同的方法被应用于将储能容量分配给每个最终用途，通过将储能放电与最终用途需求相匹配。通常，对于那些无法调整需求的最终用途，例如住宅供暖，会分配更多的储能容量，而对于那些有热储存可用的最终用途，例如工业高品位热，分配的储能容量较少。

这种分配方法是对每个**最终用途对总体风能/太阳能和储能需求的影响的方向性**估计，因为每个最终用途的需求是相互关联的，无法完全从彼此中分离。

04

原文：Generation&Storage Waterfall

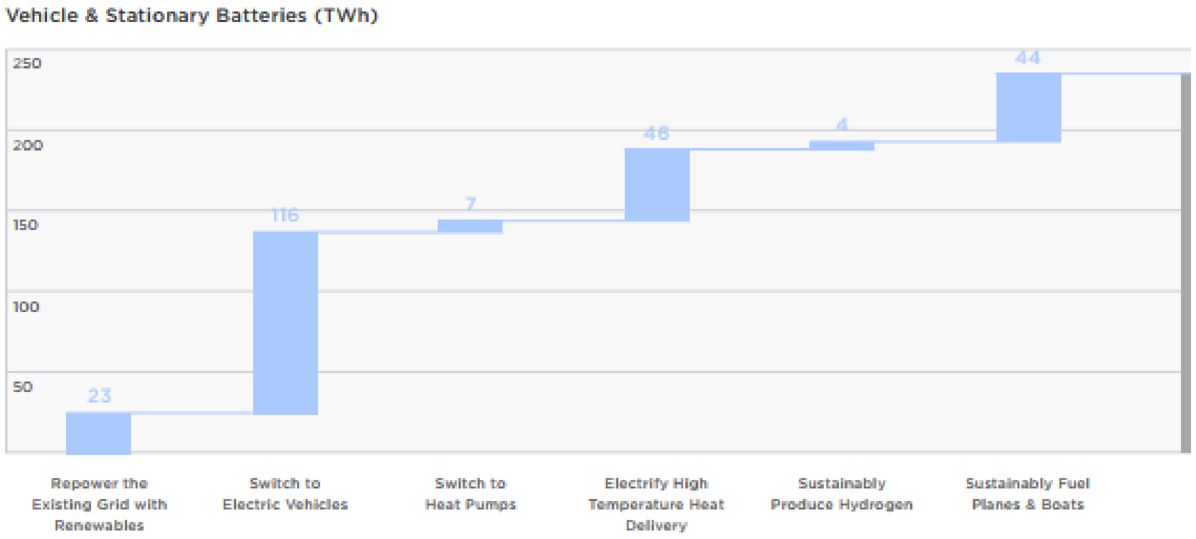


Table 10: Storage Waterfall

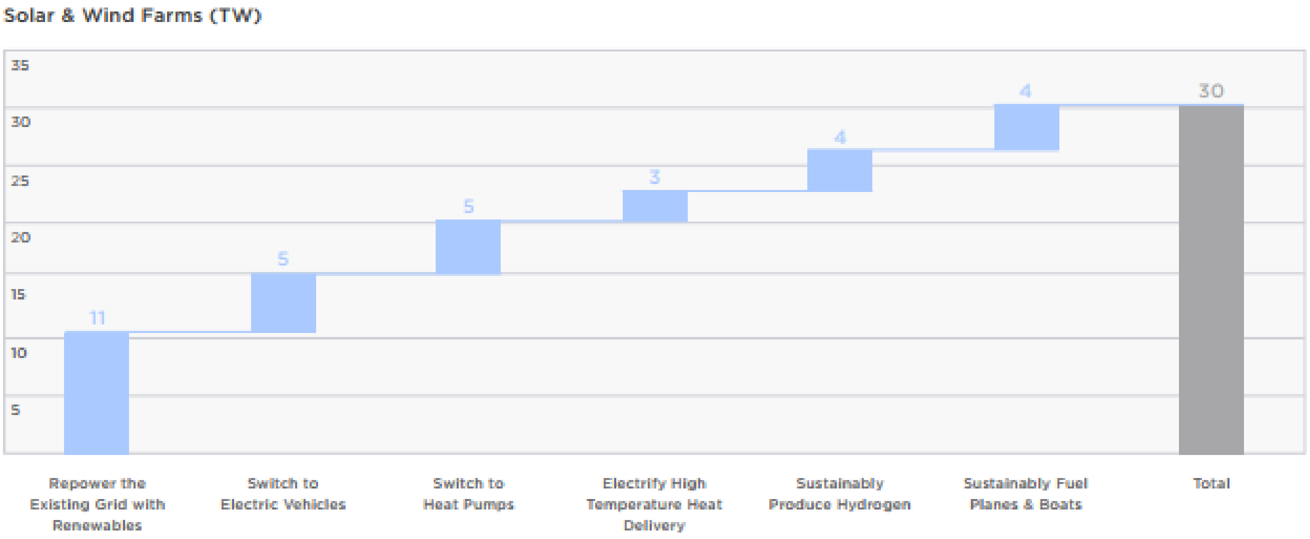
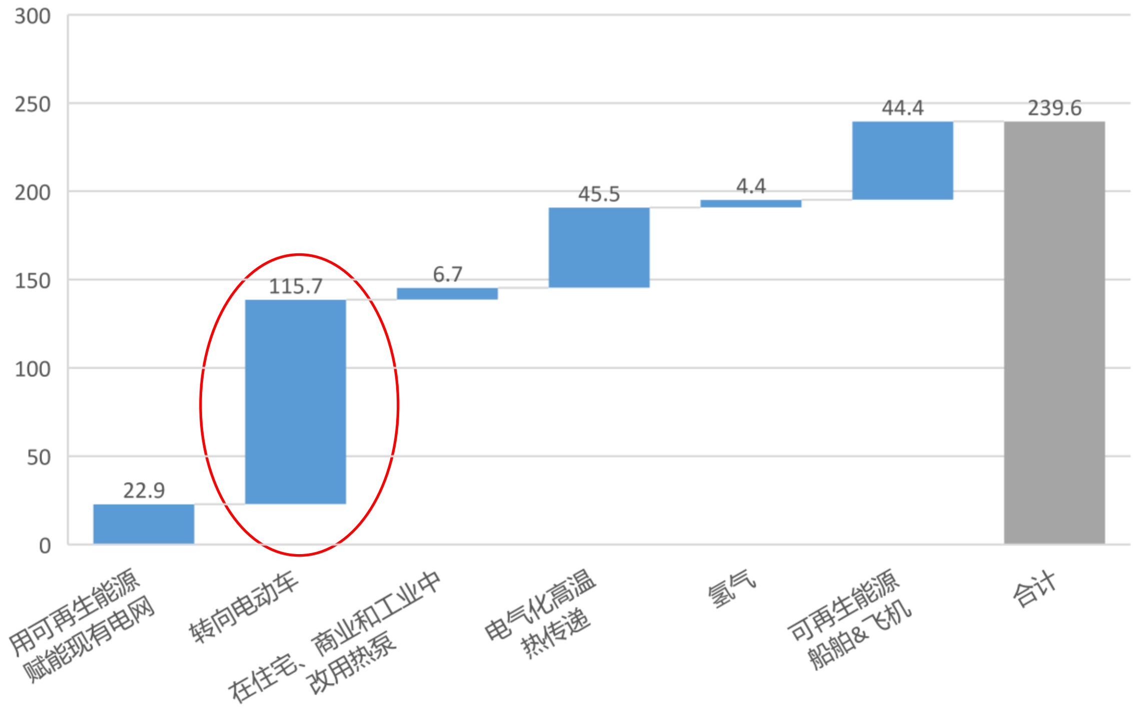


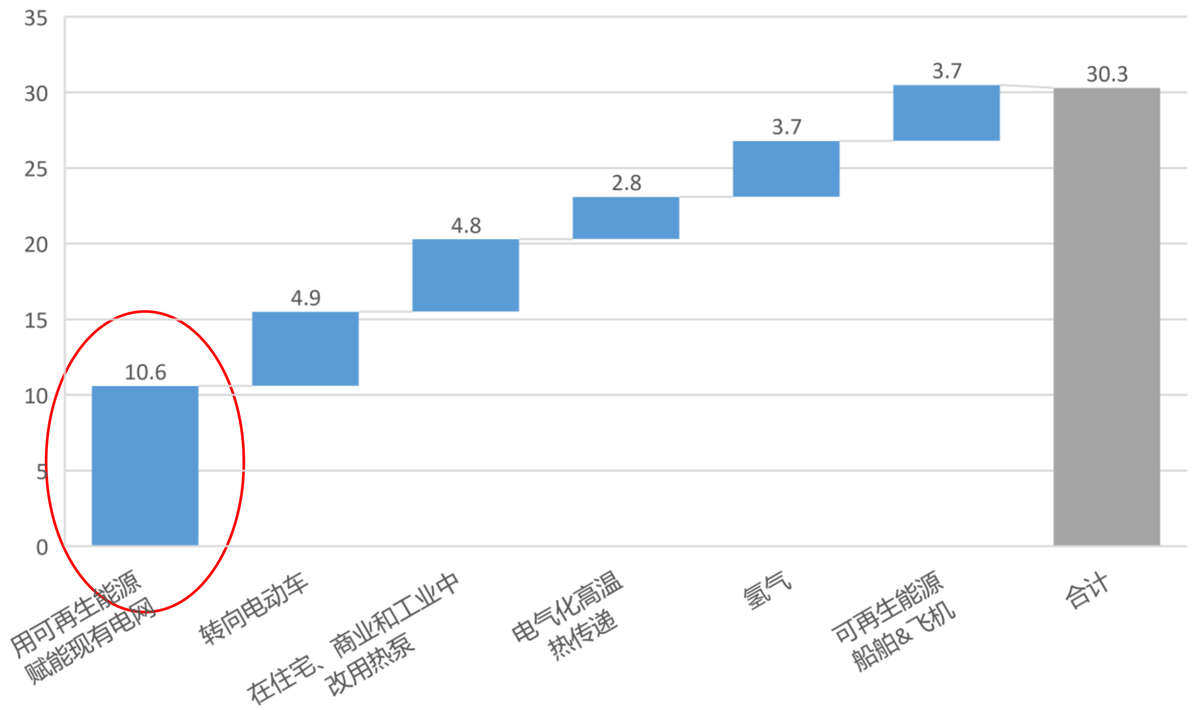
Table 11: Solar & Wind Waterfall

我们的理解：发电&交通运输电气化是重点

车用&固定电池组（TWh）



风电&光伏（TW）



电动车是电池方向的重要支撑；光伏风电主要用于现有电网的重新赋能。

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

05

投资需求

可持续能源经济需投资10万亿美

VS

维持化石燃料经济需投资14万亿美元

05 原文：Investment Required

Investment catalogued here is inclusive of the manufacturing facilities, mining and refining operations for materials that require significant growth, and hydrogen storage salt cavern installation. Manufacturing facilities are sized to the replacement rate of each asset, and upstream operations (e.g., mining) are sized accordingly[bb]. Materials that require significant capacity growth are:

For mining: nickel, lithium, graphite and copper.

For refining: nickel, lithium, graphite, cobalt, copper, battery grade iron and manganese.

In addition to initial capex, 5%/year maintenance capex with a 20-year horizon is included in the investment estimate. Using these assumptions, building the manufacturing infrastructure for the sustainable energy economy will cost $10 trillion[cc], as compared to the $14 trillion projected 20-year spend on fossil fuels at the 2022 investment rate.

