

火电与新能源 Thermal Power & Renewable Energy

长时储能需求增加，电解水制氢成本优势和环境效益日益显著

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热点速评 Flash Analysis

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电解水制氢可以满足储能对于长周期、大规模、高能量的要求，是未来储能的一种重要解决方案。随着我国大力提升绿电占比以实现能源绿色低碳转型发展，电力系统对灵活性的要求使得大规模与长时储能的需求增加。储能技术分为热储能、电储能和氢储能，其中，抽水蓄能和电化学储能是最常用的两种方式，但两者目前仍存在诸多问题。电化学储能存在安全性较差、资源紧缺、实际有效的储能效率较低、配储时长短等问题。抽水蓄能存在水资源地理分配不均、投资回收期长等缺点。对比来看，氢储能最大的优势在于可以实现长时储能。在新能源消纳方面，氢储能的放电时间（小时至季度）和容量规模（百吉瓦级别）上的优势比其他储能明显。采用化学链储氢，转化效率可达到约 70%，储能时长可以年计；采用固态储氢、有机液态储氢，储能时长可按月计。此外，氢储能具有突破地理限制、经济性强、储运方式灵活、液态氢能量密度大等特点。根据长时储能委员会 IDES 与麦肯锡于 2021 年 11 月合作发布报告《Net-zero power: Long duration energy storage for a renewable grid》，2040 年，长时储能累计装机将达 1.5-2.5TW，代表着 85-140TWh 的储能量，存储 10% 的发电量，累计带动投资 1.5-3 万亿美元。根据 Hydrogen Council，当可再生能源份额达到 60%~70% 以上时，对氢储能的需求会呈现出指数增长态势。我们认为，氢储能的能量维度、时间维度和空间维度上具有突出优势，可在新型电力系统建设中发挥重要作用。

电解水制氢技术路线多元，发展迅速，有望得到大规模应用。利用化石能源（天然气、煤炭、石油等）产生的氢气称为灰氢。灰氢虽然生产成本低，但是碳排放高，目前制 1kg 的灰氢需要排放 20kg 的二氧化碳。蓝氢指工业副产氢，目前主要的生产方式是焦炉煤气制氢、氯碱化工制氢、烷烃脱氢等方式。绿氢通过电解水制氢产生，其生产的过程几乎不涉及碳排放。电解水制氢主要有碱性水电解（AWE）、质子交换膜水电解（PEM）、阴离子交换膜水电解（AEM）以及固体氧化物水电解（SOEC）四种技术路线。其中，AWE 和 PEM 的市场化程度较高，AEM 和 SOEC 距离大规模生产还有较长的距离。AWE 的优势在于设备成本低，技术成熟，已经实现产业化应用，同时国内技术水平在全球处于第一梯队。PEM 相对于其他两种技术的优势在于：设备稳定性和寿命好，反应效率高、能源转化效率高，与波动性、随机性大的风光具有良好适配性，可以做到毫秒级的响应（AWE 为分钟级响应）。PEM 的劣势在于其设备成本远高于 AWE，国内技术水平较国外落后。政策端，2022 年 3 月，发改委发布《氢能产业发展中长期规划（2021-2035 年）》，规划提出，到 2025 年，可再生能源制氢量达到 10-20 万吨/年，成为新增氢能消费的重要组成部分，实现二氧化碳减排 100-200 万吨/年；到 2030 年，形成较为完备的氢能产业技术创新体系、清洁能源制氢及供应体系；到 2035 年，形成氢能产业体系，构建涵盖交通、储能、工业等领域的多元氢能应用生态。据不完全统计，今年前三季度，我国各地上马绿氢项目达 40 多个，主要分布在内蒙古、河北、宁夏、甘肃、新疆等风光资源丰富的地区。技术加速迭代叠加政策有力支持，未来绿氢的规模有望进一步扩大。

