广东省
二氧化碳利用技术及潜力
Guangdong CO2 Utilization Technical Report
讨论待修改稿
Draft for Discussion and Further Revision
In 2009, China's State Council proposed its 2020 goal for greenhouse gas emissions, and then in 2010 made Guangdong a low carbon pilot province. Guangdong has made remarkable achievements in greenhouse gas emission control to which the UK-China low carbon cooperation has contributed significantly. In September 2013 the UK Department of Energy and Climate Change (DECC) signed a joint statement in London with the Guangdong Development and Reform Commission, witnessed by governor Zhu Xiaodan of Guangdong Province, to strengthen low carbon cooperation. The joint statement highlights the importance of collaborating in Carbon Capture and Storage (CCS).

Supported by the Guangdong and UK governments, the UK-China (Guangdong) Carbon Capture, Utilisation and Storage Industry Promotion and Academic Collaboration Centre (the “Centre”) was officially founded on December 18th, 2013. The Centre is committed to promoting the demonstration of large-scale CCUS projects to tackle greenhouse gas emissions. At the same time, the Centre will also provide an international collaboration platform for solutions to other local pollution problems (such as haze, water pollution) caused by coal utilization, and to accelerate the industrialization for clean fossil energy technologies and to train qualified professionals.
Acknowledgements & Disclaimer

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1. 引言

1.1 CO2 利用技术简介

近年来，气候变化已严重威胁到人类可持续发展，应对气候变化成为了全球共同面临的重大挑战。政府间气候变化专门委员会（IPCC）评估报告指出大气中 CO2 浓度的增加是气候变化的最大推手（IPCC, 2013）。原则上，至少有三种方法可以减少大气中 CO2：在源头减少 CO2 排放；CO2 的捕获、封存（CCS）；CO2 的利用（Wang et al., 2014）。其中，对已经产生的 CO2 进行捕集与封存已经逐渐被公认为一项可以实现 CO2 大规模减排的方法，然而这项措施目前还存在着成本高，部分地区缺乏封存能力有不确定性等局限（Sridhar and Hill, 2011）。CO2 利用技术的经济应用和发展。CO2 的利用技术可以作为一个过渡方案，将捕集到的 CO2 附加价值，带来经济效益，补充 CCS 的成本，逐渐受到人们的关注。目前，尚未有成熟的利用技术能够为人类大幅度减排二氧化碳，除了二氧化碳提高石油采收率等地质利用，其他利用能够经济地减排二氧化碳非常有限。

具体来说，通过对排放的 CO2 回收利用至少可从四种途径缓解气候变化问题（Aresta, 2010; Audus and Oonk, 1997）：

1. 基于 CO2 利用技术的开发和利用的扶持，但从缓解气候变化问题的潜在重要措施。国际社会已经开始对 CO2 利用技术进行积极探索和发展。美国政府已经投资 10 亿美元于 CO2 利用技术开发和利用的扶持，但从缓解气候变化问题的潜力非常有限。

2. CO2 利用可以得到广泛的应用，它的减排潜力也是有限的，且并不能有效抑制大气中 CO2 的积累，可以减少 CO2 的向大气中的排放(Aresta, 2010)。尤其在现阶段，典型的利用技术中 CO2 被利用的周期只数天到数月，被利用的 CO2 存储于工业产品中，很快又会被分解，释放到大气中，很难起到减排的效果(Mikkelsen et al., 2010)。

3. CO2 利用可以减少或替代传统对气候变化有更大影响的物质，间接地缓解气候变化问题，例如在干洗业，用液体 CO2 替代氯化物溶剂（相同质量情况下，氯化物造成全球变暖的能力是 CO2 的数百至数千倍）。

4. By developing new reaction paths with CO2 as the reaction reagent to replace traditional chemicals which has greater influence on climate change, CO2 utilization may have an indirect contribution to mitigating climate change. For example, in the dry cleaning industry, chlorinated solvent and congeners are substituted with liquid CO2 (with the same mass, chloride has a climate change power many thousand-fold that of CO2).

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1.2 CO2 利用技术简介

1.1 Brief introduction to CO2 utilization technologies

The sustainable development of human beings has been greatly threatened by global warming, and the world is confronted with a big challenge to tackle climate change. The assessment report published by the Intergovernmental Panel on Climate Change (IPCC) indicated that the increase of CO2 concentration in the atmosphere is the biggest driver of climate change (IPCC, 2013). In principle, there are at least three ways to reduce CO2 in the atmosphere: CO2 emission reduction from source; CO2 capture and storage (CCS); and CO2 utilization (Wang et al., 2014). Among these, CO2 capture and storage is recognized as a technology that can realize drastic emission reductions, though its deployment and development is constrained due to its relatively high cost and limit of CO2 storage in certain regions (Sridhar and Hill, 2011). CO2 utilization technology, however, as a potential transition mechanism, is gradually attracting people's attention because it can add value to the captured CO2, bringing economic benefits and compensating for the cost of CCS. So far, there is not yet a mature utilization technology that could contribute to a deep cut of greenhouse gas emissions of human being. Apart from CO2 utilisation through geological enhancement oil recovery (EOR), other utilisation methods could only reduce or consume very limited amount of CO2 compared to the total amount of anthropogenic emissions.

CO2 geological utilization, such as enhance oil recovery (EOR), can enhance water recovery (EWR).

CO2 utilization can directly cut CO2 emissions to the atmosphere. For example, CO2 are converted to industrial chemicals and "stored" in such products.