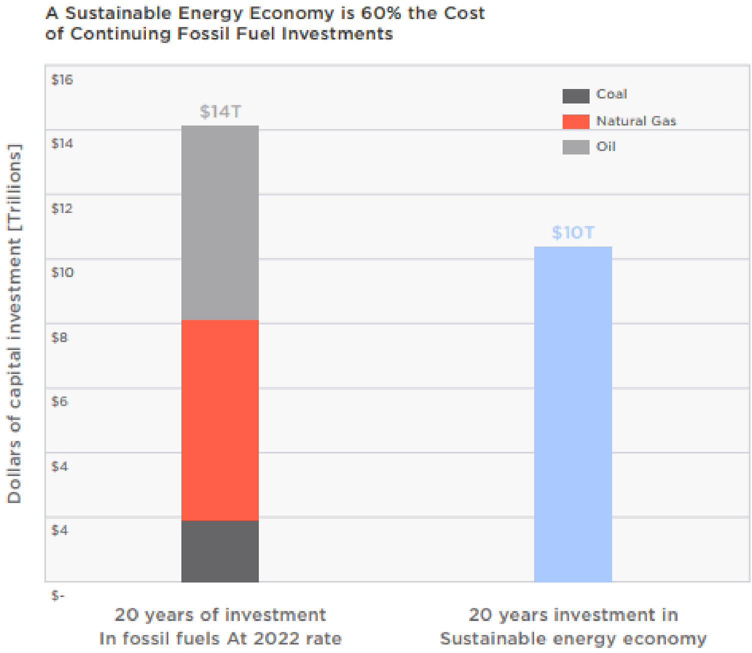

A Sustainable Energy Economy is 60% the Cost of Continuing Fossil Fuel Investments

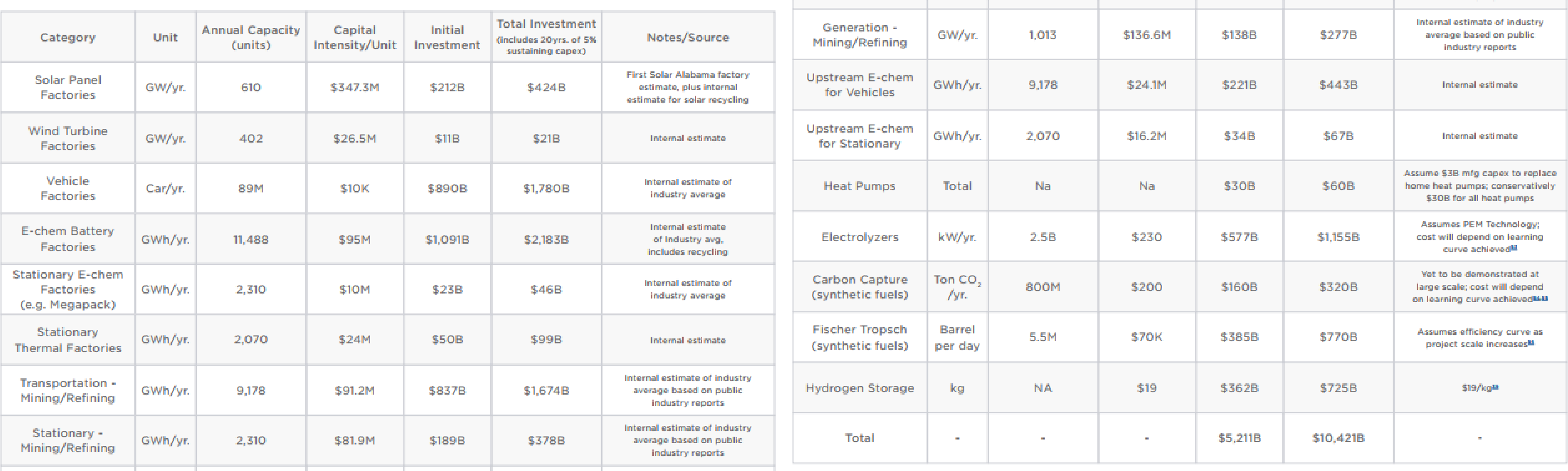
Figure 16: Investment Comparison

[bb] For example, if 46 TWh of stationary LFP battery storage is required, and the life of a battery is 20 years, then the manufacturing capacity is sized to 2.3 TWh/year.

[cc] In-scope manufacturing capacity investments: wind turbines, solar panels, battery cells, upstream battery inputs, mining, refining, electric vehicles, heat pumps, and electrolyzers, carbon capture, and Fischer Tropsch. Salt cavern hydrogen storage is also included.

05

原文：Investment Required



Category	Unit	Annual Capacity (units)	Capital Intensity/Unit	Initial Investment	Total Investment (includes 20yrs. of 5% sustaining capex)	Notes/Source
Solar Panel Factories	GW/yr.	610	$347.3M	$212B	$424B	First Solar Alabama factory estimate, plus internal estimate for solar recycling
Wind Turbine Factories	GW/yr.	402	$26.5M	$11B	$21B	Internal estimate
Vehicle Factories	Car/yr.	89M	$10K	$890B	$1,780B	Internal estimate of industry average
E-chem Battery Factories	GWh/yr.	11,488	$95M	$1,091B	$2,183B	Internal estimate of industry avg, includes recycling
Stationary E-chem Factories (e.g. Megapack)	GWh/yr.	2,310	$10M	$23B	$46B	Internal estimate of industry average
Stationary Thermal Factories	GWh/yr.	2,070	$24M	$50B	$99B	Internal estimate
Transportation - Mining/Refining	GWh/yr.	9,178	$91.2M	$837B	$1,674B	Internal estimate of industry average based on public industry reports
Stationary - Mining/Refining	GWh/yr.	2,310	$81.9M	$189B	$378B	Internal estimate of industry average based on public industry reports
Generation - Mining/Refining	GW/yr.	1,013	$136.6M	$138B	$277B	Internal estimate of industry average based on public industry reports
Upstream E-chem for Vehicles	GWh/yr.	9,178	$24.1M	$221B	$443B	Internal estimate
Upstream E-chem for Stationary	GWh/yr.	2,070	$16.2M	$34B	$67B	Internal estimate
Heat Pumps	Total	Na	Na	$30B	$60B	Assume $3B mfg capex to replace home heat pumps; conservatively $30B for all heat pumps
Electrolyzers	kW/yr.	2.5B	$230	$577B	$1,155B	Assumes PEM Technology; cost will depend on learning curve achieved
Carbon Capture (synthetic fuels)	Ton CO_2 /yr.	800M	$200	$160B	$320B	Yet to be demonstrated at large scale; cost will depend on learning curve achieved
Fischer Tropsch (synthetic fuels)	Barrel per day	5.5M	$70K	$385B	$770B	Assumes efficiency curve as project scale increases
Hydrogen Storage	kg	NA	$19	$362B	$725B	$19/kg
Total	-	-	-	$5,211B	$10,421B	-

Table 12: Investment Summary

05 译文：投资需求

此处列举的投资包括制造设施、需要大幅增长的材料的采矿和精炼操作，以及氢储存盐穴安装。制造设施的规模根据每项资产的更换率来确定，上游操作（如采矿）相应地进行规模调整。需要大幅增长的材料包括：

对于采矿：**镍、锂、石墨和铜**。

对于精炼：**镍、锂、石墨、钴、铜、电池级铁和锰**。

除了初期的资本支出外，还包括20年期限内每年5%的维护资本支出。根据这些假设，建设可持续能源经济的制造基础设施将花费**10万亿**美元，若按2022年化石燃料支出预计，20年内化石燃料支出将达**14万亿美元**。

A Sustainable Energy Economy is 60% the Cost of Continuing Fossil Fuel Investments

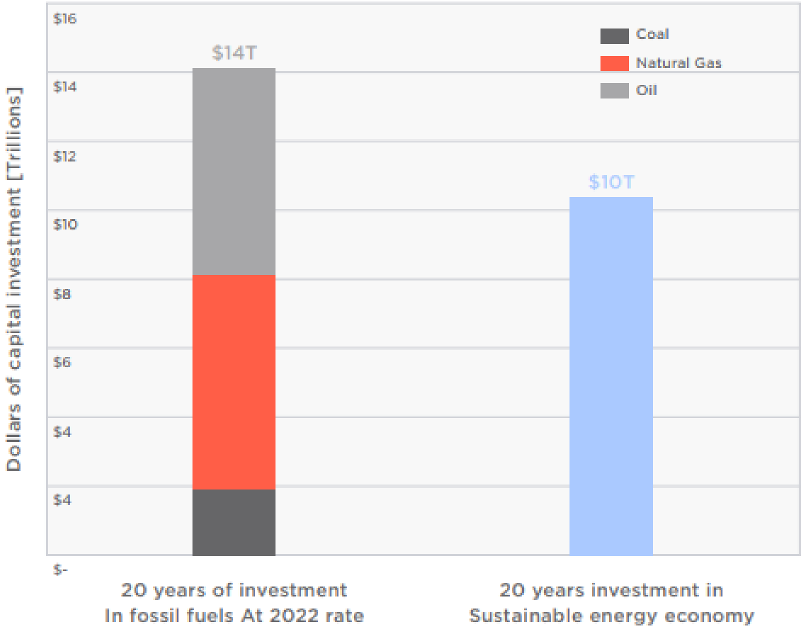


Figure 16: Investment Comparison

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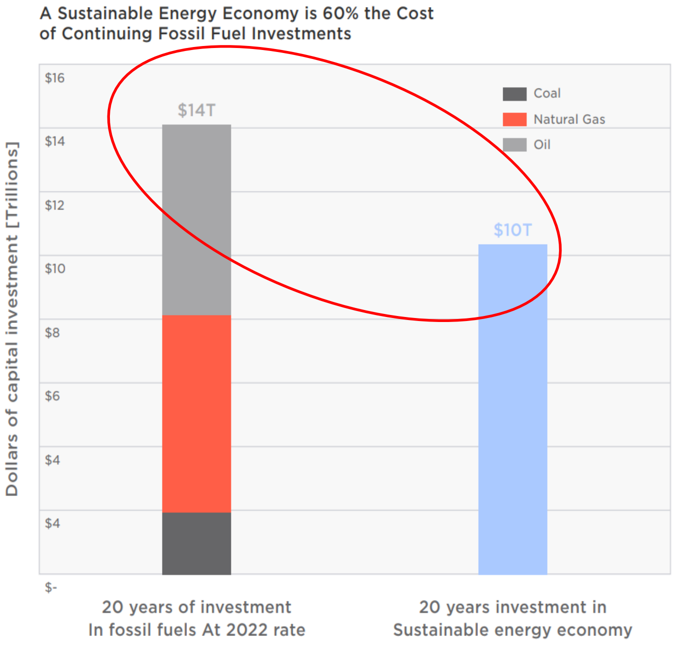
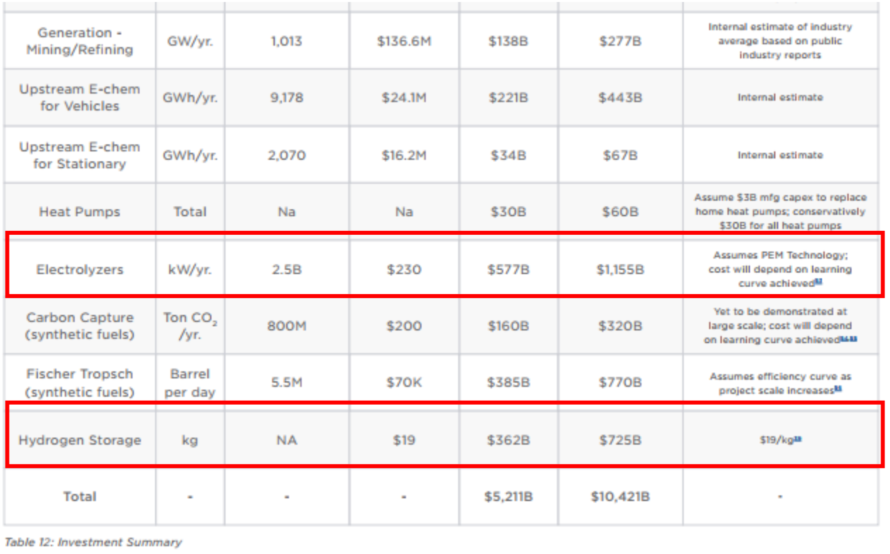
bb 例如，如果需要46 TWh的固定LFP电池存储，且电池寿命为20年，那么制造容量将达到每年2.3 TWh。

cc 范围内的制造能力投资：风力涡轮机、太阳能电池板、电池单元、上游电池输入、采矿、精炼、电动汽车、热泵和电解器、碳捕获和费希尔-特罗普反应。盐穴氢储存也包括在内。

05 我们的理解：10万亿 VS 14万亿，可再生能源优势巨大

- ✓ 可再生能源所需**资本投入更低**；
- ✓ 电动汽车工厂需投入**1.78万亿美元**，电池工厂需投资**2.18万亿美元**；
- ✓ 电动汽车材料开采精炼需投资**1.67万亿美元**，制氢电解槽与储氢需**1.88万亿美元**资本投入，规模震撼！


A Sustainable Energy Economy is 60% the Cost of Continuing Fossil Fuel Investments