近年来，煤和天然气价格处于高位，灰氢和蓝氢生产成本较高，随风光发电度电成本及电解槽成本下降，AWE 和 PEM 电解水制氢生产成本有望进一步压缩。经我们测算，在天然气价格 4.0 元/立方米（不含税，下同）时，天然气制氢成本为 1.64 元/立方米；煤炭价格为 450 元/吨时，煤制氢成本为 0.87 元/立方米。根据工业用电价格约为 0.56 元/kWh，光伏发电度电成本为 0.3 元/kWh，海风发电度电成本为 0.4 元/kWh，陆风发电度电成本为 0.1 元/kWh，对应电耗成本分别为 2.8 元、1.5 元、2 元、0.5 元，假设 1000Nm³/h 的碱性电解槽和 PEM 电解槽成本分别为 850 万元和 3000 万元，对应碱性电解槽制氢气成本分别为 3.47、2.17、2.67、1.17 元/Nm³，PEM 制氢成本为 4.28、3.11、3.56、2.21 元/Nm³。其中，对于碱性电解水制氢，其电解槽价格稳定，技术成熟，电耗成本占比较高，超过 80%。碱性电解槽在年工作时长 2000 小时，并使用陆上风电发电时，其制氢成本已经低于天然气制氢成本；对于 PEM 电解水制氢，其电解槽成本较高，随技术进一步成熟，电解槽成本下降，其成本有望低于当前主流碱性电解槽制氢成本。我们认为，随度电成本和电解槽成本降低及电解槽工作时间延长，电解水制氢将凸显价格优势。

碳中和背景下，各国计划推出碳税和碳交易体系，电解水制氢环境效益凸显。从 20 世纪 90 年代以来，芬兰、瑞典等欧洲国家首先开始实施碳税政策，目前全球已经有 27 个国家推出碳税计划。当前欧盟和美国等纷纷着手制定谈便捷调整计划。欧盟议会和理事会已于 2022 年 12 月表决通过碳边境调节机制（CBAM），将于 2023 年 10 月开始实施，对进口产品引入碳价格。根据碳交易网，美国《清洁竞争法案》（CCA）采用政府定价机制，碳税起始价格为 55 美元/吨，预计最早于 2023 年完成立法。中国于 2013 年以来，相继在深圳等八个试点省市启动碳排放交易市场，并于 2021 年启动全国碳市场，不断完善碳定价政策。随着各国碳税政策和碳交易体系的不断完善，传统化石能源制氢相关行业被纳入碳交易体系，将有助于引导高碳排放制氢工艺向绿色制氢工艺转变，电解水制氢的环境效益将逐渐凸显。

2023 年，中国风光装机量有望达到 80GW 和 140GW，电解水制氢储能需求上涨；叠加风光发电度电成本下降，电解水制氢成本有望进一步降低。风电光伏装机量攀升：2023 年，风机原材料成本回落，交付价格下降，叠加海上风电需求放量，2023 年中国风电装机量有望达到 80GW；光伏上游硅料、硅片价格熔断式下跌，全产业链价格下降，将刺激光伏装机需求释放，2023 年全球光伏新增装机量有望达到 350GW，中国光伏新增装机量有望达到 140GW。绿电装机速度超过电网消纳能力增速，加大储能比例成为趋势。电化学制氢适合长周期和大规模储能，随着风电光伏电站对于灵活性资源的需求快速上涨，电化学制氢储能需求提升。**风电光伏的度电成本逐渐降低：**2021 年陆上风电度电成本最低已达到 0.1 元/度，海上风电度电成本约为 0.4 元/度，光伏发电度电成本已下降至 0.3 元/度。随着技术的不断推进，风光发电度电成本有望进一步下降，电解水制氢的成本有望进一步降低。