1.1 CO2 利用技术简介

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视角专门对 CO2 利用技术进行评估，总结和支持还是近年来的事。需要提及的是本报告中 CO2 利用技术既指利用化学和生物的方法将 CO2 转化为其它分子形态的物质并从源来附加价值的技术，也指利用 CO2 自身的物理化学性质协助或强化其他过程（有时可以同时将 CO2 封存）的技术。特别需要注意的是，在实际发展 CO2 利用技术的过程中，需要对技术进行综合的评估，包括各个生命周期过程的减排潜力、能耗、环境影响、成本、原料等（Singh et al., 2014; Angunn et al., 2014;），同时还需根据 CO2 利用技术对地理位置、CO2 利用规模与纯度的要求，选择与相应的 CO2 排放源相结合，以实现真正的减排或其他社会经济收益。由于时间和专业知识的限制本报告仅对广东省几个典型的 CO2 利用技术进行初步的介绍和分析。

1.2 当今政策环境下 CO2 利用技术的意义

近些年来，中国一直努力推进低碳经济，循环经济以及二氧化碳的减排工作。2009 年的哥本哈根峰会上，中国承诺于 2020 将 CO2 排放强度较 2005 年减少 40%-45%。而现阶段，“十二五规划纲要”于 2011年 10 月底，批准 7省市开启碳排放权交易试点。广东省委和科技部在推动 CCS 和政策文委在推动 CCS 的技术支持，但目前尚不清楚碳市场能够支持哪种利用技术。CO2 利用技术作为是弥补 CCS 高成本的一项方法，也可能会得到进一步的促进，但目前尚不清楚碳市场能够支持哪种利用技术。

1.3 本报告的研究方法及结构

本报告通过现场调查、访问专家和文献收集的方法对广东省 CO2 利用技术进行了调查和总结，并根据技术发展阶段的介绍、技术研发、成本、示例、工业化等其他方面对技术进行综合评价。技术的成熟度可以评估为技术的进展程度，同时从减排潜力等其他方面对技术进行综合评价。技术和经济收益等其他方面对技术进行综合评价。分析其在当今政策环境下的重要方法。本报告的主体部分对广东省典型的 CO2 利用技术进行了介绍和总结。这些技术根据商业化程度，学科领域和创新度差异等分类进行描述。商业化 CO2 利用技术（第 2 章），CO2 的地质利用技术（第 3 章）以及创新型 CO2 利用技术（第 4 章）等相互协调，决定性的技术条件对技术进行综合评价。CO2 利用技术将对未商业化的技术对地理位置，CO2 利用规模与纯度的要求，选择与相应的 CO2 排放源相结合，以实现真正的减排或其他社会经济收益。由于时间和专业知识的限制本报告仅对广东省几个典型的 CO2 利用技术进行初步的介绍和分析。
China has been working for some time on a low carbon and circular economy, and CO2 emission reduction. The “Circular Economy Promotion Law” passed in 2008 actively promotes the reduced use, reuse and recycling of resources, reducing greenhouse gas emissions from the source and the production process (Li and Wu, 2014). CO2 utilization technology is a typical method to boost the circular economy and emission reduction at the same time as utilizing greenhouse gases as a resource. Chinese government has put stronger effort on greenhouse gas control. During the 2009 Copenhagen Summit, China committed to reduce its CO2 emissions intensity by 40%-45% over the 2005-2020 period. Most recently, China’s 12th 22 FYP set a national target for reducing CO2 emission intensity by 17% over the 2011-2015 period (Yan and Fang, 2015). The Outline also clearly put forward the intention to build a national carbon emissions trading market, to push for the transition from relying purely on administrative power to control greenhouse gas emissions to gradually relying more on market forces (Zheng, 2014). Consequently, the National Development and Reform Committee approved 7 provinces and cities to carry out carbon emissions trading pilot work. Guangdong province, as one of these provinces, started a carbon trading market in November 2013. In addition, both NDRC and Ministry of Sciences and Technology highlighted the role of CO2 utilization in promoting CCUS technologies and demonstration projects. With these policy background, the advantage of CO2 utilization technology which can bring both economic and social benefits is becoming more and more obvious. Because the application of CO2 utilization technologies is a potential “sink” of CO2, which may bring additional profit to such practice. In addition, if the carbon market can promote the development of CCS, CO2 utilization technologies may also be popularized since these can help mitigate the high cost of CCS, although it is still unclear which CO2 utilisation technology would be qualified for support from the carbon market.

1.3 Methodology and structure of the report
This report investigates and summarizes CO2 utilization technology in Guangdong province through field investigation, visiting experts, and literature review. It evaluates the maturity of those technologies which are not commercialized according to the technology development phase (the various phases are usually acknowledged as basic research, technology research and development, pilot test, demonstration, industrialization), and at the same time comprehensively evaluates the technologies in relation to their emissions reduction potential and other aspects.

This report is divided into five chapters. Chapter 1 makes a brief introduction to CO2 utilization technologies and analyzes their significance under today’s policy environment. The main body of the report introduces and summarizes the typical CO2 utilization technologies in Guangdong province. These technologies are described according to the level of commercialization, discipline and different levels of innovation in the following three chapters: commercial CO2 utilization technology (Chapter 2), CO2 geological utilization technology (Chapter 3), as well as innovative CO2 utilization technology (Chapter 4). Chapter 2 mainly deals with market supply and demand for commercial CO2 utilization. Chapter 3 and 4 mainly explain the technologies themselves, technical maturity and their development potential. Finally, Chapter 5 compares the maturity of those technologies that are not commercialized and indicates their potential in Guangdong based on their characteristics.

2. Traditional Commercial CO2 Utilization Technologies

2.1 Traditional Commercial CO2 Utilization Technologies

2.1.1 Technology Introduction
CO2, as a resource, has some important physical and chemical properties. CO2 gas is odorless at low concentration, but its acidic smell in relatively high concentration can cause suffocation and irritation. Under standard temperature and pressure, the density of CO2 is about 1.98 kg/m3, 1.67 times that of air. The CO2 will sublimate at minus 78.51°C, and solid CO2 is commonly known as “dry ice” which is usually used for freezing. Dry ice will gasify at room temperature at the same time absorbing a large amount of heat. CO2has a double molecular bond with two oxygen and a carbon atom, its structure is stable, and it is chemically inert, non-ignitable and non-toxic without flash points. CO2 is necessary for the photosynthesis of plants. Liquid and supercritical CO2 can both be used as a solvent, and the latter has a higher solubility than the former (its density and high solubility are close to liquid, and it is also of low viscosity and high penetration), but it requires more handling equipment than liquid CO2.