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Wind Turbine Factories	GW/yr.	402	$26.5M	$11B	$21B	Internal estimate
Vehicle Factories	Car/yr.	89M	$10K	$890B	$1,780B	Internal estimate of industry average
E-chem Battery Factories	GWh/yr.	11,488	$95M	$1,091B	$2,183B	Internal estimate of industry avg, includes recycling
Stationary E-chem Factories (e.g. Megapack)	GWh/yr.	2,310	$10M	$23B	$46B	Internal estimate of industry average
Stationary Thermal Factories	GWh/yr.	2,070	$24M	$50B	$99B	Internal estimate
Transportation - Mining/Refining	GWh/yr.	9,178	$91.2M	$837B	$1,674B	Internal estimate of industry average based on public industry reports
Stationary - Mining/Refining	GWh/yr.	2,310	$81.9M	$189B	$378B	Internal estimate of industry average based on public industry reports
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Upstream E-chem for Vehicles	GWh/yr.	9,178	$24.1M	$221B	$443B	Internal estimate
Upstream E-chem for Stationary	GWh/yr.	2,070	$16.2M	$34B	$67B	Internal estimate
Heat Pumps	Total	Na	Na	$30B	$60B	Assume $3B mfg capex to replace home heat pumps; conservatively $30B for all heat pumps
Electrolyzers	kW/yr.	2.5B	$230	$577B	$1,155B	Assumes PEM Technology; cost will depend on learning curve achieved
Carbon Capture (synthetic fuels)	Ton CO_2 /yr.	800M	$200	$160B	$320B	Yet to be demonstrated at large scale; cost will depend on learning curve achieved
Fischer Tropsch (synthetic fuels)	Barrel per day	5.5M	$70K	$385B	$770B	Assumes efficiency curve as project scale increases
Hydrogen Storage	kg	NA	$19	$362B	$725B	$19/kg
Total	-	-	-	$5,211B	$10,421B	-

Table 12: Investment Summary

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

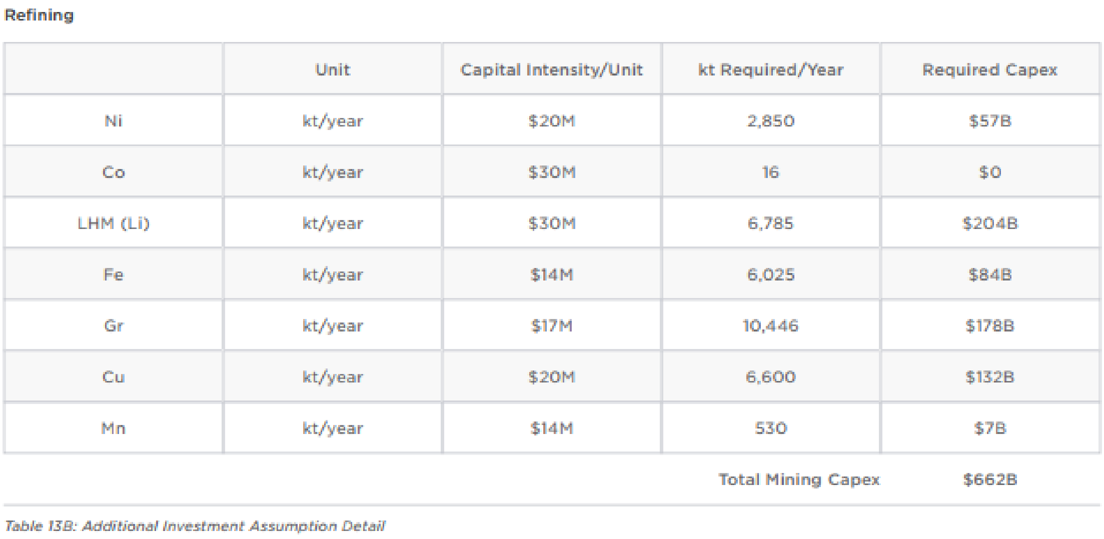
05 原文：Investment Required——details

Table 13 Provides additional detail into mining, refining, vehicle factories, battery factories and recycling assumptions. Mining and refining assumptions are an internal estimate of industry average based on public industry reports:

Mining

	Unit	Capital Intensity/Unit	kt Required/Year	Required Capex
Ni	kt/year	$51M	2,850	$145B
LHM (Li)	kt/year	$25M	6,785	$170B
Gr	kt/year	$10M	10,446	$104B
Cu	kt/year	$12.5M	6,600	$83B
			Total Mining Capex	$502B

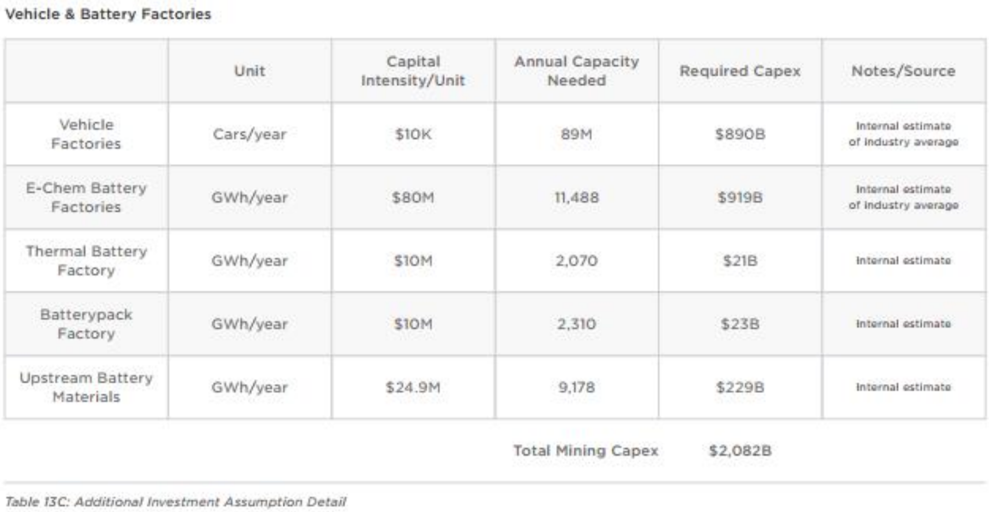
Table 13A: Additional Investment Assumption Detail



Refining

	Unit	Capital Intensity/Unit	kt Required/Year	Required Capex
Ni	kt/year	$20M	2,850	$57B
Co	kt/year	$30M	16	$0
LHM (Li)	kt/year	$30M	6,785	$204B
Fe	kt/year	$14M	6,025	$84B
Gr	kt/year	$17M	10,446	$178B
Cu	kt/year	$20M	6,600	$132B
Mn	kt/year	$14M	530	$7B
			Total Mining Capex	$662B

Table 13B: Additional Investment Assumption Detail



Vehicle & Battery Factories

	Unit	Capital Intensity/Unit	Annual Capacity Needed	Required Capex	Notes/Source
Vehicle Factories	Cars/year	$10K	89M	$890B	Internal estimate of industry average
E-Chem Battery Factories	GWh/year	$80M	11,488	$919B	Internal estimate of industry average
Thermal Battery Factory	GWh/year	$10M	2,070	$21B	Internal estimate
Batterypack Factory	GWh/year	$10M	2,310	$23B	Internal estimate
Upstream Battery Materials	GWh/year	$24.9M	9,178	$229B	Internal estimate
			Total Mining Capex	$2,082B	

Table 13C: Additional Investment Assumption Detail

Recycling

	Unit	Capital Intensity/Unit	Annual Capacity Needed	Required Capex	Notes/Source
Echem Battery Recycling	GWh/year	$15M	11,488	$172B	Internal estimate
Thermal Battery Recycling	GWh/year	$14M	2,070	$29B	Internal estimate
Solar Recycling	GW/year	$14M	610	$9B	Internal estimate
Turbine Recycling	GW/year	$14M	402	$6B	Internal estimate
			Total Mining Capex	$215B	

Table 13D: Additional Investment Assumption Detail

05 译文：开采、精炼、汽车电池、回收资本开支细节

开采、精炼、汽车电池工厂、回收再利用细则

开采细节

	单位	单位成本/万美元	开采量/千吨/年	亿美元
Ni	千吨/年	5100	2850	1450
LHM (Li)	千吨/年	2500	6785	1700
Gr	千吨/年	1000	10446	1040
Cu	千吨/年	1250	6600	830
合计				5020

精炼细节

	单位	单位成本/万美元	开采量/千吨/年	亿美元
Ni	千吨/年	2000	2850	570
Co	千吨/年	3000	16	4.8
LHM (Li)	千吨/年	3000	6785	2040
Fe	千吨/年	1400	6025	840
Gr	千吨/年	1700	10446	1780
Cu	千吨/年	2000	6600	1320
Mn	千吨/年	1400	530	70
合计				6624.8

汽车电池工厂

	单位	单位成本/万美元	容量需求 辆/年 GWh/年	亿美元
汽车工厂	辆/年	1	8900	8900
电化学电池工厂	GWh/年	8000	11488	9190
热电池工厂	GWh/年	1000	2070	210
大储工厂	GWh/年	1000	2310	230
上游电池材料	GWh/年	2490	9178	2290
合计				20820

回收再利用

	单位	单位成本/万美元	开采量/年	亿美元
电化学电池回收	GWh/年	1500	11488	1720
热电池回收	GWh/年	1400	2070	290
光伏回收	GW/年	1400	610	90
涡轮回收	GW/年	1400	402	60
合计				2150

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

06

占地需求

光伏与风能发电占地总需求约

为全球面积0.21%

06 原文：Land Area Required

Solar land area requirement is estimated based on a US Lawrence Berkeley National Laboratory (LBNL) empirical assessment of actual US projects, which found that the median power density for fixed-tilt systems installed from 2011-2019 was 2.8 acres/MWdc57. Converting MWdc to MWac using a 1.4 conversion ratio yields roughly 3.9 acres/MWac. Therefore, the global solar panel fleet of 18.3TW will require roughly 71.4 million acres, or 0.19% of the total 36.8 billion acres global land area.

Wind land area requirement is estimated based on a US National Renewable Energy Laboratory (NREL) study which found that the direct land usage is 0.75 acres per MW58. Therefore, the global wind turbine fleet of 12.2TW will require an estimated 9.2 million acres, or 0.02% of total land area.

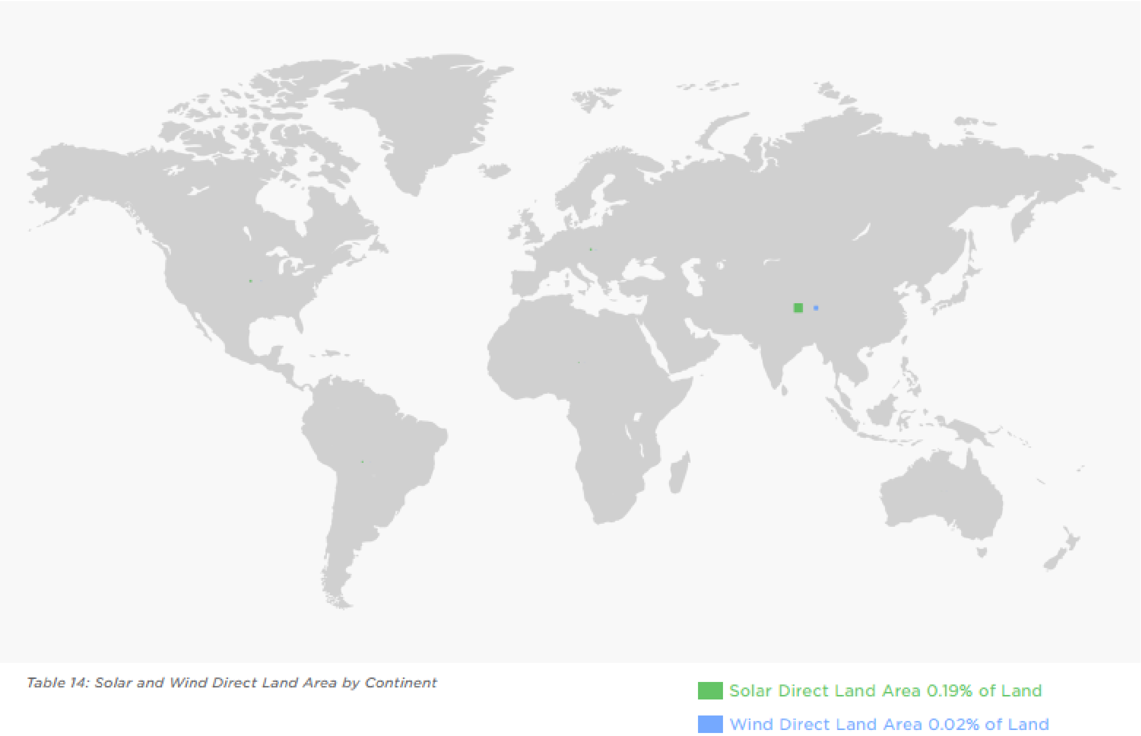


Table 14: Solar and Wind Direct Land Area by Continent

06

译文：占地规模——光伏&风电占地极少

太阳能用地面积需求是根据美国劳伦斯伯克利国家实验室（LBNL）对实际美国项目的经验评估得出的，该评估发现，2011-2019年安装的固定倾斜系统的中位数功率密度为2.8英亩/MWdc。将MWdc转换为MWac，使用1.4的转换比率，得到大约3.9英亩/MW。因此，全球**18.3TW**的太阳能电池板组需要大约**7140万英亩（2.89万平方公里）**，占全球总共368亿英亩土地面积的**0.19%**。

风能用地面积需求是根据美国国家可再生能源实验室（NREL）的一项研究得出的，该研究发现直接用地面积为每兆瓦0.75英亩58。因此，全球**12.2TW**的风力涡轮机组预计需要约**920万英亩（3723平方公里）**，占总土地面积的**0.02%**。

Table 14: Solar and Wind Direct Land Area by Continent

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

07

材料需求

30TW的装机、240TWh的电池存储和6000万英里输电线路共需128.15亿吨材料

锂/铜/镍年需求量为700万吨/700万吨/300万吨

07 原文：Materials Required

Assumptions

The total materials required for solar panels, wind turbines, and circuit miles miles are calculated based on third party material intensity assumptions. Battery material intensity is based on internal estimates. Solar panel and wind turbine material intensity assumptions are from a European Commission report. Solar cells are wafer-based crystalline silicon, and rare earth minerals are eliminated from wind turbines, given the progress demonstrated in developing technologies.