中国本土电解水制氢设备供应商充分受益，碱性电解槽产品占主流，PEM 电解槽国产化率较低。碱性电解槽国产化程度高，市场占比超过 97%：碱性电解水技术和设备制造方面，国内技术水平与国外相近，拥有完全自主知识产权的设备制造和工艺集成能力，市场占比较高，2022 年中国电解水制氢电解槽出货量约 800MW，碱性电解槽出货量为 776MW，占比超过 97%。本土供应商纷纷布局碱性电解槽设备，其中隆基氢能、中船派瑞氢能和考克利尔竞立为全国前三，CR3 市占率超过 80%。国内厂商纷纷较快研发及发布 1000Nm³/h 及以上的碱性水电解制氢设备，并纷纷扩充产能。如隆基氢能 2022 年底已具备 1.5GW 电解水制氢设备产能，公司预计 2025 年产能将达到 5GW。**本土供应商加速布局 PEM 电解槽，技术储备仍落后于海外顶尖供应商，关键零部件国产化程度低：**以上海电气、中国石化为代表的央国企和以康明斯、阳光电源为代表的头部供应商纷纷布局 PEM 电解槽和 PEM 制氢项目。当前，中国 PEM 技术储备仍落后于海外顶尖供应商，美国的 Proton Onsite 及 Giner 等公司 PEM 电解槽已经实现 400Nm³/h 产氢量，而中国 PEM 电解槽最大制氢速率为 200Nm³/h，400Nm³/h 的设备仍在试验阶段。此外，PEM 的两大关键部件——催化剂和质子交换膜，国产化程度较低，主要依赖进口。电催化剂主要使用铂和铱，主要从南非、南美等地进口，且本土供应商制作工艺劣于 TKK 等外国供应商。质子交换膜制备工艺复杂，长期被科慕、陶氏、旭硝子、戈尔等日美公司垄断，国内供应商如科润新材料、东岳集团及泛亚微透正逐步进入相关领域，但产品仍存在一定差距。

国内碱性电解槽产能逐步扩张，碱性电解槽设备成本已普遍降至 1500 ~ 2000 元/kw，我们预计 2023 年碱性电解槽设备出海竞争力有望进一步提升。欧洲方面，根据欧洲 REPowerEU 计划，2030 年欧洲绿氢需求 2000 万吨，中国碱性电解槽系统成本优势明显，龙头企业已经实现出口。中东方面，国家主席习近平在利雅得王宫同沙特王储兼首相穆罕默德举行会谈，其中谈及“中方支持沙特‘绿色中东’倡议”，“沙方愿同中方加强清洁能源、绿色发展等领域合作”，两国领导人共同出席了共建“一带一路”、司法、教育、氢能、投资、住房等领域合作文件文本交换仪式。南亚地区，中国船舶集团第七一八研究所下属中船派瑞氢能公司近期同巴基斯坦客户签订柜式 PEM 制氢设备供货合同。我们认为，随全球范围对绿氢的需求量加大，制氢设备的需求量持续增加，中国碱性电解槽设备具有成本优势，2023 年相关企业有望加速出海。