The traditional use of CO2 is mainly based on its physical and chemical properties, and the theory is relatively simple. The table below shows the physical and chemical properties of CO2 and their corresponding uses.
### 表 2.1 CO2 的物理化学性质与对应的利用方式

| 性质                        | 应用                                         |
|-----------------------------|----------------------------------------------|
| 较高浓度有窒息和刺激性     | 抑制细菌，食品保鲜，酿酒                   |
| 密度大约是空气的 1.67 倍，且不助燃 | 灭火                                         |
| 分子结构稳定，化学惰性     | 焊接时的保护气体                            |
| 固态 CO2（干冰）升华放热   | 制冷剂                                       |
| 植物光合作用原料          | 植物气肥                                    |
| 无色无臭；水溶液呈弱酸性，可缓冲溶液 | 饮料充气添加剂                               |
| 液体 CO2 气化膨胀         | 烟丝膨胀剂                                  |
| 液体 CO2 和超临界 CO2 高溶解性 | 清洗、萃取剂                               |

### 2.1.2 传统 CO2 应用行业分布

CO2 的物理和化学应用主要集中在工业级（纯度 >99.0）和食品级（纯度 >99.9）两个方向。总体上说工业级中应用包括：(1) 二氧化碳气体保护焊接；(2) 制冷剂（汽车空调制冷剂、干冰研磨清洗）；(3) 消防气体；(4) 固化硬化剂；(5) 超临界萃取和超临界清洗剂；(6) 植物气肥；食品级的主要应用行业有：(1) 饮料行业；(2) 酿酒行业；(3) 烟草行业；(4) 食品保鲜。这些传统的 CO2 利用技术大多对 CO2 的存储时间在几天到几个月间不等，存储时间较长的为植物气肥。需要注意的是，由于大多是的传统利用技术并没有转化 CO2，一旦应用，CO2 就释放到了大气中，因而对 CO2 的实际存储量主要在于存货量而不在于产量。

### 2.1.3 新型 CO2 应用行业分布

新型 CO2 的物理和化学应用主要集中在工业级（纯度 >99.0）和食品级（纯度 >99.9）两个方向。新型上说工业级中应用包括：(1) 二氧化碳气体保护焊接；(2) 制冷剂（汽车空调制冷剂、干冰研磨清洗）；(3) 消防气体；(4) 固化硬化剂；(5) 超临界萃取和超临界清洗剂；(6) 植物气肥。食品级的主要应用行业有：(1) 饮料行业；(2) 酿酒行业；(3) 烟草行业；(4) 食品保鲜。

### 2.2 CO2 商业化应用的市场供求状况

#### 2.2.1 中国 CO2 市场供求现状

#### 2.2.1.1 价值链

如图 2.1 所示，中国较为典型的二氧化碳市场价值链主要分为供应商、中间商和最终需求方 3 个环节。
第二章

2.2.2.2 供应商与成本分析

目前中国二氧化碳制造行业刚刚起步，业内约100多家生产企业可划分为三类：第一类为自建二氧化碳回收设备的化工企业，如化肥厂、酒精厂等，这类企业主要利用自身的工业废气，通常规模较小，仅万吨左右；第二类为自建二氧化碳回收设备的大型化工集团下属公司，如中石化广州分公司华达气体厂，这类企业可利用集团下多个子公司废气资源，逐个复制二氧化碳回收模式，现阶段规模较小，但有依托集团成长为大规模的潜力。目前仅中石化、中海油下的几个公司有此类业务；第三类为以二氧化碳为主营业务的生产型企业，如凯美特气，具有较大规模优势、产品技术/质量优势、物流配送优势、品牌/优质客户优势。这类企业包括凯美特气（310万吨/year），Praxair（a total of 90 thousand tons per year in Nanjing and Beijing），Chongqing Tonghui（70 thousand tons per year），等。二氧化碳的主要生产成本包括原材料成本、电费成本，折旧费等，主要采用对象为工业废气，电力等相关能源资源（图2.2以凯美特气为例展示了二氧化碳生产成本）。

对于回收工业废气的二氧化碳企业来说，由于工业尾气中二氧化碳浓度不同，回收的能耗差异较大，成本也有巨大差异。回收不同浓度尾气每吨用电成本为150～350元，加上其他费用，总成本为250～450元。如浓度为80%的尾气，每吨总成本要超过300元。在设备投资方面，回收设备的投资巨大，二氧化碳浓度较高的尾气装置需要投入上千万元，较低的甚至达到亿元。

对于采集地下二氧化碳气井的企业来说，由于地下气井中二氧化碳浓度不同，回收的能耗差异较大，成本也有巨大差异。回收不同浓度尾气每吨用电成本为150～350元，加上其他费用，总成本为250～450元。如浓度为80%的尾气，每吨总成本要超过300元。在设备投资方面，回收设备的投资巨大，二氧化碳浓度较高的尾气装置需要投入上千万，较低的甚至达到亿元。
二氧化碳产品不易储存与运输，需要低温、高压环境，还需要专用槽车进行运输，所以其经济运输半径较短，约为300 km的销售半径，相对于生产成本而言，二氧化碳的储藏与运输成本较高，运输距离过长。

2.2.1.3 供求现状

尽管CO2产品利润高，再加上CO2减排指标下降，排污权有偿使用、碳交易政策和碳税补贴的逐步落实，中国CO2利用行业可能进入快速发展阶段。同时，目前CO2的市场需求量相对每年的排放量极小。2013年总需求量占同年全国排放量（74.6亿吨）的0.02%以下，而部分利用技术只是普通二氧化碳排放，表明传统CO2利用技术很难起到减排作用。

从消费领域来看，全国二氧化碳需求的增长仍以饮料、食品保鲜、卷烟、焊接为主。从增长速度来看，预计2010-2015年间年均增长率最高为集装箱运输20%，其次为干冰19%，冷冻和冷凝16%，粮食包装16%，粮食储存12%，卷烟11%，焊接10%，啤酒8%，饮料5%，其他用途9.6%。

2.2.2 广东省CO2供应与需求概况

2.2.2.1 供应概况

根据数据，最大供应商凯美特气在广东液态CO2市场占有率为11%(2011年)，而2011年凯美特气在广东销售为8.3万吨，广东二氧化碳供给约为76万吨。按照30%的年增长率来看大约到2015年广东的CO2供给约为150万吨。然而CO2的供给也受到需求量和政策的影响大，技术和装备的更新水平，气源的稳定性等也会影响CO2的回收供应量。

过去数据显示，广东省的CO2产业利润高，同样以凯美特气公司为例，2007-2009年二氧化碳产品的平均毛利率高达73.4%，远高于国际大型气体生产企业。然而，对于公司中提取碳纤维的二氧化碳，由于其纯度达到99.9%，利用高压喷射回收方法，高压喷射混合气-液态，其综合成本每吨约为200元，其中电费成本约为40元，但其他成本包括资源费用，管理和设备维护费用。而且，气井不需要压缩系统，因此投资仅为回收公司的二分之一。

2.2.2.2 需求概况

广东省二氧化碳主要用于焊接和干冰研磨清洗。超临界萃取和气肥目前应用水平不高。根据凯美特气的估计，在2015年广东二氧化碳总需求约为160-200万吨，其中工业级约100-110万吨，食品级为50-90万吨。

2.2.1.3 Current supply and demand status

With high profits from CO2 products, the CO2 utilisation industry in China may experience a stage of rapid growth, fuelled by the gradual introduction of CO2 emission reduction targets, the need to pay for the use of pollution rights, guidelines on carbon trading policies and carbon tax subsidies. However, compared with national annual CO2 emissions, the current CO2 demand is limited. The estimated total demand in 2013 is less than 0.02% of the national annual CO2 emissions (7.46 billion tonnes), which means that it is difficult for traditional CO2 utilisation technologies to contribute to a massive emission reduction.