Based on IEA's 2050 Net Zero pathways study, approximately 60 million circuit miles will need to be added or reconductored globally to achieve a fully sustainable, electrified global economy. Distribution capacity will primarily be expanded by reconductoring existing lines and expanding substation capacity that can accommodate significant growth in peak and average end-user demand. High-voltage transmission will primarily expand geographic coverage to connect large wind and solar generation capacity to densely populated areas. For purposes of estimating material requirements, 90% of the 60 million circuit miles will be reconductoring of existing low-voltage distribution systems and 10% will be new circuit-miles from high-voltage transmission, which is the current ratio of US circuit miles between high-voltage transmission and low-voltage distribution.

Using the above assumptions, 12,815 million tonnes in total (444 million tonnes annually) will be required to manufacture 30 TW of generation, 240 TWh of battery storage, and 60M transmission miles.

07 译文：材料投入

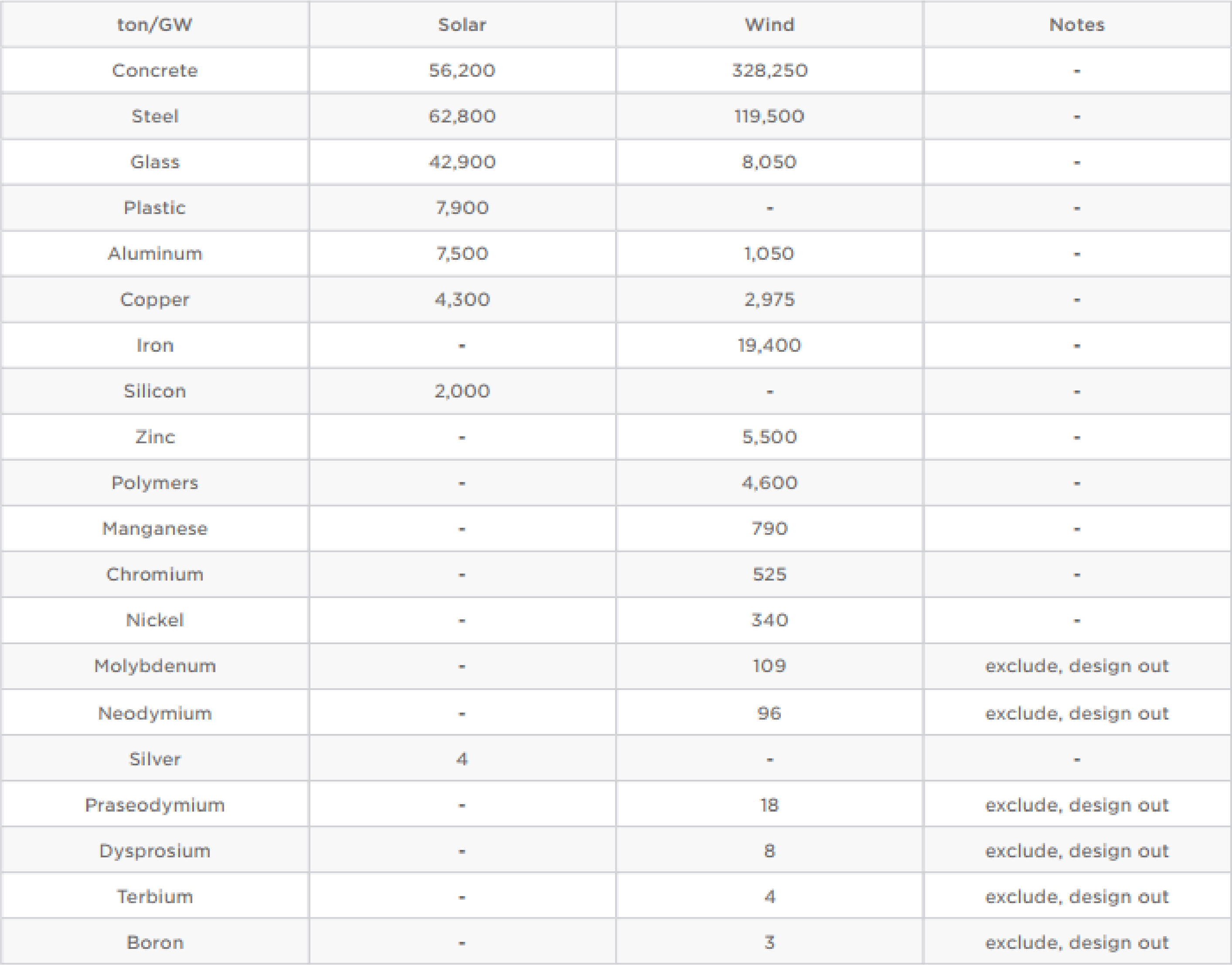
太阳能电池板、风力涡轮机和电路英里所需的总材料是根据第三方材料密度假设计算的；电池材料密度基于内部估算；太阳能电池板和风力涡轮机材料密度假设来自欧洲委员会的报告；考虑到开发技术的突破进展，太阳能电池采用晶体硅晶片，而风力涡轮机中将消除稀土矿物的使用。

根据IEA的2050年净零排放途径研究，全球需要新增或改造约6000万电路英里，以实现完全可持续、电气化的全球经济。配电容量主要通过改造现有线路和扩大能够适应峰值和平均终端用户需求显著增长的变电站容量来扩大。高压输电主要扩大地理覆盖范围，将大型风能和太阳能发电能力连接到人口密集地区。为了估算材料需求，6000万电路英里中的**90%**将是对现有低压配电系统的**改造**，**10%**将是来自高压输电的**新电路**，这是美国高压输电和低压配电之间的电路英里的当前比例。

根据以上假设，为制造**30TW**的装机、**240TWh**的电池存储和**6000万英里**的输电线路，总共需要**128.15亿吨**（每年**444百万吨**）的材料。

07

原文：Materials Required——Generation Details



ton/GW	Solar	Wind	Notes
Concrete	56,200	328,250	-
Steel	62,800	119,500	-
Glass	42,900	8,050	-
Plastic	7,900	-	-
Aluminum	7,500	1,050	-
Copper	4,300	2,975	-
Iron	-	19,400	-
Silicon	2,000	-	-
Zinc	-	5,500	-
Polymers	-	4,600	-
Manganese	-	790	-
Chromium	-	525	-
Nickel	-	340	-
Molybdenum	-	109	exclude, design out
Neodymium	-	96	exclude, design out
Silver	4	-	-
Praseodymium	-	18	exclude, design out
Dysprosium	-	8	exclude, design out
Terbium	-	4	exclude, design out
Boron	-	3	exclude, design out

Table 15: Generation Materials: Tons per GW[62]

07

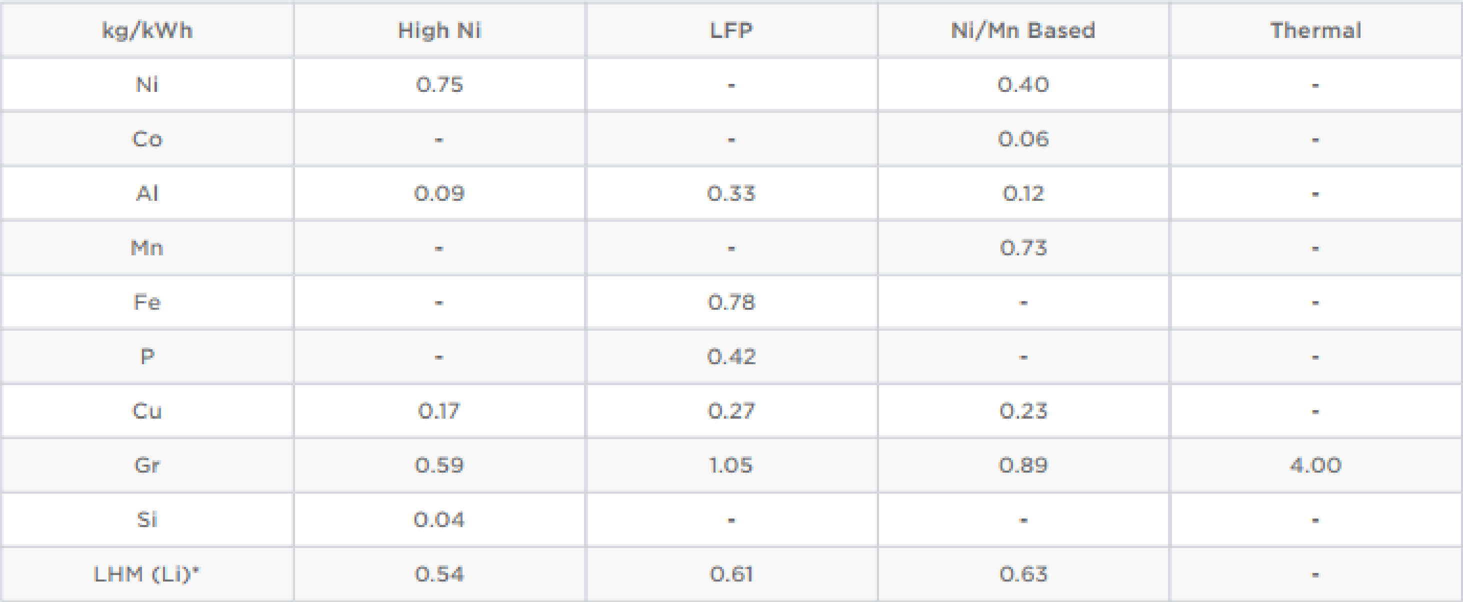
译文：材料投入：发电材料细节

发电材料（吨/GW）

吨/GW	太阳能	风能	备注
混凝土	56200	328250	-
钢铁	62800	119500	-
玻璃	42900	8050	-
塑料	7900	-	-
铝	7500	1050	-
铜	4300	2975	-
铁	-	19400	-
硅	2000	-	-
锌	-	5500	-
聚合物	-	4600	-
锰	-	790	-
铬	-	525	-
镍	-	340	-
钼	-	109	排除, 设计消除
钕	-	96	排除, 设计消除
银	4	-	-
镨	-	18	排除, 设计消除
镝	-	8	排除, 设计消除
铽	-	4	排除, 设计消除
硼	-	3	排除, 设计消除