投资建议：建议关注拥有光伏下游组件资源并布局电解槽设备的供应商隆基绿能；全球最大的太阳能制绿氢企业宝丰能源；建有 5MW 电解水制氢系统测试平台的企业阳光电源。

风险：风光装机不及预期；电解水制氢技术发展不及预期；出现其他可替代电解水制氢的储能方案。

表 1: 电化学储能和抽水蓄能问题分析

存在问题		具体分析
电化学储能	安全性较差	近 5 年来, 全球共发生了 30 起电化学储能电站安全事故, 其中 25 起事故来自三元锂电池。今年 6 月, 国家能源局发布《防止电力生产事故的二十五项重点要求(2022 年版)(征求意见稿)》, 将三元锂电池、钠硫电池剔除中大型电化学储能电站。
	资源紧缺	据 USGS 数据, 截至 2021 年, 全球金属锂资源量达到 8900 万吨, 74% 集中于玻利维亚、阿根廷、智利、美国、澳洲。南美锂三角合计占比高达 56%, 中国锂资源总量全球位列第六, 占比约 6%, 国内 65% 锂原料依赖进口。
	实际有效的储能效率较低	电化学储能的堆栈越大, 所需要的通风散热的设备越大, 附属设施所耗的电量递增, 实际有效的储能效率则需要在其初始储能上减去支持储能所耗费的能源。
抽水蓄能	配储时长短	根据美国电力研究院 (EPRI), 持续放电时间为 4 小时的储能系统的获得利润是持续放电时间 20 小时的长时储能系统的 76%。而当前发电侧电化学储能时长大多在 2 小时左右, 仅可以一定程度上缓解弃电现象, 不能完全实现“削峰填谷”。采用长时储能可以更好调节电力供需, 同时可以更加充分利用峰谷电价提高利润。
	水资源地理分配不均	我国的可再生能源分布主要在西北、东北地区, 而这些区域缺水较为验证, 开展抽水蓄能在资源上有限制。
投资回收期长		抽水蓄能的投资回收期在 15-20 年, 比较而言, 电化学储能的投资回收期在 2-4 年。

Source: HTI

表 2: 氢储能优势分析

优势	具体分析
长时储能	在新能源消纳方面, 氢储能放电时间 (小时至季度) 和容量规模 (百吉瓦级别) 上的优势比其他储能明显。采用化学链储氢, 氢能以化学链的形式储存, 转化效率可达到约 70%, 储能时长可以年计; 采用固态储氢、有机液态储氢等方式, 储能时长可按月计。
突破地理限制, 实现生态保护	相较于抽水蓄能和压缩空气储能等大规模储能技术, 氢储能不需要特定的地理条件且不会破坏生态环境。
规模储能经济性强	随着储能时间的增加, 储能系统的边际价值下降, 可负担的总成本也将下降, 规模化储氢比储电的成本要低一个数量级。
储运方式灵活	氢能可采用长管拖车、管道输氢、天然气掺氢、特高压输电-受端制氢和液氢等方式, 不受输配电网络的限制, 从而实现大规模、跨区域调峰。
液态氢能量密度大	液态氢能量密度为 143MJ/kg, 可折算为 40kWh/kg, 约为汽油、柴油、天然气的 2.7 倍、电化学储能 (根据种类不同, 在 100~240Wh/kg) 的百倍, 氢储能是少有的能够储存百 GWh 以上的方式。

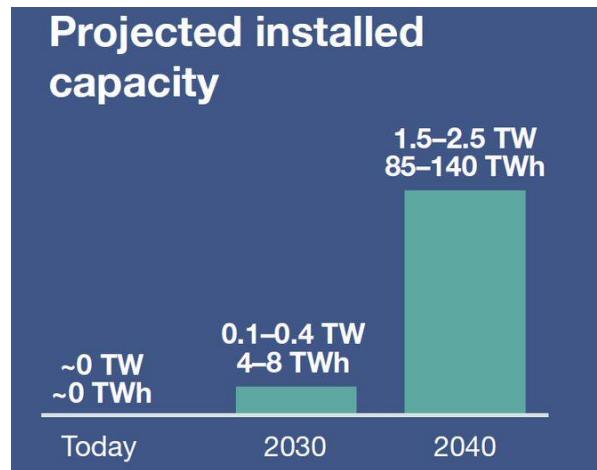
Source: HTI

表 3: 电解水制氢技术路线比较

	碱液电解水(AWE)	质子交换膜电解(PEM)	固体氧化物电解(SOEC)
电解质限膜	30% KOH 石棉膜	质子交换膜	固体氧化物
电流密度/(A.cm ⁻²)	<0.8	1-4	1-10
电耗(kW.h.N ⁻¹ .m ⁻³)	4.5-5.5	3.7-4.5	2.6-3.6
工作温度/C	70-90	70-80	700-1000
产氢纯度	>99.8%	>99.99%	>99.99%
能量效率	60-75%	75-90%	85-100%
操作特征	快速启停, 产气需要脱碱	快速启停, 产物仅水蒸气	启停不便, 产物仅水蒸气
电能质量要求	稳定电源	稳定或波动电源	稳定电源
动态响应能力	较强	强	较弱
电解槽寿命	12000 h	10000 h	-
可维护性	强碱腐蚀强, 运维成本高	无腐蚀性介质, 运维成本低	-
技术成熟度	充分产业化	初步产业化	研发期
特点	技术成熟, 成本低	良好的可再生能源适应性	转化效率较高

