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News & Highlights

绿氢产业前景广阔

Sarah Derouin

Senior Technology Writer

长期以来，氢气一直被认为是化石燃料的替代品，前途不可限量，但氢气作为能源载体并未如预期那样得到广泛使用[1]。当下，低碳生产愈加实用，一系列立法激励措施的颁布，如美国《通胀削减法案》（IRA）的出台，正在促使人们谨慎思考：氢气到底能否作为一种具有成本效益、零排放的能源解决方案？2022年8月，美国电气与电子工程师协会《光谱》杂志刊载了一篇文章，标题为：2022年——氢经济启动的一年？[2] 无独有偶，2023年1月，可再生能源行业领先的商业情报来源Recharge上刊载的一篇文章宣称，2023年将是“绿色氢气”的“全球起飞年”[3]。

国际上的碳中和承诺、天然气价格的上涨以及可再生能源技术成本的下降，使许多国家和公司开始重新审视氢能[2]。专家认为，氢气能够实现几乎零碳和按需的电力生产，因此它成为全球经济中工业和交通部门去碳化的关键组成部分[4]。

美国科罗拉多州戈尔登市国家可再生能源实验室（NREL）能源系统集成设施项目电转气/电转X能力开发经理和负责人Kevin Harrison说：“《基础设施投资和就业法案》以及IRA便是近期最大立法尝试，这些法案希望通过在美国各地建立6~10个氢气中心，并颁布激励措施以生产低碳氢气，推动氢气技术的发展。”Harrison表示，一直以来，美国能源部氢燃料电池技术办公室每年会获批约1亿~1.5亿美元的资金支持，新立法则将与氢有关的能源技术（如氢气中心）的拨款提升至80亿美元。他说，全球各地政府以及工业界也在为氢气技术注入资金，以帮助降低技术成本和加速设施部署。事实上，除美国[2,5]外，近期多国都承诺会将氢气作为一种重要的能源载体，新的氢能项目也正在澳大利亚和亚洲[6–9]（图1）、欧洲[10–11]、中东[12–13]以及南美[14]等区域相继落地。

图1. 国际绿色氢气项目计划建立两处可再生能源发电厂，为电解提供动力。例如，位于西澳大利亚州的亚洲可再生能源中心（Asian Renewable Energy Hub）将包括一座可在白天收集太阳能的光伏农场以及在多风的夜晚进行能量收集的风电机组，上图为该中心的设想图。可再生能源的组合使用可为绿色氢气生产提供持续的能源，从而摆脱对化石燃料的依赖。来源：Pixnio（CC0）。

根据生产方法的碳足迹，氢气可被分为三种类型，即灰色氢气、蓝色氢气和绿色氢气[15]。目前最普遍的氢气类型为灰色氢气，它可通过蒸汽甲烷重整法进行生产。该方法通过燃烧化石燃料产生高温，将甲烷转化为氢气和二氧化碳[15–16]。天然气燃烧过程会排放大量二氧化碳，每生产1 kg氢气就会产生8~12 kg的二氧化碳[2,17]。如果以煤为动力，每千克氢气产生二氧化碳量则跃升至18~20 kg [2]。蓝色氢气的生产过程与之相同，但该过程中约

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85%~95%的碳会被捕集并封存[18]，因此每生产1 kg蓝色氢气约产生1~4 kg的二氧化碳[17]。

相比之下，以可再生能源（包括太阳能、风能、地热能和水力）为动力的电解法可将水分解成氢气和氧气，进而生产出绿色氢气，也称为低碳氢气。据估计，目前全球生产的氢气中绿色氢气占比不到2% [19]。从传统技术上来看，灰色氢气的生产成本明显低于绿色氢气——灰色氢气成本大约为每千克1~2美元，而绿色氢气成本则为每千克3~8美元[20]。政府通过颁布激励措施对其增加的成本进行抵消，使绿色氢气更具吸引力。美国IRA规定的每千克3美元的补贴或使绿色氢气的生产成本降至每千克0美元[21]。国际能源署预测，到2050年，氢气生产将增加五倍，其中大部分新生氢气类型为绿色氢气或蓝色氢气[22]。

虽然补贴能够降低生产成本，但要想实现绿色氢气的广泛应用，技术进步和基础设施投资同样不可或缺[2,12,23]。一些大型化石燃料公司已开始向包括绿色氢气在内的低碳或无碳能源领域进行投资[23–24]。例如，英国石油公司（英国伦敦）为澳大利亚亚洲可再生能源中心项目的主要投资者[22,25]；2022年7月，壳牌公司（英国伦敦）宣布将在荷兰建设欧洲最大的绿色氢气生产工厂[26]。

政府和工业界也正在投资改进绿色氢气生产技术。由于绿色氢气生产依赖由可再生能源驱动的电解槽（图2和图3），因此降低其成本尤为重要[27]。2021年，位于英国谢菲尔德的业内领先电解槽制造商ITM Power公司将其10 MW的系统定价为850万美元（85 000 USD·MW^{-1}）上下。该公司还表示，预计在2025年左右，他们能够以约5300万美元（530 000 USD · MW^{-1}）的成本制造出100 MW的系统[28]。“目前，一台电解槽的购置成本很高。”Harrison表示，“粗略地讲，要使绿色氢气的成本接近通过蒸汽甲烷重整生产的氢气，资本成本需要减少一半；要进一步实现氢气的广泛利用，该成本则需要进一步降低。”