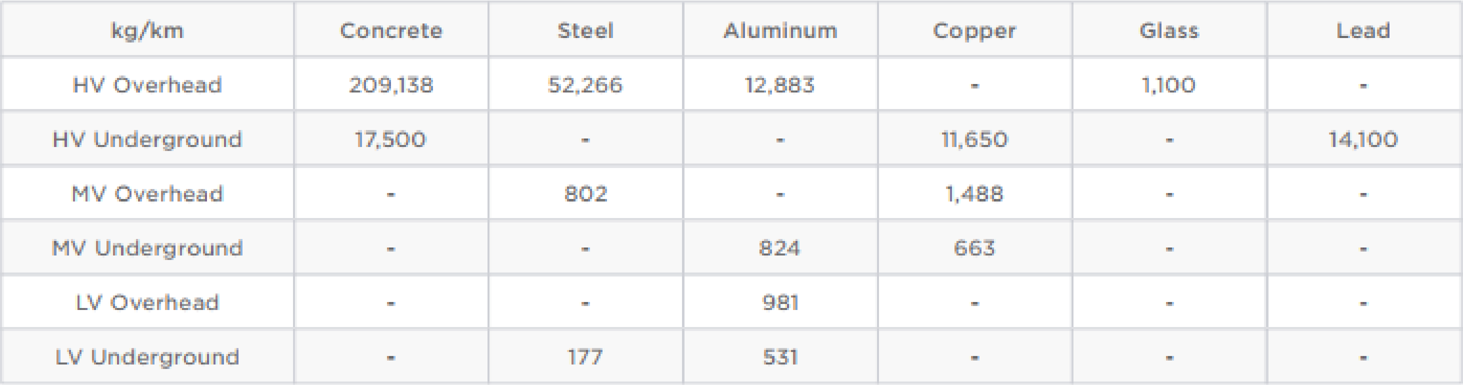
资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

07 原文：Materials Required——Battery&Transmission Details



kg/kWh	High Ni	LFP	Ni/Mn Based	Thermal
Ni	0.75	-	0.40	-
Co	-	-	0.06	-
Al	0.09	0.33	0.12	-
Mn	-	-	0.73	-
Fe	-	0.78	-	-
P	-	0.42	-	-
Cu	0.17	0.27	0.23	-
Gr	0.59	1.05	0.89	4.00
Si	0.04	-	-	-
LHM (Li)*	0.54	0.61	0.63	-

Table 16: Battery Materials: kg per kWh



kg/km	Concrete	Steel	Aluminum	Copper	Glass	Lead
HV Overhead	209,138	52,266	12,883	-	1,100	-
HV Underground	17,500	-	-	11,650	-	14,100
MV Overhead	-	802	-	1,488	-	-
MV Underground	-	-	824	663	-	-
LV Overhead	-	-	981	-	-	-
LV Underground	-	177	531	-	-	-

Table 17: Transmission Materials: kg per km

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* LHM is equivalent to LiOH-H2O and has approximately 6x the mass as the Lithium alone

07 译文：材料投入：电池材料/输电材料细节

电池材料需求密度（kg/kWh）

kg/kWh	高镍	LFP	镍/锰基	热储
Ni	0.75	-	0.4	-
Co	-	-	0.06	-
Al	0.09	0.33	0.12	-
Mn	-	-	0.73	-
Fe	-	0.78	-	-
P	-	0.42	-	-
Cu	0.17	0.27	0.23	-
Gr	0.59	1.05	0.89	4.00
Si	0.04	-	-	-
LHM（Li）＊	0.54	0.61	0.63	-

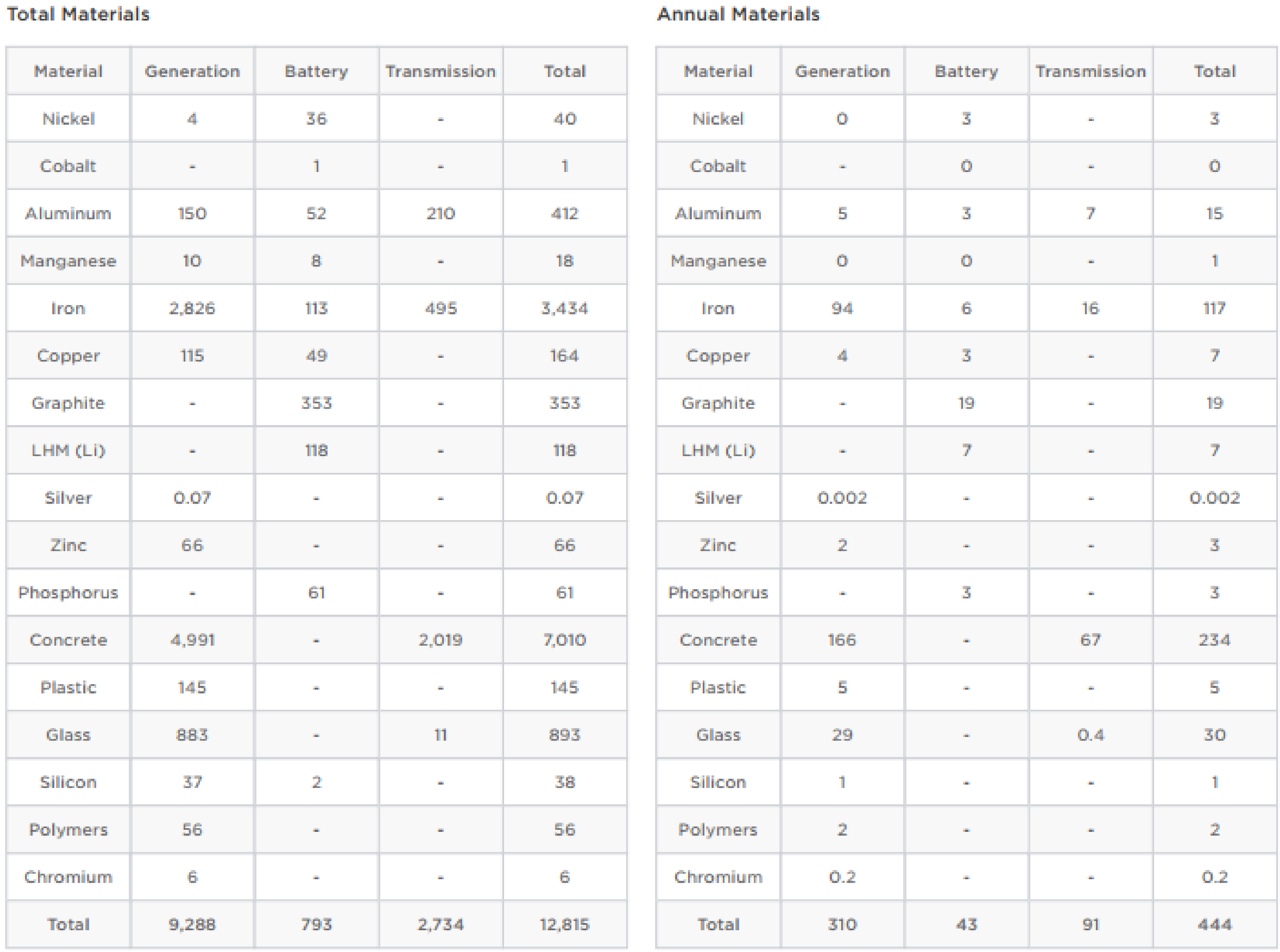
输电材料需求密度（kg/km）

kg/km	混凝土	钢	铝	铜	玻璃	铅
高压架空	209,138	52,266	12,883	-	1,100	-
高压地下	17,500	-	-	11,650	-	14,100
中压架空	-	802	-	1,488	-	-
中压地下	-	-	824	663	-	-
低压架空	-	-	981	-	-	-
低压地下	-	177	531	-	-	-

＊ LHM相当于$LiOH\text{-}H_2O$，质量约为锂的6倍

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

原文：Materials Required——Summary



Total Materials

Material	Generation	Battery	Transmission	Total
Nickel	4	36	-	40
Cobalt	-	1	-	1
Aluminum	150	52	210	412
Manganese	10	8	-	18
Iron	2,826	113	495	3,434
Copper	115	49	-	164
Graphite	-	353	-	353
LHM (Li)	-	118	-	118
Silver	0.07	-	-	0.07
Zinc	66	-	-	66
Phosphorus	-	61	-	61
Concrete	4,991	-	2,019	7,010
Plastic	145	-	-	145
Glass	883	-	11	893
Silicon	37	2	-	38
Polymers	56	-	-	56
Chromium	6	-	-	6
Total	9,288	793	2,734	12,815

Annual Materials

Material	Generation	Battery	Transmission	Total
Nickel	0	3	-	3
Cobalt	-	0	-	0
Aluminum	5	3	7	15
Manganese	0	0	-	1
Iron	94	6	16	117
Copper	4	3	-	7
Graphite	-	19	-	19
LHM (Li)	-	7	-	7
Silver	0.002	-	-	0.002
Zinc	2	-	-	3
Phosphorus	-	3	-	3
Concrete	166	-	67	234
Plastic	5	-	-	5
Glass	29	-	0.4	30
Silicon	1	-	-	1
Polymers	2	-	-	2
Chromium	0.2	-	-	0.2
Total	310	43	91	444

Table 18: Total Material Intensity [Mt]

07 译文：材料投入——汇总

总材料投入（百万吨）

	发电	电池	输电	总计
镍	4	36	-	40
钴	-	1	-	1
铝	150	52	210	412
锰	10	8	-	18
铁	2826	113	495	3434
铜	115	49	-	164
石墨	-	353	-	353
LHM (锂)	-	118	-	118
银	0.07	-	-	0.07
锌	66	-	-	66
磷	-	61	-	61
混凝土	4991	-	2019	7010
塑料	145	-	-	145
玻璃	883	-	11	893
硅	37	2	-	38
聚合物	56	-	-	56
铬	6	-	-	6
总计	9288	793	2734	12815

每年材料投入（百万吨）

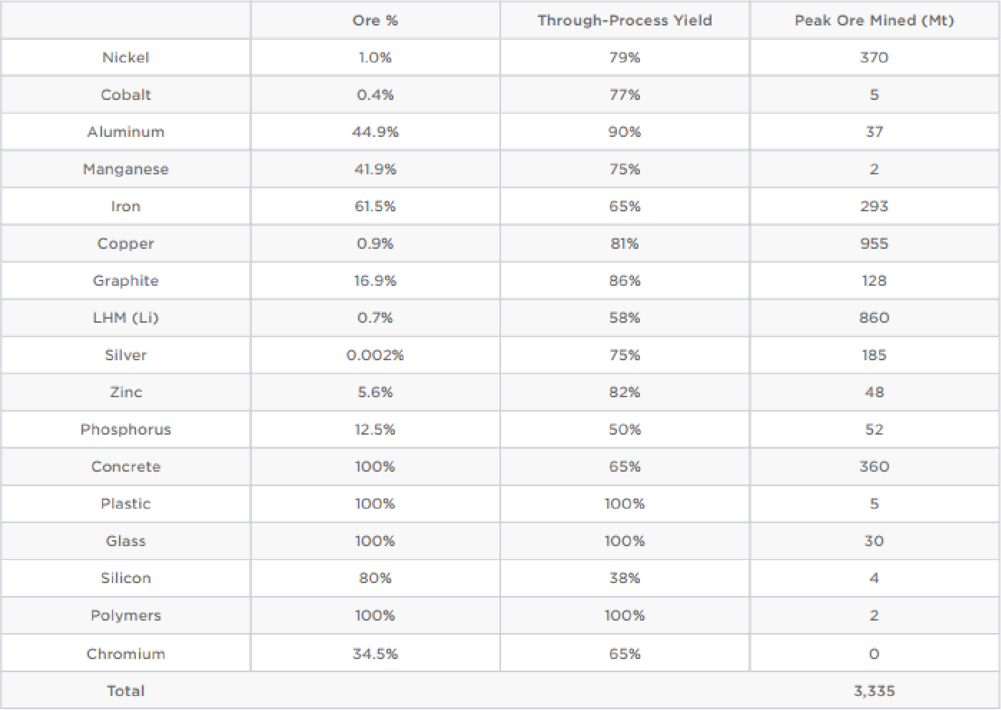
材料	发电	电池	输电	总计
镍	0	3	-	3
钴	-	0	-	0
铝	5	3	7	15
锰	0	0	-	1
铁	94	6	16	117
铜	4	3	-	7
石墨	-	19	-	19
LHM (锂)	-	7	-	7
银	0.002	-	-	0.002
锌	2	-	-	3
磷	-	3	-	3
混凝土	166	-	67	234
塑料	5	-	-	5
玻璃	29	-	0.4	30
硅	1	-	-	1
聚合物	2	-	-	2
铬	0.2	-	-	0.2
总计	310	43	91	444

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

07 原文：Material Extraction

The mass flows associated with these materials (i.e., how much earth is moved) relies on ore grade and through-process yield. Using an internal estimate of industry average compiled from public industry reports (See Table 19), the required annual mass flow is estimated to be 3.3 gigatonnes (Gt). Mass flows can reduce if aluminum (50% ore grade) is substituted for copper (1% ore grade), which is possible in many use cases. It is assumed that 50% of lithium is extracted from brine 100% ore grade, if this is not the case, then the mass flow associated with lithium would increase by 0.8Gt.