In the consumer sector, the growth of carbon dioxide consumption in China mostly occurs in the beverage, food preservation, cigarette, and welding industries. In terms of growth, the highest annual average growth rate (AAGR) in 2010-2015 was 20% for container transport, 19% for dry ice, 16% for freezing and cold storage, 16% for food packaging, 12% for food storage, 11% for cigarette production, 10% for welding, 8% for beer, 5% for beverage and 9.6% for other uses.

Figure 2.2 CO2 production costs by Kaimeite Gases

2.2.2 Overview on supply and demand of CO2 in Guangdong

2.2.2.1 On supply

Based on public data, the largest supplier Kaimeite Gas accounted for an 11% share of the liquified CO2 market of Guangdong in 2011, selling 83,000 ton the CO2 supply in Guangdong is about 760,000 ton. CO2-supply of Guangdong in 2015 will be about 1.5 million ton with a 30% annual rate of growth. However, the supply of CO2 is influenced by the demand and policy issues greatly, and the renewal of technologies and equipment and the stability of the gas sources will also affect the supply of recovered CO2.
The history profit margins of the CO2 production in Guangdong Province is large, taking Kaimeite Gas as an example, their average gross margin in 2007-2009 reached 73.4%, much higher than large international gas production companies like Linde (its average gross margin was 32.7%) and Praxair (that figure was 41.5%).

2.2.2.2 On Demand

Industrial-grade CO2 in Guangdong is mainly used in the welding and grinding industries and for cleaning with dry ice. Supercritical fluid extraction and gas fertilizers have not been applied at a high level. According to an estimate from Kaimeite Gas, the total demand for CO2 in Guangdong in 2015 will be around 1.5-2 million ton, nearly 1-1.1 million ton for industrial-grade and 500-900 thousand ton for food-grade.

Carbonated beverage industry

The distribution of welding businesses in Guangdong is as follows: according to Alibaba’s company news, there are 62 automatic welding businesses in Guangdong. If companies that also provide welding services are added together, there are nearly 150 companies that could possibly be involved in CO2 gas shielded arc welding.

Beer industry

CO2 is not only needed to increase the taste and quality of beer itself, but also useful in many processes during the production (such as cleaning and preloading). It is estimated that on average the production of one hundred litres of beer requires about 1.8-2.0 Kg of CO2 (Chen and She, 2006). In fact, fermentation process can produce a large amount of CO2, but only a little will dissolve in the beer. Although currently

CO2 recovery technology has been applied widely in domestic breweries with a recovery rate from 74% to 84%, the total amount of CO2 required by production of every thousand kl of beer is still greater than the recycled CO2, and the gap is about 2.4 ton (Tang, 2013). Based on 2014 data, brewers in Guangdong produced 4,8079 million kl of beer.As a result, the total demand is about -11,500 ton.

2.2.3 Development trend analysis

Compared to other types of industrial gases, the CO2 industry is unique in that it is greatly affected by limits on raw materials, transport conditions and policies. In recent years, because governments and enterprises have improved their environmental credentials, and CO2 emission reduction policies have tended to become more stringent, many enterprises with strong social responsibility now actively promote the fact that they recycle high CO2 concentration waste gases.
第三章

3. CO2 地质利用技术

3.1 CO2 驱油技术

3.1.1 技术简介

CO2 驱油 (Carbon Dioxide Enhanced Oil Recovery, CO2-EOR) 指将 CO2 注入油田，从而提高原油采收率的一项技术，也是目前唯一能够同时实现大规模 CO2 利用和大规模 CO2 封存的关键技术 (Manrique et al., 2010)。石油属于不可再生资源，一次开采大概能采出原油总量的 5%~20% 左右 (Sen, 2008; Uemura et al., 2014)，之后油田的储层条件会随之改变。二次开采即向油层注水来保持压力，一般能采出 15% 到 20% 的原油。二次开采之后一般还会有 60% 的原油未被采出。CO2 驱油作为一种二次开采技术被运用来驱油，4%到 15% 左右的原油有机会被采出。在美国，CO2 驱油技术现如今已经成为石油生产工业的重要部分（生产总量占美国陆上石油产量的 6%），并且不论在陆上还是海上产油都有强大的潜力。根据美国能源部的分析报告，全美 CO2 驱油产量是海上产油都有强大的潜力。根据美国能源部的分析报告，全美 CO2 驱油产量是海上产油量的 6%)，并且不论在陆上还

CO2 驱油技术现如今已经成为石油生产工业的重要部分，CO2 驱油技术可以分为混相驱油和非混相驱油。根据 CO2 与石油的混合情况，CO2 驱油技术可以分为混相驱油和非混相驱油。混相驱油适合运用于轻质油驱油，CO2 与原油充分混合为单相液体具有较小年

3.2 CO2 地质利用技术

3.2.1 技术简介

CO2 地质利用技术 (CO2 Geological Utilization Technology) 是指将 CO2 沉淀在油藏中，实现了 CO2 的封存。CO2 地质利用技术是目前唯一的能同时实现大规模 CO2 利用和大规模 CO2 封存的关键技术，也是目前唯一的能同时实现大规模 CO2 利用和大规模 CO2 封存的关键技术 (Manrique et al., 2010)。CO2 地质利用技术的开展需要限制，不能适用于所有的油田 (Ren et al., 2010)。CO2 地质利用技术的开展需要限制，不能适用于所有的油田 (Ren et al., 2010)

限制因素还有：驱油过程复杂；气体注入井的位置和数量的限制；废弃井的安全问题；在开采过程中发生的断裂 (Xie et al., 2014; Alvarado and Manrique, 2010)。

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CO2-EOR technology is relatively mature compared to other geological utilization technologies, but the development progress differs at home and abroad as well as onshore and offshore. The onshore oil fields in the US have used CO2–EOR for more than 40 years, whereas offshore oil fields have been developing at a slower pace. Several comprehensive studies on offshore CO2-EOR have been carried out over the past 10 years. However, the development of CO2-EOR technology in offshore oil fields faces many challenges, including limited platform space for CO2 recycling equipment, the expense of drilling new CO2 injection wells, and the need to transport CO2 from onshore sources to offshore platforms (Godec et al., 2013). Therefore, EOR applicability in offshore fields is limited compared to onshore fields (Manrique et al., 2010). In the future, advances in technology are required for undertaking the challenge of deploying innovative designs and advanced CO2–EOR technology in offshore oil fields (Godec et al., 2013).