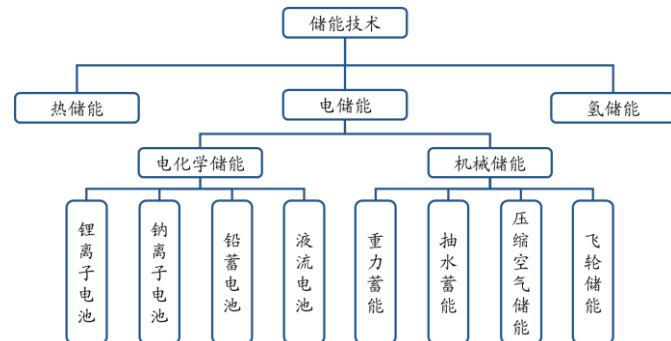
Source: HTI

图 1: 长时储能累计装机容量预测



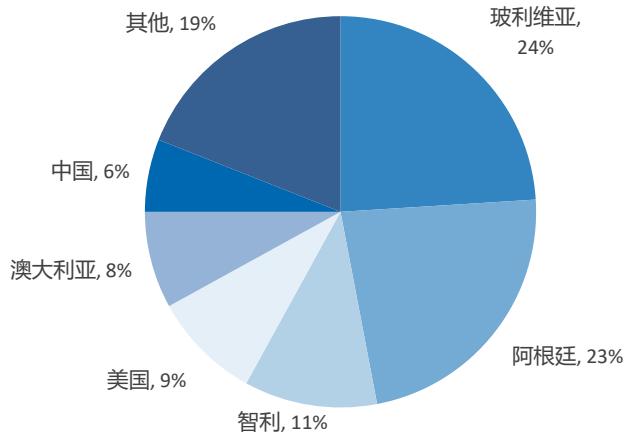
Source: 《Net-zero power: Long duration energy storage for a renewable grid》, HTI

图 2: 储能技术分类



Source: 派能科技招股说明书, HTI

图 3: 2021 全球锂资源储量占比, 中国占 6%



Source: 美国地质调查局, HTI

表 4: 天然气制氢和煤制氢成本测算假设

成本类型	假设
原材料成本	原料按 11 月底天然气到厂价约 4.0 元/立方米(不含税、热值 35,948kJ/立方米), 煤炭 450 元/t(不含税、热值 22,990kJ/kg)
能耗	氧气外购 0.5 元/立方米; 3.5MPa 蒸汽 100 元/t, 10MPa 蒸汽 70 元/t; 新鲜水 4 元/立方米; 电 0.56 元/kWh
建设投资成本	煤制氢采用水煤浆技术, 建设投资 12.4 亿元、天然气制氢建设投资 6 亿元。人员费用统一装置 10 年折旧后残值 5%; 修理费 3%/年, 财务费用按建设资金 70% 贷款, 年利率按 5% 计
其他	比较范围为装置界区内, 建设投资不含征地费以及配套储运设施

Source: 《煤制氢与天然气制氢成本分析及发展建议》, HTI

表 5: 天然气和煤制氢成本测算

项目	成本/(元/立方米)	
	天然气制氢	煤制氢
原料(天然气/煤炭)	1.341	0.340
氧气		0.210
辅助材料	0.014	0.043
燃料动力能耗	0.184	0.069
电	0.020	0.024
循环水	0.002	0.008
新鲜水	0.001	0.001
脱盐水	0.022	0.036
3.5 MP 蒸汽	-0.018	
1.0 MP 蒸汽	0.000	
燃料气	0.157	
直接工资	0.012	0.012
制造费用	0.065	0.135
财务及管理费	0.029	0.060
体积成本(标准状态)	1.645	0.869