According to the Circularity Gap Report 2023, 68Gt of material, excluding biomass, is extracted from the earth each year – fossil fuels account for 15.5Gt of this. In a sustainable energy economy, material extraction will decrease by 10.8Gt – with most fossil fuel extraction replaced by 3.3Gt of renewable material extraction. The assumption is that fossil fuel extraction associated with non-energy end uses (i.e. plastics and other chemicals) continues, approximately 9% of the fossil fuel supply, according to the IEA.



	Ore %	Through-Process Yield	Peak Ore Mined (Mt)
Nickel	1.0%	79%	370
Cobalt	0.4%	77%	5
Aluminum	44.9%	90%	37
Manganese	41.9%	75%	2
Iron	61.5%	65%	293
Copper	0.9%	81%	955
Graphite	16.9%	86%	128
LHM (Li)	0.7%	58%	860
Silver	0.002%	75%	185
Zinc	5.6%	82%	48
Phosphorus	12.5%	50%	52
Concrete	100%	65%	360
Plastic	100%	100%	5
Glass	100%	100%	30
Silicon	80%	38%	4
Polymers	100%	100%	2
Chromium	34.5%	65%	0
Total			3,335

Table 19: Annual Material Extraction Required[dd]

译文：材料提取

这段内容主要讨论了与这些材料相关的质量流量（即，移动了多少地球物质），它依赖于**矿石品位**和整个加工过程的**产量**。根据公共行业报告汇编的内部估计的行业平均水平（见P133右表：材料提取参数/开采量），所需的年度质量流估计为3.3吉吨（Gt）。在许多用例中，如果用铝（50%矿石品位）替代铜（1%矿石品位），质量流可以减少。假设50%的锂是从卤水中提取的，矿石品位为100%，如果实际情况不是这样，那么与锂相关的质量流将增加0.8吉吨。

根据《2023年循环缺口报告》，每年从地球上提取68吉吨物质，不包括生物质，其中化石燃料占15.5吉吨。在可持续能源经济中，物质提取将**减少10.8吉吨**，其中大部分化石燃料提取将被3.3吉吨可再生物质提取所替代。假设与非能源最终用途（如塑料和其他化学品）相关的化石燃料提取仍在继续，根据国际能源署（IEA），占化石燃料供应的约9%。

我们的理解：锂、铜、镍空间广阔，大有可为！

每年材料投入需求（百万吨）

材料	发电	电池	输电	总计
镍	0	3	-	3
钴	-	0	-	0
铝	5	3	7	15
锰	0	0	-	**1**
铁	94	6	16	117
铜	4	3	-	7
石墨	-	19	-	19
LHM (锂)	-	7	-	7
银	0.002	-	-	0.002
锌	2	-	-	3
磷	-	3	-	3
混凝土	166	-	67	234
塑料	5	-	-	5
玻璃	29	-	0.4	30
硅	1	-	-	1
聚合物	2	-	-	2
铬	0.2	-	-	0.2
总计	310	43	91	444

材料提取参数/开采量

类型	矿石含量	开采产出比	开采量 (百万吨/年)
镍	0.01	0.79	370
钴	0.004	0.77	5
铝	0.449	0.9	37
锰	0.419	0.75	2
铁	0.615	0.65	293
铜	0.009	0.8[illegible]	955
石墨	0.169	0.86	128
LHM (锂)	0.007	0.58	860
银	0.00002	0.75	185
锌	0.056	0.82	48
磷	0.125	0.5	52
混凝土	1	0.65	360
塑料	1	1	5
玻璃	1	1	30
硅	0.8	0.38	4
聚合物	1	1	2
铬	0.345	0.65	0
总计			3335

支柱材料需求：锂 **700万吨/年**、铜 **700万吨/年**、镍 **300万吨/年**；对应资本开支：锂 **3740亿美元**，铜 **2150亿美元**，镍 **2020亿美元**。

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

07 原文：Material Availability

The total material in Table 18 extraction is evaluated against 2023 USGS resources to assess feasibility. For silver, the USGS does not publish a resources estimate, so reserves were used. The analysis suggests that solar panels will require 13% of the 2023 USGS silver reserves, but silver can be substituted with copper, which is cheaper and more abundant. Graphite demand can be met with both natural and artificial graphite - the former is mined and refined, and the latter is derived from petroleum coke.

As a result, the graphite resource base was increased to account for artificial graphite production from oil products. If only a small fraction of the world’s oil resource is used for artificial graphite production, graphite resources will not be a constraint. Ongoing development is aimed at evaluating other carbon containing products as feedstock for artificial graphite production, including CO2 and various forms of biomass.

In sum, there are no fundamental materials constraints when evaluating against 2023 USGS estimated resources. Furthermore, Resources and Reserves have historically increased – that is, when a mineral is in demand, there is more incentive to look for it and more is discovered. Annual mining, concentrating, and refining of relevant metal ores must grow to meet demand for the renewable energy economy, for which the fundamental constraints are human capital and permitting/regulatory timelines.

Materials to Build Required 30TW Generation, 240TWh Storage, and 60M Miles of Conductors Relative to 2023 USGS Estimated Resources

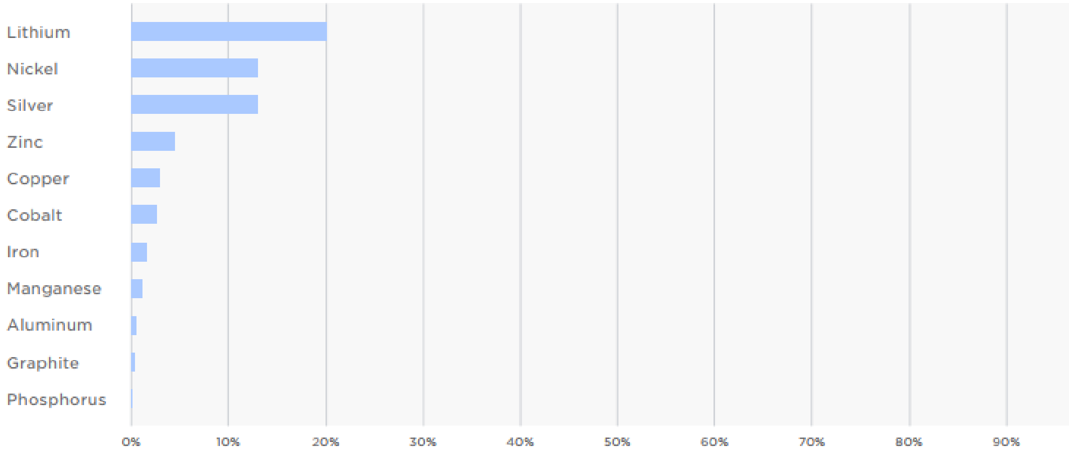


Figure 17: Materials Required Relative to 2023 USGS Estimated Resources

Global Minerals Reserve/Resource Base – Correcting Public Perception

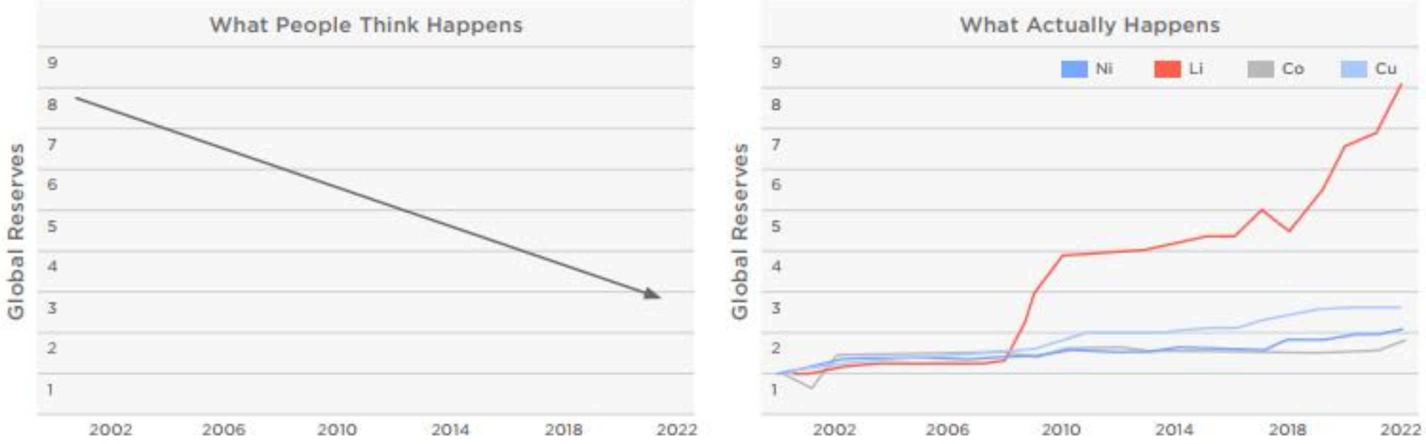


Figure 18 Global Minerals Reserve/Resource base - Correcting Public Perception

07 译文：材料可获得性

根据 2023 年 USGS 公布的资源数据对表 18（对应报告P130左表） 的总材料投入进行评估，以评估可行性。对于银，USGS没有公布资源估计，因此使用了储量。分析表明，太阳能电池板将需要2023年USGS银储量的13%，但银可以用价格更便宜、更丰富的铜替代。石墨需求可以用天然石墨和人造石墨满足，前者是开采和提炼的，后者是从石油焦炭衍生的。因此，石墨资源基础增加了，以考虑从石油产品中生产人造石墨。如果仅使用世界石油资源的一小部分用于人造石墨生产，石墨资源将不会成为约束。正在进行的开发旨在评估其他含碳产品作为人造石墨生产原料，包括CO2和各种形式的生物质。

总之，**在评估2023年USGS预估的资源时，没有根本性的材料限制。此外，历史上资源和储量都在增加，即当矿物受到需求时，寻找和发现它的激励就更大。**为满足可再生能源经济的需求，必须增加相关金属矿石的年度开采、选矿和提炼，其根本制约因素是人力资本和许可/监管计划。