3.1.2 Technology Maturity

CO2-EOR technology is relatively mature compared to other geological utilization technologies, but the development progress differs at home and abroad as well as onshore and offshore. The onshore oil fields in the US have used CO2-EOR for more than 40 years, whereas offshore oil fields have been developing at a slower pace. Several comprehensive studies on offshore CO2-EOR have been carried out over the past 10 years. However, the development of CO2-EOR technology in offshore oil fields faces many challenges, including limited platform space for CO2 recycling equipment, the expense of drilling new CO2 injection wells, and the need to transport CO2 from onshore sources to offshore platforms (Godec et al., 2013). Therefore, EOR applicability in offshore fields is limited compared to onshore fields (Manrique et al., 2010). In the future, advances in technology are required for undertaking the challenge of deploying innovative designs and advanced CO2-EOR technology in offshore oil fields (Godec et al., 2013).

3.1.3 China’s CO2-EOR Potential

China has a large potential for CO2-EOR in offshore oil fields, with several projects underway. One of the largest projects is in the Qaidam Basin, where a CO2-EOR project is being developed. This project involves injecting CO2 into oil reservoirs to enhance oil recovery. The Qaidam Basin is known for its high CO2 content, which makes it an ideal location for CO2-EOR. Other potential areas for CO2-EOR in China include the Bohai Bay Basin and the South China Sea. These areas have large oil reserves and are located near CO2 sources, making them attractive for CO2-EOR projects.
Chapter 3

3.1.3 CO2-EOR Potential Analysis of Northern South China Sea

Encompassing nearly 200,000 square kilometers (Figure 3.2), the Pearl River Mouth Basin is a Cenozoic oil and gas sedimentary basin, which includes all the oil fields which have been found so far in the northern South China Sea. Some natural gas fields have been found on the continental slope area in recent years. According to the 2008 assessment, the geological resources in the Pearl River Mouth Basin are 2.2 billion tons (16 billion barrels) of oil and 743 billion cubic meters of natural gas, of which the proven reserves are 583 million tons (4.25 billion barrels) of oil and 58.5 billion cubic meters of natural gas (Ministry of Land and Resources, 2008). Oil production in the Pearl River Mouth Basin began in 1990, and 16 oilfields have been put into production. Since 1996, the basin’s annual output of crude oil has remained efficiency. “Next Generation” CO2-EOR is planned for use in the project: intelligent well completions, dynamic down hole monitoring, tracer injections, extensive CO2 recycling, etc. for deep water.

In reservoir characterization phase, Extended Well Tests (EWTs) is used to define reservoir connectivity. The CO2 content from associated gas is recycled for miscible CO2-EOR. The existing wells and infrastructure are required for retrofit for corrosion resistant. Lula EOR includes one gas injector, two WAG (Water alternating gas injection) injectors and multiple producers. From 2013, the commercial scale CO2-EOR was opened. When the platform reaches full production, it could re-inject about 710 thousand tons of CO2 per year. From Lula case study, it comes to the conclusion that piloting phase is important in test how oil recovery will be effected by CO2-EOR.
Chapter 3

3.2 CO2 增强地热系统技术

3.2.1 技术简介

地热资源是一种稳定持续的清洁可再生资源，是未来能源利用的热点。由于目前主要开采利用的中低温，水热型地热资源有发电效率低，油田规模小的特点。因此，人们逐渐开始广泛关注地底3-10 km，以干热岩热能为主的增强型地热系统。CO2 增强地热系统 (Carbon Dioxide Enhanced Geothermal Systems, CO2-EGS) 在该技术的基础上发展而来，即使用超临界CO2 (压力 >7.382 MPa，温度 >31.04 ℃) 替代水作为增强型地热系统的工作介质。碳-岩增强地热系统(Carbon Dioxide Enhanced Geothermal Systems, CO2-EGS)在该技术的基础上发展而来，即使用超临界CO2 (压力 >7.382 MPa，温度 >31.04 ℃) 替代水作为增强型地热系统的工作介质。CO2-EGS在该技术的基础上发展而来，即使用超临界CO2 (压力 >7.382 MPa，温度 >31.04 ℃) 替代水作为增强型地热系统的工作介质。
3.2.3 The Potential for Guangdong Developing Geothermal Systems

Guangdong province is an area relatively rich in geothermal resources (as shown in Figure 3.4). Guangdong province is in the Circum-Pacific geothermal belt, and there are several fracture zones in geological structure, such as: Dianbai-Longchuan zone, Guangzhou-Conghua-Hailin zone, Lianhua mountain zone in northeast, etc. Lianhua mountain fracture zone traverse Shenzhen, Zhuhai, Zhongshan and other Pearl River Delta Region, in which the southwest of the Zhongshan, the south of Xinhui, the southeast of Doumen in Zhuhai and the south of shawan are potential large geothermal field in the future (Mao and Ma, 2011).

In addition, the development of geothermal utilization in Guangdong province take its place in the front ranks of China. In 1970, the first 86 kW geothermal power plant of Fengshun Fuxing in Guangdong Province is successful in its generating units trial test. In 1982, with the support of the Guangdong Department of Energy and the Science and Technology Committee, Guangzhou institute of energy conversion and other institutes built a 300 kW generating unit, which is still in normal operation. (Mao and Ma, 2011). What's more, recent research found that,
### 4. 创新型 CO2 利用技术

#### 4.1 CO2 合成可降解塑料

**Biodegradable plastics synthesized by CO2**

#### 4.1.1 技术简介

The theory of biodegradable plastics synthesized from CO2 relies on carbon dioxide and propylene oxide polymerized as C4H6O3 using a catalyst, as shown in Figure 4.1.