Source: 《煤制氢与天然气制氢成本分析及发展建议》, HTI

表 6: 碱性电解槽制氢成本分析

项目	具体成本
折旧成本	假设 $1000\text{Nm}^3/\text{h}$ 的电解槽成本为 850 万元, 土木和设备安装 150 万元, 采用直线折旧, 设备折旧期 10 年, 土建和安装折旧期 20 年。假设每年工作 2000h, 每年制氢 200 万 Nm^3 , 折旧成本为 0.46 元/ Nm^3
原料成本	每 1m^3 氢气消耗原料水 0.001t, 冷却水 0.001t, 水费 5 元/t, 原料成本为 0.01 元/ Nm^3
人工运维成本	人工成本和维护成本每年 40 万元, 人工运维成本为 0.2 元/ Nm^3
电耗成本	每 1m^3 氢气耗电 5kWh, 考虑到电解水制氢未来作为风光伏发电的储能用途来使用, 作为风光伏配套项目, 电解水制氢的电耗成本仅为风光伏发电的度电成本。因此, 我们分别采用工业用电价格、光伏度电成本、陆上风电度电成本与海上风电的度电成本作为单位电力成本进行测算。假设工业用电价格约为 0.56 元/kWh, 光伏发电度电成本为 0.3 元/kWh, 海上风电发电度电成本为 0.4 元/kWh, 陆上风电发电度电成本为 0.1 元/kWh。电耗成本分别为 2.8 元、1.5 元、2 元、0.5 元
单位体积氢气成本	根据电价差异, 氢气成本分别为 3.47、2.17、2.67、1.17 元/ Nm^3

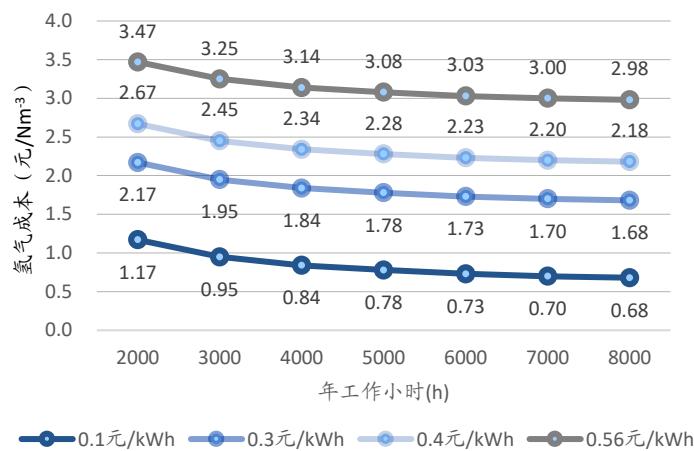
Source: 《电解水制氢成本分析》, HTI

表 7: PEM 电解槽制氢成本分析

项目	具体成本
折旧成本	1000 Nm^3/h 的 PEM 电解槽成本为 3000 万元, 土建和设备安装 200 万元, 设备折旧期 10 年, 土建和安装折旧期 20 年。假设每年工作 2000h, 每年制氢 200 万 m^3 , 折旧成本为 1.55 元/ Nm^3
原料成本	每 1m^3 氢气消耗原料水 0.001t, 冷却水 0.001t, 水费 5 元/t, 原料成本为 0.01 元/ Nm^3
人工运维成本	人工成本和维护成本每年 40 万元, 人工运维成本为 0.2 元/ Nm^3
电耗成本	每 1m^3 氢气耗电 4.5kWh, 考虑到电解水制氢未来作为风光伏发电的储能用途来使用, 作为风光伏配套项目, 电解水制氢的电耗成本仅为风光伏发电的度电成本。因此, 我们分别采用工业用电价格、光伏度电成本、陆上风电度电成本与海上风电的度电成本作为单位电力成本进行测算。假设工业用电价格约为 0.56 元/kWh, 光伏发电度电成本为 0.3 元/kWh, 海上风电发电度电成本为 0.4 元/kWh, 陆上风电发电度电成本为 0.1 元/kWh。电耗成本分别为 2.52、1.35、1.8、0.45 元/ Nm^3
单位体积氢气成本	根据电价差异, 氢气成本分别为 4.28、3.11、3.56、2.21 元/ Nm^3