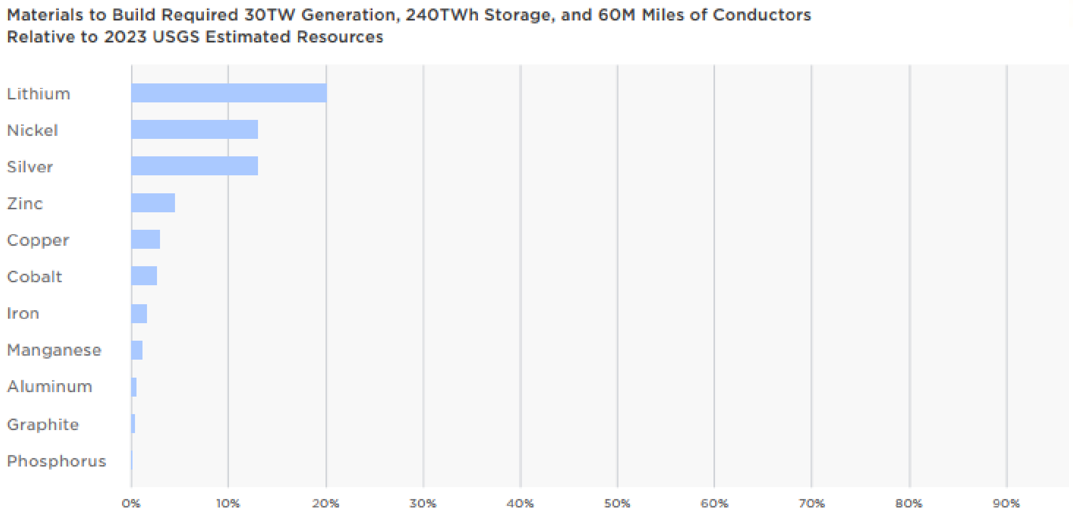


Figure 17: Materials Required Relative to 2023 USGS Estimated Resources

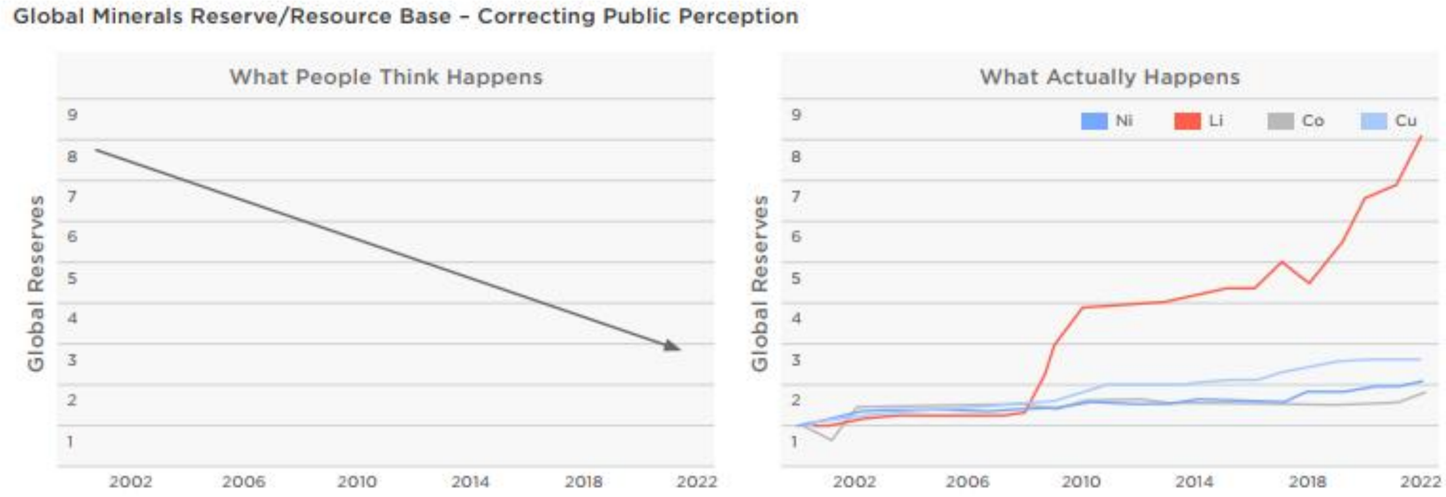


Figure 18 Global Minerals Reserve/Resource base • Correcting Public Perception

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

07 我们的理解：新能源材料需求仅是储量冰山一角

Materials to Build Required 30TW Generation, 240TWh Storage, and 60M Miles of Conductors Relative to 2023 USGS Estimated Resources

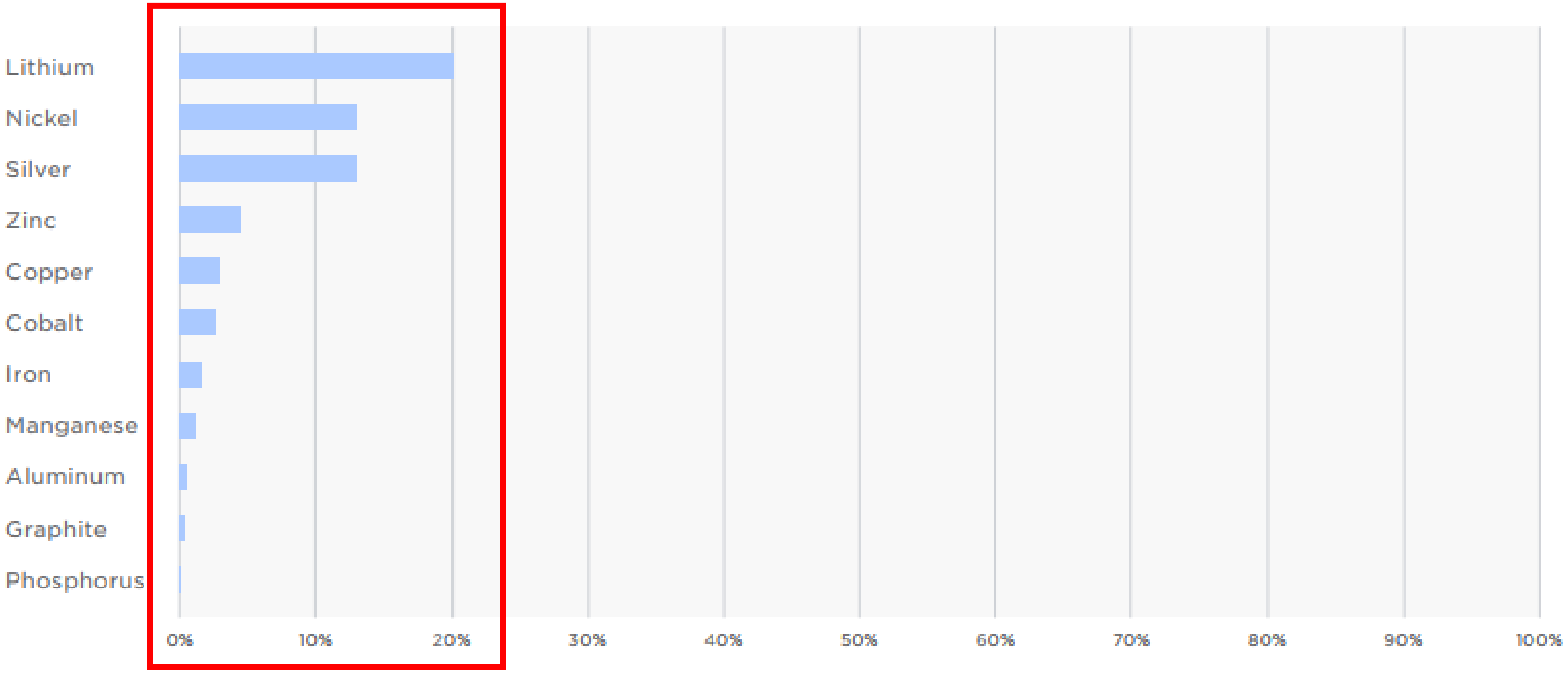


Figure 17: Materials Required Relative to 2023 USGS Estimated Resources

- ✓ 新能源材料需求广阔，**储备更为广阔**，无需担忧竭泽而渔；
- ✓ 与丰富的储量相比，**需求仅是冰山一角**，冰面下的世界更为精彩；
- ✓ 百花齐放的下游需求将会催生一批新能源材料**破冰企业**！

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

原文：Recycling

To support this plan, significant primary material demand growth is required to ramp manufacturing for the sustainable energy economy, once the manufacturing facilities are ramped, primary material demand will level out. In the 2040's, recycling will begin to meaningfully reduce primary material demand as batteries, solar panels and wind turbines reach end-of-life and valuable materials are recycled. Although mining demand will decrease, refining capacity will not.

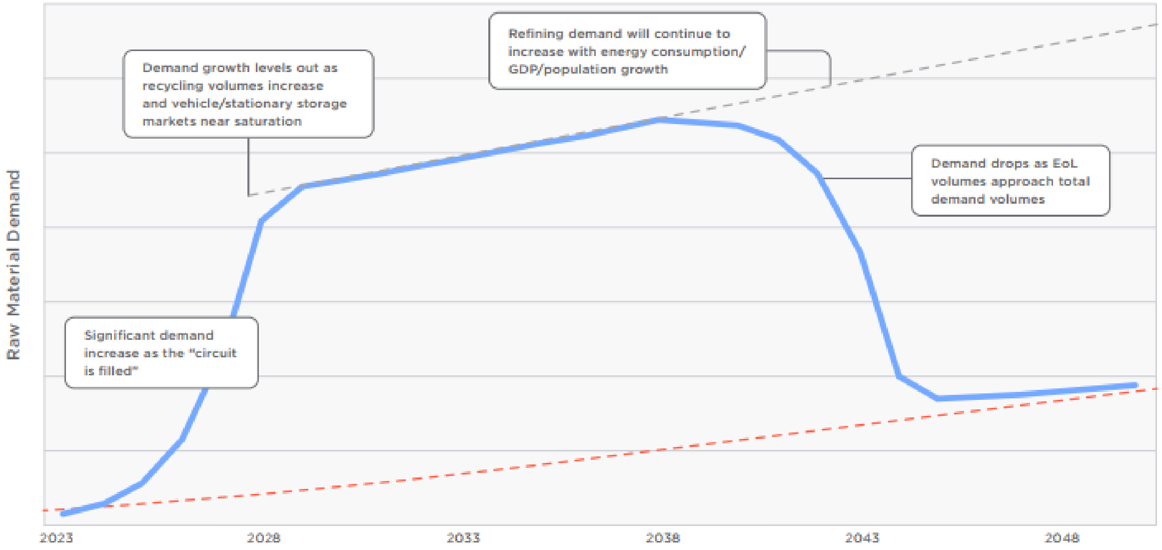


Figure 20 Illustrative Recycling Impact on Process Flow, assuming 80% critical material recovery

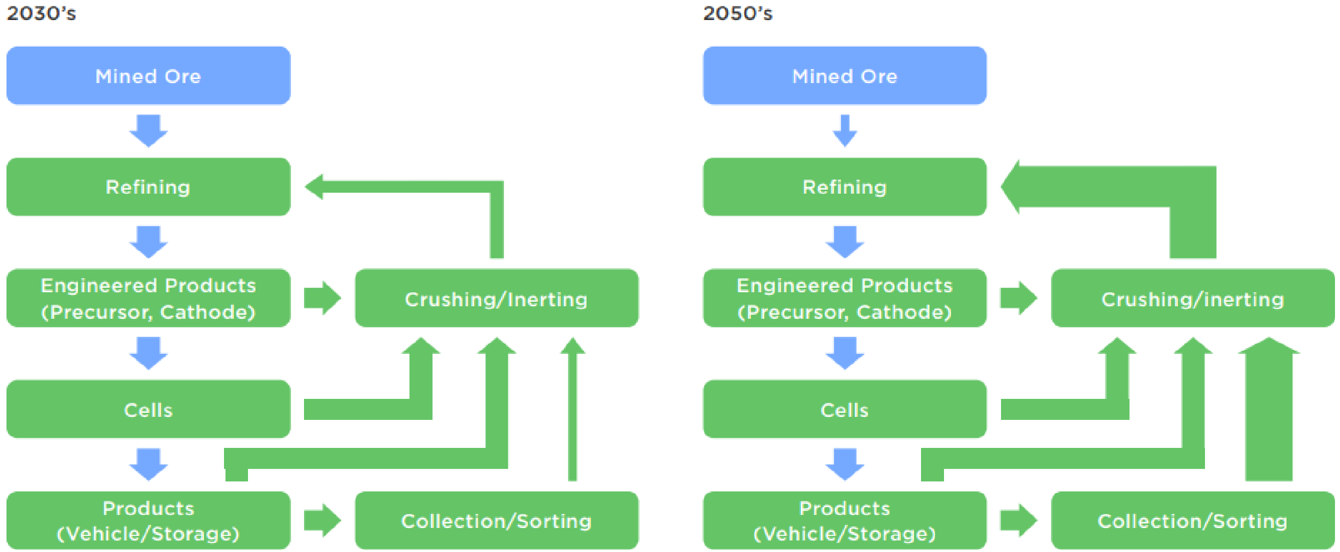


Figure 19: Illustrative Recycling Impact on Process Flow, assuming 80% critical material recovery

07 译文：假设80%的关键材料可回收

为了支持宏图计划，需要显着增长初级材料需求，以促进可持续能源经济的制造，一旦制造设施启动，初级材料需求将趋于平稳。到 2040 年代，随着电池、太阳能电池板和风力涡轮机的使用寿命结束，有价值的材料将被回收利用，回收将开始显着减少对初级材料的需求。尽管采矿需求会减少，但炼油能力不会。

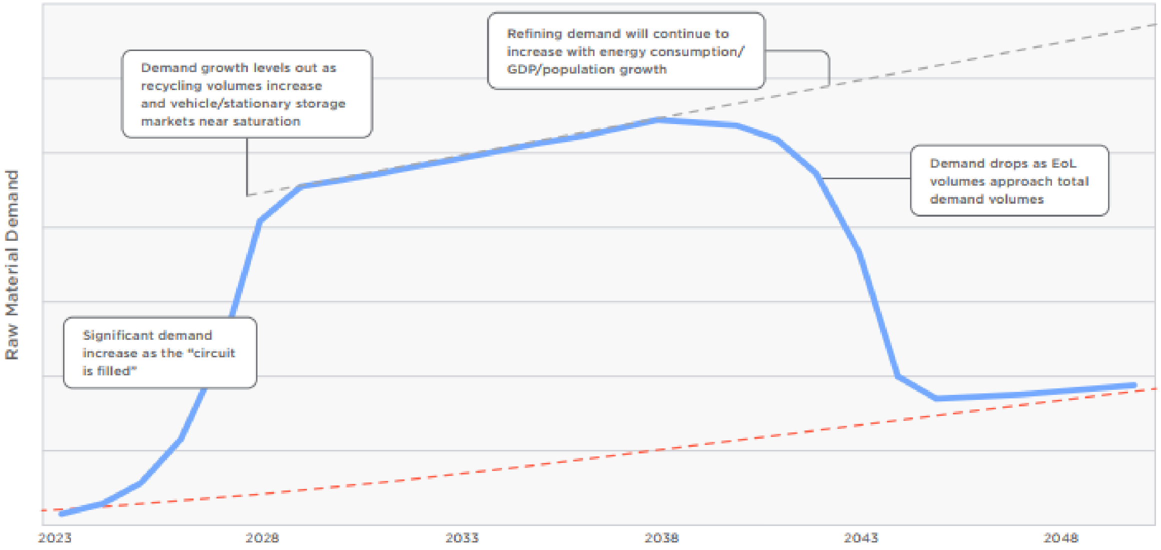


Figure 20 Illustrative Recycling Impact on Process Flow, assuming 80% critical material recovery