![Figure 4.1 copolymerization between CO2 and epoxide](image)

**CO2 和环氧化合物共聚技术的关键点和难点之一是催化剂的设计。CO2 是一种相对稳定的化学物质，如何将化学惰性的 CO2 活化并获得较高转化率是其资源化利用的关键，也是全世界科学家的研究的重要科学问题。**

由 CO2 和环氧丙烷的聚合而成的聚碳酸丙烯脂（C4H6O3）是一种脂肪族聚碳酸酯，具有较好的阻氧能力和一定的强度、透明性，还有良好的生物降解性能（Luinstra and Borcherdt, 2012），在使用内能完全堆肥降解，而传统的塑料通常不具备这种特性（Du et al., 2004）。

C4H6O3 polymerized by CO2 and epoxide is a form of aliphatic polycarbonate with good oxygen barrier properties, some intensity, transparency and biodegradability (Luinstra and Borcherdt, 2012), which can be completely composted and degraded within six months, while conventional plastic does not have this property (Du et al., 2004).

4.2 聚碳酸丙烯脂（C4H6O3）是目前可降解塑料中的主要成员之一，由于其良好的生物降解性能，被广泛用于包装、纺织、农业等多个领域。C4H6O3 copolymerization with CO2 and epoxide is a representative of degradable plastics with good oxygen barrier properties, some intensity, transparency and biodegradability. A survey report showed that, in the future, the demand for degradable plastic has increased significantly in various sectors such as packaging, textiles, agriculture, etc. The survey also indicated that the industry is in a nascent stage with high potential for growth. As a result, it is recommended to invest in R&D and market development to tap into the growing demand for degradable plastics.
4.1.2 技术成熟度及示范工程

CO2合成可降解塑料的催化合成技术已经进入了产业化示范阶段。由广东省研发机构和研发的技术应用于工业生产的示范工程主要有河南天冠集团有限公司和江苏金龙绿色化学有限公司的CO2基塑料生产线（表4.1）。

其中中山大学孟跃中团队通过发明高效催化剂，根据其发表资料显示，成功利用工业废气CO2合成出完全生物降解的塑料并开发出了中低压体聚合工艺和无污染、全循环、三级脱挥后处理工艺。这些工艺在河南天冠企业集团建成全球首个年产25000吨CO2基全降解塑料生产线（图4.2），并实现了长期稳定运转。此工艺利用中国科学院广州化学研究所生产每吨产品大约消耗0.43吨CO2，理论直接利用量为0.43吨CO2。除此之外，生产过程中CO2替代化石原料，还实现了间接减排。

4.1.3 减排潜力及环境社会效益

直接合成聚合物材料技术可以同时实现02的直接减排和间接减排。直接利用量：如反应方程式所示（图4.1），CO2与环氧丙烷共聚生成CO2基塑料PPC，生产每吨产品大约消耗0.43吨CO2，理论直接利用量为0.43吨。除此之外，生产过程中CO2替代化石原料，还实现了间接减排。
该技术由于以工业废气为原料,大大降低了合成塑料工业的原料成本,随着研发技术的日趋成熟,这种优势会越来越大,其带来的经济效益也将会逐年增加。该技术的环境社会效益有以下几点:

(1) 实现了工业废气 CO2 的资源化利用,有利于 CO2 减排;
(2) 合成的生物全降解塑料有利于解决“白色污染”;
(3) 用工业废气合成塑料,开发了新碳源,减少了对石油资源的依赖;
(4) 产品附加值高,原料成本低,有利于推动经济发展和调整塑料产业结构。

4.2 CO2 合成汽油添加剂
CO2 Synthetic Gasoline Additive

4.2.1 技术简介

碳酸二甲酯 (Dimethyl Carbonate, DMC) 作为一种化学原料没有毒性,被称为绿色化学品。近年来,美国已提出用 DMC 逐步替代甲基叔丁基醚作为汽油添加剂,提高辛烷值 (其具有 3 倍于甲基叔丁基醚的含氧量、高辛烷值、低挥发性以及生物可降解性) (Li and Zhong, 2002; Pacheco and Marshall, 1997)。简单来说,只需在汽油中加入 6% 的 DMC 即可将 90# 汽油优化为 98# 汽油。合成碳酸二甲酯的方法有光气法、甲醇氧化羰基化法、酯交换法和 CO2 和甲醇直接反应法 (Tundo and Selva, 2002)。前三种方法分别有环境污染、不安全、和高成本的缺点。由 CO2 和甲醇直接合成 DMC 不仅在合成化学、碳资源利用和环境保护方面具有重大意义,而且可使生产过程简化,生产成本显著降低,它是发展 DMC 生产的一条新途径 (Zhou et al., 2003),如图 4.3 所示。

该技术的难点是设计有效的催化剂和反应条件以打破二氧化碳的惰性及热力学平衡限制,另外产物分离也具有一定难度。

4.2.2 技术成熟度

目前,文献记录国内外 CO2 和甲醇直接反应合成 DMC 的技术还处于基础研究阶段 (Peng et al., 2014)。
中山大学孟跃中团队掌握的合成 CO2 和甲醇直接合成碳酸二甲酯技术走在了世界的前列，其开发的电辅助催化二氧化碳和甲醇直接合成 DMC 的规模化制备技术已经在河南南阳中聚天冠低碳科技股份有限公司进行中试（图 4.4）。

4.2.3 减排潜力

CO2 和甲醇直接合成 DMC 可以同时实现 CO2 的直接减排和间接减排。直接利用量：如反应方程式所示（图 4.3），生产每吨 DMC 可以约消耗 0.5t CO2，理论上是直接利用量为 0.5t CO2。除此之外，该技术较传统的酯交换和氧化羟基合成 DMC 技术，CO2 替代了化石原料，实现了间接减排。其中需要注意的是，如果对 DMC 进行生命周期评价，可以发现 DMC 最终燃烧又变成 CO2 释放到大气中，所以其减排效果主要体现在间接减排。

4.2.3 Potential to cut emissions

Synthesizing DMC by carbon dioxide and methyl alcohol can achieve both direct and indirect emission reductions of carbon dioxide. Direct uses: as demonstrated in the reaction equation (Figure 4.3), to produce a ton of DMC can consume about 0.5t CO2, which is equivalent to direct uses in theory. In addition, in comparison between this technology and conventional synthesis technology of DMC through transesterification and oxidation hydroxylation, CO2 replaces fossil fuel and indirect emission reductions are achieved. It should be noted that at the end of life cycle, DMC will be combusted and released into the atmosphere as CO2, so the emission reduction effect is mainly reflected in the indirect reduction.