尽管可能不会直接影响电解槽的初期购买成本，但研究人员目前正在探索提高电解槽效率及规模产出以实现其长期经济效益的方法[27,29–30]。在一项2022年12月报道的最新研究中，澳大利亚研究人员将声波引导到正在运行的电解槽上[31]。他们发现，高频波（10 MHz）可加速破坏水的氢键，可将水分解为氢的速度加快14倍，而使用的能量却比标准电解减少27% [31]。

其他一些研究工作集中于研究使用清洁水（对世界上许多地方来说是稀缺资源）进行电解的必要性，以避免腐蚀和有毒气体释放。2022年12月，一个来自中国的研究小组报告称，他们开发了一种使用海水进行电解的方法，并研发出一种膜，这种膜可使海水杂质远离电解系统中的电极[32]。在另一项于2022年9月报道的研究中，一个来自澳大利亚的团队提供了一种方法，即利用在吸水电解质液体中浸泡过的海绵从半干燥的空气中吸取水分，然后通过电解将水分解为氢气和氧气[33]。

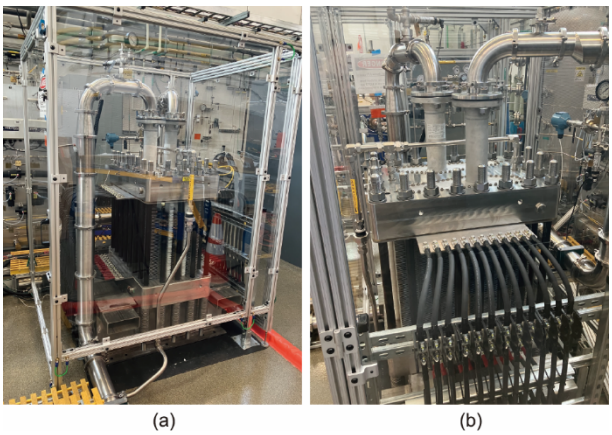

图2. 图为NREL的能源系统集成设施项目运行的1 MW的低温质子交换膜电解槽组，该装置以可再生能源为动力，可将水分解成氢气和氧气。总部位于美国科罗拉多州戈尔登市的NREL致力于推进经济实惠的氢气技术，为多个能源部门提供绿色氢气的生产、运输、储存和利用。资料来源：Kevin Harrison，授权使用。

图3. 图为由ITM Power公司于2021年在其位于英国谢菲尔德的工厂建造的电解槽，该电解槽利用可再生能源将自来水分解为绿色氢气和氧气。来源：Wikimedia（CC BY-SA 4.0）。

最近该领域的创新步伐已然加快，Harrison的经验证实了这一点。“在过去的15年里，我通常与两到三个小组合作，在NREL为他们的电解器技术提供性能和验证支持。”他说，“在过去的八个月里，我一直在努力为来自全球各地的十个团体提供支持，他们需要我们的帮助来验证并降低他们的技术成本。”

氢能格局确实在发生变化，权威经济政策研究所

Bruegel（比利时布鲁塞尔）的附属研究员Marie Le Mouel表示。她说：“就创新、经济和新技术的部署而言，我们可将其与太阳能行业的发展相提并论。”

可再生能源的可用性和可负担性也有助于增加绿色氢气的竞争力。在过去十年中，公用事业规模的光伏系统成本下降了82% [34]。风力涡轮机的进步也提高了其能源产量。例如，GE Renewable Energy公司称，较之以前的海上风力涡轮机，它们的巨型涡轮机的能源产量增加了45% [35]。

但绿色氢气的运输是区别于生产的另一项挑战。一些人建议重新利用现有的天然气基础设施来运输氢气 [36]，但这并不像设想中的那般简单。现有设施材料的兼容性以及对更高压力条件的承受能力均有待研究。相反，从实际和经济角度来看，将氢气集中到氢能中心——如目前许多区域计划建立的氢能中心，包括美国IRA法案支持建立的氢能中心——并将氢气用于某些特定工业部门，似乎是最可行的建议。

“氢气似乎更适合大规模应用。氢气运输的成本高昂且固定；因为你需要将它加压或低温冷冻到特别低的水平，所以在工业规模上大量使用它可能是最有意义的。”Le Mouel道，“人们对于氢能的一些典型的工业应用似乎已经达成了共识，如用于炼钢或制造化肥用氨。”在交通方面，以电池为动力的电动汽车几乎已经完全超越了以氢燃料电池为动力的汽车[1]。然而，仍有一些人认为在为重型车辆（如卡车、公共汽车和火车）提供动力方面，氢燃料电池拥有很大潜力，这些重型车辆可从中心站点补充燃料[1,23,36–40]。

Harrison表示，虽然补贴可在短期内增加低碳氢气的竞争力，但随着大规模生产使规模扩大以及科学和工程的进步，氢气作为无碳能源的经济可行性将在未来几十年内继续提高。“我们将保持与能源部以及行业伙伴之间的合作，力求在未来十年内，以最低成本，使水电解制氢的生产与其他形式的氢气生产持平。”他说道，“然后世界也会随之改变。”

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