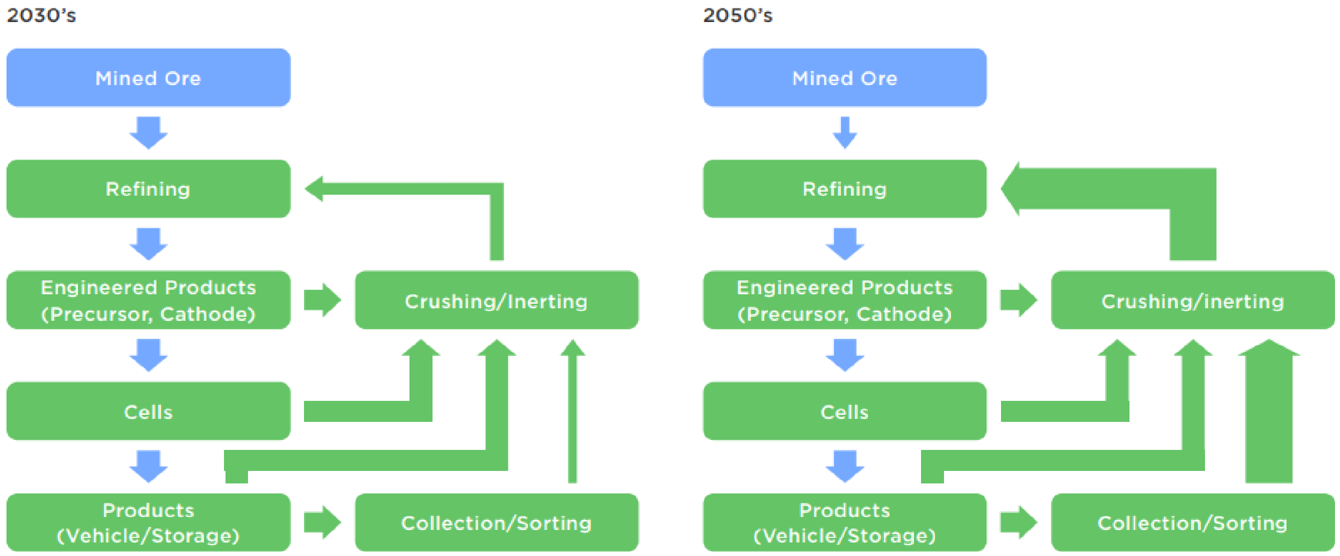
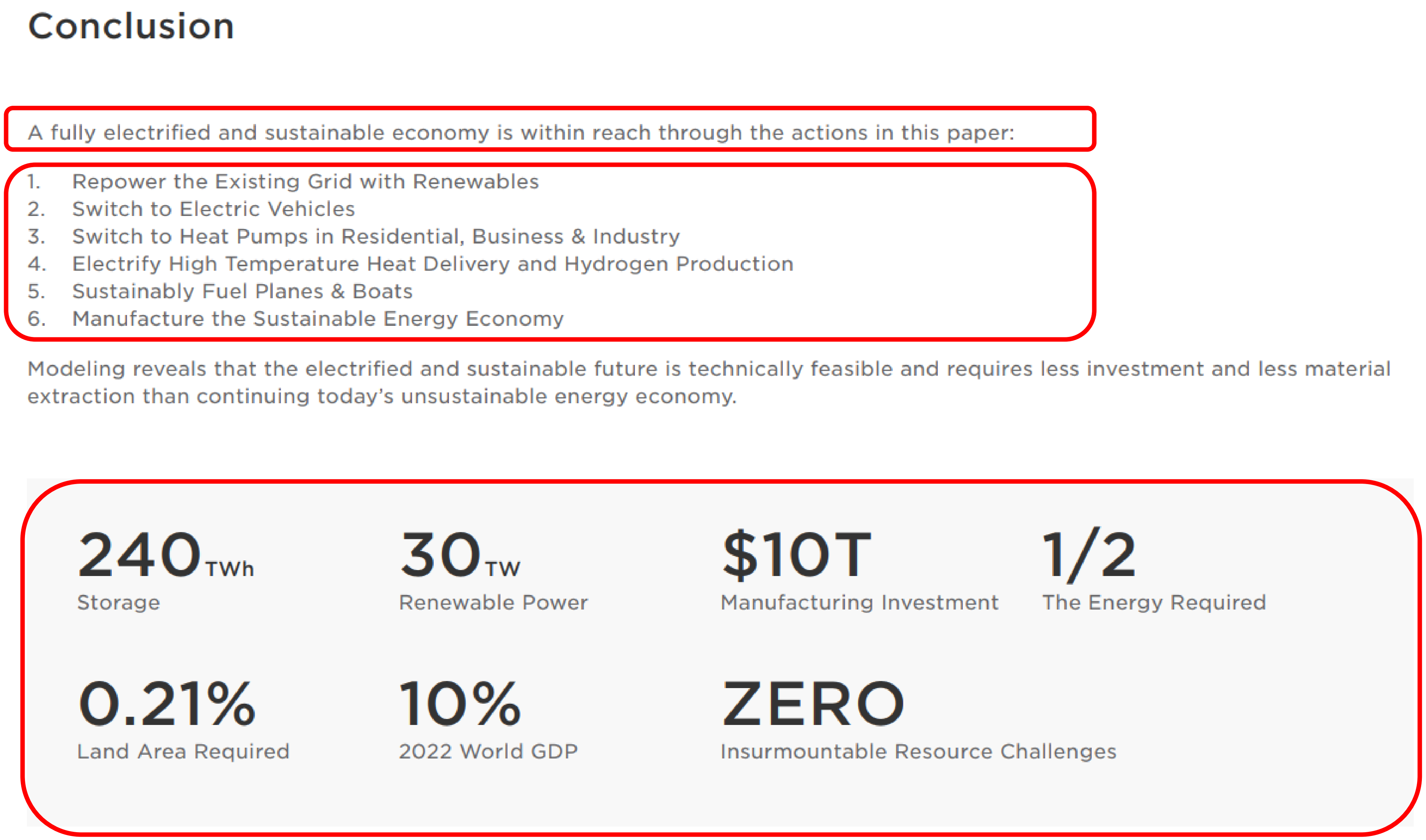


Figure 19: Illustrative Recycling Impact on Process Flow, assuming 80% critical material recovery

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

总结：Master Plan——宏伟愿景



Conclusion

A fully electrified and sustainable economy is within reach through the actions in this paper:

1. Repower the Existing Grid with Renewables
2. Switch to Electric Vehicles
3. Switch to Heat Pumps in Residential, Business & Industry
4. Electrify High Temperature Heat Delivery and Hydrogen Production
5. Sustainably Fuel Planes & Boats
6. Manufacture the Sustainable Energy Economy

Modeling reveals that the electrified and sustainable future is technically feasible and requires less investment and less material extraction than continuing today's unsustainable energy economy.

240 TWh
Storage

30 TW
Renewable Power

$10T
Manufacturing Investment

1/2
The Energy Required

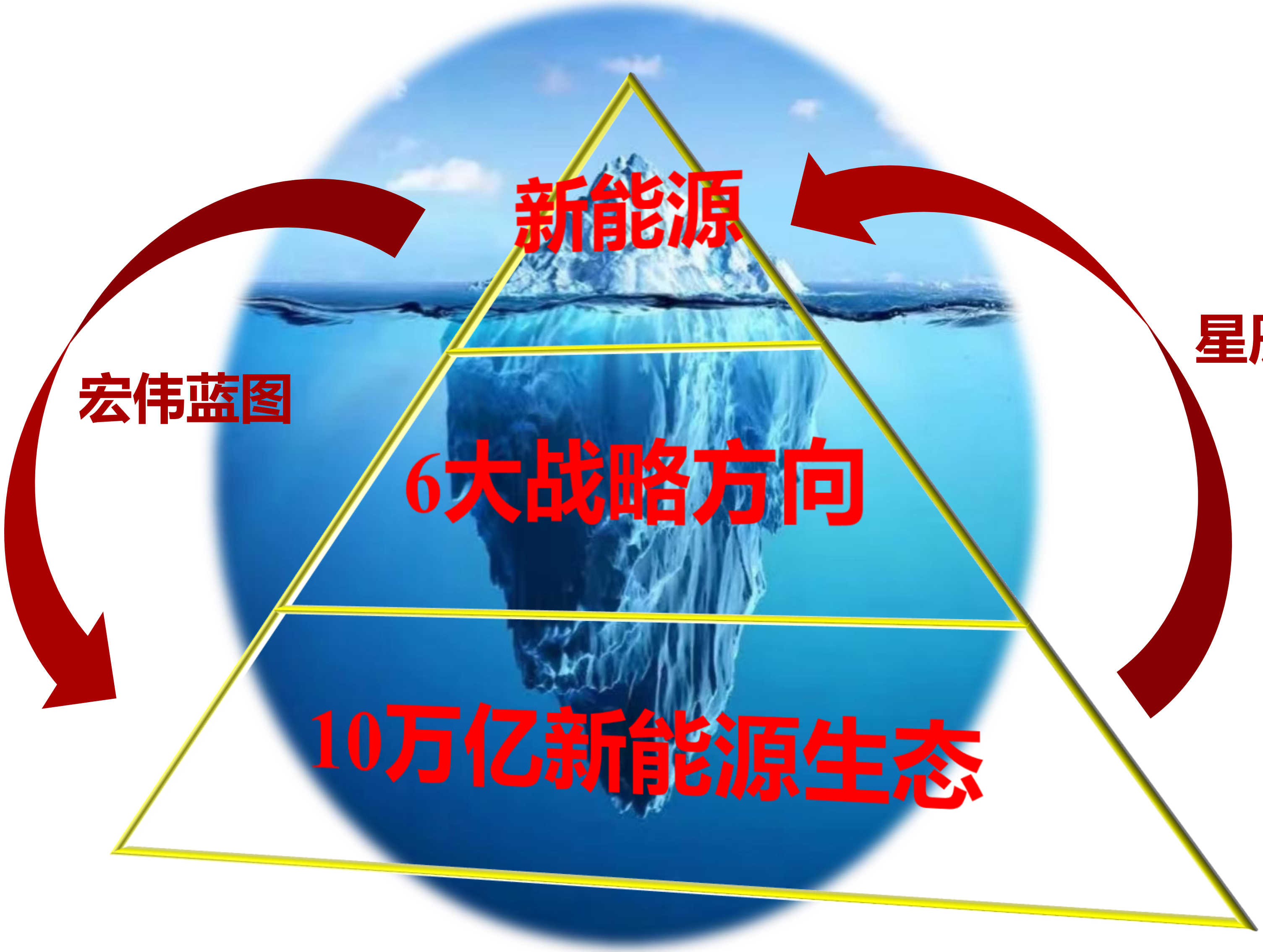
0.21%
Land Area Required

10%
2022 World GDP

ZERO
Insurmountable Resource Challenges

资料来源：Tesla-《Master Plan Part 3》，浙商证券研究所

长坡厚雪，久久为功



新能源

6大战略方向

10万亿新能源生态

宏伟蓝图

星辰大海

资料来源：浙商证券研究所

09 风险提示

1、可再生能源技术突破受限；

2、可再生能源经济替代进程不及预期；

3、各国对可再生能源经济政策激励不足；

4、全球供应链体系不稳定性增加；

5、翻译错误风险，报告涉及《Master Plan Part 3—Sustainable Energy for All of Earth》等文章译文，或因语法理解、翻译有误、翻译不完整等原因造成与原表述存在偏差的风险，译文内容仅供参考，准确内容请详见原文.

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