4.3 微藻养殖耦合 CO2 减排

Microalgae Breeding Coupled with CO2 Emission Reduction

4.3.1 技术简介

Microalgae carbon sequestration technologies often refer to the process whereby autotrophic microalgae uses solar energy to absorb CO2 and converts it into its own material (Yang et al., 2009). As shown in Figure 4.5, CO2 usually exists in the atmosphere as a gas, and when
The technical requirements for microalgae carbon storage technology mainly include: 1 The selection of high-concentration-CO2-endured, high-carbon-storage-rate and anti-pollution algae, (good algae is the basis of efficient microalgae carbon storage); 2 Microalgae scale cultivation (culture conditions optimization and optical bioreactor design), to achieve efficient CO2 storage and high-density breeding of microalgae; 3 Microalgae recovery, to gain microalgae biomass and use it for the development of downstream products (microalgae biodiesel, food, health food, fish bait, feed, etc.).

If the CO2 is contained in flue gas, it can be purified by absorbing the NO and SO2 (Lam and Lee, 2012).

Table 4.2 Illustration of Microalgae Carbon Storage Demonstration Projects

| Company                        | Culture area(m2) | Application        | Source of technology                                                                 |
|--------------------------------|------------------|--------------------|--------------------------------------------------------------------------------------|
| Sanya Neptunus MarineBiological Technology Co., LTD | About 30,000     | Food Production    | South China Sea Institute of Oceanology, Chinese Academy of Sciences                 |
| Zhongshan Cyanobacteria Biological Food Co., LTD    | About 30,000     | Food Production    | South China Sea Institute of Oceanology, Chinese Academy of Sciences                 |
| Beihai SBD Bioscience Technology Co., LTD           | About 30,000     | Food Production    | South China Sea Institute of Oceanology, Chinese Academy of Sciences                 |
| Shenzhen Ludebao Health Food Co., LTD               | About 30,000     | Food Production    | South China Sea Institute of Oceanology, Chinese Academy of Sciences                 |

4.3.2 Technology Maturity

Technology for microalgae breeding to produce food coupled with CO2 emission reductions is currently in the industrialization demonstration stage. Wenzhou XIANG’ team in the South China Sea Institute of Oceanology of the Chinese Academy of Sciences has applied microalgae carbon storage technology to multiple food production demonstration projects, shown in Table 4.2.

If combined with flue gas, CO2 can also be absorbed to purify NO and SO2 (Lam and Lee, 2012).
The Institute has been focusing on demonstrating larger-scale industrialized microalgae carbon storage, pilots of new technologies and cultivation and testing of new algae breeds. One of the algae breeds being cultivated, chlorococcum alkaliphilus MC-1 (Figure 4.6), has great potential for emission reduction and oil production. Under domesticated cultivation, its oil content (which is rich in astaxanthin, linolenic acid, and can be used in the production of high value products) can exceed 55%. It is susceptible to large-scale outdoor cultivation and can adapt to cultivation in flue gas conditions. Finally, it has an automatic sinking characteristic in the later period of culture, which makes it easier to recover.

With abundant superior algae breeds available, the constant optimizing of culture techniques, and the accelerated development and enlargement of effective optical bioreactors (Huang et al., 2010), the resulting improvement in oil production rates and the efficient use of CO2 (Chen et al., 2009) are important means to reduce the cost gap between microalgae biodiesel and petroleum diesel, giving this technology great potential.

4.4 太阳光催化转化 CO2 技术

Sunlight Catalytic Conversion CO2 Technology

4.4.1 技术简介

Photoncatalytic reduction of CO2 is based on the simulation of plant photosynthesis. Its principle is that it uses solar energy to stimulate semiconductor photocatalytic materials to produce photoproduction electron-holes to induce oxidation-reduction reaction, converting CO2 and H2O into hydrocarbon fuels. The reaction equation is shown as Figure 4.7. Developing microalgae carbon storage technologies can also drive the development of China’s other many technology fields, and play an important role in China’s economic development: 1 by the comprehensive use of desert and wasteland, realizing CO2 storage could mitigate the pressure on China’s land; 2 using agricultural waste CO2 (CO2 separated from biogas) and wastewater to implement large-scale microalgae breeding and produce animal feed, would develop a regional green circular economy; 3 using industrial waste CO2 emissions (without CO2 capture, separation and purification) from existing big CO2 emitters such as power plants, steel mills, chemical plants for microalgae scale cultivation can produce energy (Yao et al., 2010).
直接以清洁可再生能源——太阳能作为驱动力无需耗费辅助能源；原料简单易得，可真正实现碳材料的循环使用；可将 CO2 转化为甲烷、甲醇等高附加值的燃料及其它化学品。

基于以上优点，该技术因而被认为是最具前景的 CO2 转化方法，但同时也是极具挑战性的前沿方向。

4.4.2 技术成熟度及难点
太阳光催化还原 CO2 技术还处于研发阶段，其技术难点之一在于太阳能的利用效率低（Wu and Lin, 2005）。以现有的可应用的光催化材料 TiO2, ZnO, SrTiO3 为例，反应只能利用占太阳能 4% 的紫外光，而要实现高效地利用太阳能，必须使用占太阳光能 43% 左右的可见光部分。目前已有一些报道高效可见光催化还原 CO2 反应体系的建立（Pan and Chen, 2007; Woolerton et al., 2010）。其它的技术难点有光催化材料对 CO2 吸附性能差以及对 CO2 活化和光生电子 - 空穴分离效率考虑不足等问题（Wu et al., 2011）。

4.4.3 前景展望
光催化还原 CO2 的研究与开发面临着许多问题。但是在持续不变的政策与经费的支持下，随着新型体系、新型结构的高效光催化剂的开发、光吸收、气体吸附、气体活化与光生载流子基本行为等诸多因素的最佳匹配的物理参数的调控，光催化材料纳米尺度的多功能化集成式设计，以及太阳能高效率利用、超强气体吸附与高效气体转化的光还原反应体系的最终建立，那么未来光催化还原 CO2 技术的规模化商业化应用并不是梦想（Wu et al., 2011）。

conversion, etc. In most technological approaches, conversion of CO2 needs demanding conditions; however, light catalytic reaction can be completed in relatively mild conditions with low energy input (Li et al., 2012). Other advantages of photocatalytic CO2 conversion technology include (Wu et al., 2011; Li et al., 2012): the direct use of clean and renewable energy (solar energy being the driving force, there is no need to consume auxiliary energy); its raw materials are simple and easy to find, and it genuinely recycles carbon material since it can convert CO2 into high value-added fuel such as methane, methanol and other chemicals.