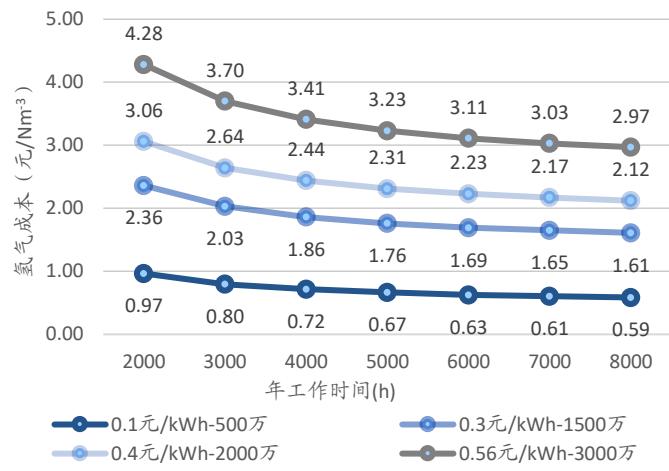
Source: 《电解水制氢成本分析》, HTI

图 4: 碱性电解槽制氢成本与电价和工作时间的关系



Source: 《电解水制氢成本分析》, HTI

图 5: PEM 电解槽制氢成本与电价、电解槽成本和工作时间的关系



Source: 《电解水制氢成本分析》, HTI

图 6: 中国光伏新增装机量 (GW) 及增长率 (%)



Source: CPIA, HTI

图 7: 中国风电新增装机量 (GW) 及增长率 (%)



Source: askci, HTI

附录 APPENDIX

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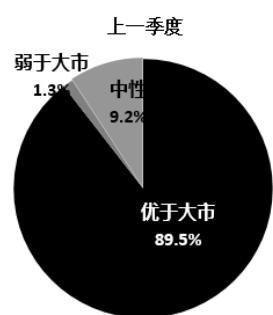
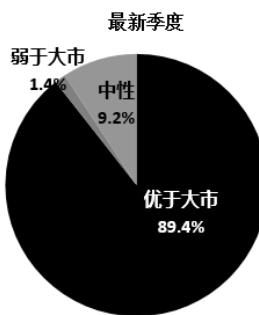
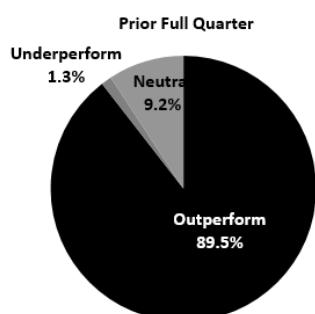
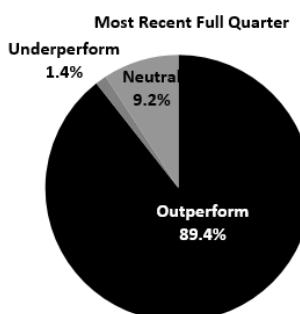
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卖出，未来 12-18 个月内预期相对基准指数跌幅在 10%以上，基准定义如下

各地股票基准指数：日本 – TOPIX, 韩国 – KOSPI, 台湾 – TAIEX, 印度 – Nifty100; 其他所有中国概念股 – MSCI China.

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*Percentage of investment banking clients in each rating category.

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