Based on the above advantages, the technology is considered as one of the most promising CO2 conversion methods, but it will also be very challenging to take forward.

4.4.2 Technology Maturity and Difficulties
Technology for the catalytic reduction of CO2 by sunlight is still in the development stage, one of its technical difficulties being the low efficiency in the conversion of solar energy (Wu and Lin, 2005). Based on existing applicable photocatalysis materials, e.g. TiO2, ZnO, and SrTiO3, the reaction only uses 4% of the solar ultraviolet light, and to achieve greater efficiency, the reaction must use the visible spectrum which accounts for about 43% of sun light energy. There have been some reports about the establishment of efficient visible light catalytic reduction of CO2 systems (Pan and Chen, 2007; Woolerton et al., 2010). Other technical difficulties include photocatalytic materials for CO2 with poor adsorption performance and the insufficient consideration of CO2 activation and photoproduction electron-hole separation efficiency (Wu et al., 2011).

4.4.3 Prospect Outlook
The research and development of photocatalytic reduction of CO2 is faced with many problems. These include (i) the development of high efficiency photocatalysts with new systems and new structures, (ii) regulating and controlling the best match of physical parameters for many factors such as light absorption, gas adsorption, gas activation and the basic behavior of photon-generated carriers, (iii) multi-functional integrated design of photocatalytic materials on the nanometer scale, (iv) as well as the efficient utilization of solar energy, super strong gas adsorption and the final establishment of light reduction reaction systems with highly efficient gas conversion. However, under sustained policy and funding support, the large-scale commercial application of photocatalytic reduction of CO2 technology in future may not be a dream (Wu et al., 2011).
调查结果表明，广东省从技术的掌握程度和发展条件上具备进一步发展 CO2 利用技术的潜力，但目前利用技术对碳减排效果不明显。广东省 CO2 利用技术涵盖从传统的商业化 CO2 利用技术到地质利用技术，再到一些创新型的利用技术。广东省 CO2 利用技术涵盖从传统的商业化 CO2 利用技术到地质利用技术，再到一些创新型的利用技术。覆盖类型广，层次多。已经商业化的利用技术在广东省主要分布焊接和饮料业，已形成成熟的市场价值链，但技术主要利用 CO2 自身性质，较少涉及对 CO2 的转化等深层次的利用，产品附加值小，且典型的利用技术 CO2 被利用的周期只有数天到数月，应用规模小，减排的效果小。未实现商业化的 CO2 利用技术主要包括对 CO2 的化学或物理转化和地质利用。总体上减排潜力相对传统技术大，且产品附加值高，但不同 CO2 利用技术成熟度不同。

具体来说，两种化工应用 CO2 利用技术（CO2合成降解塑料、汽油添加剂）发展较为成熟，已经到达技术中试以及以上水平。这是因为这些技术本身的发展累积外，还由于相关科研机构科研团队自主研发能力的提高。两种在广东省发展的潜力的地质利用技术成熟度差异较大。CO2-EOR 技术在国际上已经工业化，中国在其他地区也积累了丰富的经验，广东省虽然未有具体的实践，但技术问题不会制约其应用，目前比较急迫的是对珠江口盆地的油田进行 CO2-EOR 可行性分析。广东省有良好的发展 CO2-EGS 技术的条件如有高地热梯度地热资源，目前首要的任务是对技术的研发和试验。微藻养殖耦合 CO2 减排生产食品的技术已经发展到示范阶段，但最新的研究成果和技术的革新需要进一步的中试。

太阳光催化转化 CO2 技术是被认为是最具前景的 CO2 转化方法，同时也是最具挑战性的前沿方向，需要大力推进基础研究和技术研发。广东省发展二氧化碳利用技术还有一定的紧迫性。这是因为一些技术的应用有最佳时期，一旦错过就无法挽回。例如 CO2-EOR 技术，必须在油田废弃之前若干年完成评估工作，因为从作业成本考虑，海上油田的开采速度一般较高，而一旦油田枯竭就要及时废弃，那时再考虑 CO2-EOR 就不再可能。另一方面从 CO2 利用技术的成熟度来看，广东省掌握着一些技术走在全国前列甚至是世界前列，加快促进这些技术的规模化和商业化，才能保持竞争力，带来较大的经济效益。而随着全世界对 CO2 利用技术的关注度的增加，一些前沿的创新型的技术正逐渐越来越受到科学家重视，需要把握机遇，学习和自主创新研发这些技术，以增加广东省减排和可持续发展的潜力。
Further comprehensive studies of carbon dioxide utilization technologies might achieve the following:

1. CO2 geological utilization has the highest potential in carbon reduction, but it requires further feasibility study in Guangdong. On the other hand, there is not yet a mature utilization technology that could potentially achieve a deep cut of carbon emissions in Guangdong. CO2 offshore geological storage technology remains the most important abatement technology.

2. To develop CO2 utilization technologies, the technologies should be evaluated in a lifecycle method, including the emission reduction potential, energy consumption, environmental impact, the cost and raw materials etc. in the entire life cycle. During the estimation of emissions reduction potential, every potential "source" and "sink" for CO2 in different process of application should be considered, such as energy and products consumption. But emissions reduction potential should not be the only criteria, any CO2 utilization technology which can achieve overall higher social and economic benefits could be listed among the objects of development.

3. To combine other projects on environmental management so as to promote sustainability. Because some technological developments are facing high cost barriers, cost cutting and social and environmental benefits can increasing be achieved if development is promoted in combination with other environmental management projects. For instance, microalgae cultivation coupled with carbon dioxide emission reductions could be integrated with waste water treatment.

4. To increase scientific and technological innovations so as to enhance the added value of products. Scientific and technological innovations are catalysts for carbon dioxide utilization technologies, which can not only improve the efficiency of carbon dioxide utilization but also increase economic benefits. Therefore, progressively promoting innovative carbon dioxide utilization technologies with those which urgently await R&D can have a multiplier effect.
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