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# Non-Sequestration Utilization Options for Carbon Dioxide ($CO_2$)

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Report Abstract
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Nexant

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## INTRODUCTION

Carbon dioxide ($CO_2$) is a colorless gas, normally odorless, but in high concentration, can have a sharp smell. It is released into the atmosphere and within the oceans naturally by a range of mechanisms including plant and animal respiration, organic matter decay, and volcanic activity.

Since the Industrial Revolution in the 1700s, human activities, such as the burning of oil, coal and gas, and deforestation, have increased $CO_2$ concentrations in the atmosphere. According to the U.S. Environmental Protection Agency (EPA), global atmospheric concentrations of $CO_2$ were 35 percent higher than they were before the Industrial Revolution. Left unchecked, the atmospheric concentration of $CO_2$ can only be expected to grow, as developing nations undergo their own large-scale industrial growth, and seek a standard of living comparable to much of the industrial world.

The prospect of increased $CO_2$ concentrations is problematic because it is considered a greenhouse gas (GHG). GHGs are defined as gaseous constituents of the atmosphere that both absorb and emit radiation within the thermal infrared range. It is widely believed that excess greenhouse gases have contributed to the trapping of heat in the earth's surface atmospheres (commonly referred to as the greenhouse effect).

Scientists have recommended that society regulate emissions of $CO_2$ to avoid dangerous shifts in climate change. As a result of this, coupled with supporting government legislation, several potential options aimed at reducing the amount of $CO_2$ emitted to the atmosphere from human activities have been and are continuing to be developed.

There is the carbon capture option whereby carbon dioxide emitted from human operations such as fuel power plants can be captured using techniques such as the conventional absorption of carbon dioxide using an amine solvent, such as monoethanoloamine (MEA). This technology has been retrofitted throughout the world and used for various industrial and commercial processes (for example, in enhanced oil recovery and urea yield boosting). Other carbon capture options exist. Once captured, sequestration technologies may be employed. Sequestration includes methods that involve storing the chemical, for example, by injection into structural reservoirs in geological formations such as aquifers and depleted oil and gas fields, or liquid storage in the ocean. However, carbon capture and sequestration (CCS) is not the focus of this report and will not be discussed (Nexant will publish a PERP report on CCS in April 2013).

Non-sequestration utilization options for $CO_2$ is the focus of this report and in this report is defined as those processes using $CO_2$ as a feedstock and its conversion into another chemical or material. Nexant has covered those non-sequestration options it judges to be the most achievable and potentially profitable (non-sequestration) technologies for utilizing $CO_2$.

## $CO_2$ UTILIZATION OPTIONS COVERED IN THE REPORT

The existing and potential and developing non-sequestration $CO_2$ utilization technologies covered in this report include:

- Organic carbonates

  Used in engineering plastics such as polycarbonate and in developing "green polyurethane" some of the greatest success in monetizing carbon dioxide has occurred through the production of organic carbonates. Conventional technology already exists and is widely used throughout Asia. Additionally significant headway is being made in producing carbon dioxide based isocyanates and polyether carbonate polyols based on carbon dioxide.

- Algae biofuels

  Using natural non-sequestration options, algae convert carbon dioxide and water to sugar by photosynthesis. Algae can be used to convert carbon dioxide into carbon forms such as oil, protein, lipids, and carbohydrates, which can then be extracted and further processed for biofuels and co-products. Compared to other biomass feedstocks such as palm and jatropha, algae have a much higher oil yield per acre, though currently this option is seen as expensive.

- Synthesis gas

  An important, versatile feedstock used in the production of commodity chemicals such as methanol and ammonia. It is a gaseous mixture of carbon monoxide and hydrogen gas thus its use in supplying hydrogen as a fuel is commonly a topic of interest. Carbon dioxide can be converted to syngas by methane (or dry) reforming. Additionally it can be used in the reverse water gas shift reaction, a useful reaction that can alter the stoichiometric quantities of syngas.

- Urea, salicylic acid, food and beverage

- Urea is the largest user of carbon dioxide in organic synthesis globally having been used for more than 40 years. Urea is the most important nitrogenous fertilizer in the world. Carbon dioxide reacts with ammonia to produce ammonium carbamate followed by its slow dehydration to urea.

  The food and beverage industry is the second largest industrial carbon dioxide consumer; it is used for decaffeination of coffee, carbonation of fizzy drinks, and as a refrigerant amongst other uses.

  Salicylic acid, used in aspirin production, has utilized a carbon dioxide feedstock for at least 100 years. Produced through reaction of phenol and carbon dioxide in a simple process requiring no specialized catalyst.

- Methanol

  Production is conventionally enhanced by reaction of hydrogen with carbon dioxide, however a direct route also occurs.

- Miscellaneous fuels

  The Holy Grail of carbon dioxide non-sequestration options, converting carbon dioxide to jet fuel. Bacteria that can produce fuels and a novel method of producing formic acid, a potential fuel storage source for use in fuel cells.

- Cement

Potentially the most lucrative option. Cement production is the world's third largest industrial source of carbon dioxide emissions, with each ton of cement production emitting up to one ton of carbon dioxide. Nexant reviews the companies trying to reverse the process, to produce cement from carbon dioxide, and also those that strengthen cement by absorbing carbon dioxide in the process known as carbonation.

## OUTLINE OF THE REPORT

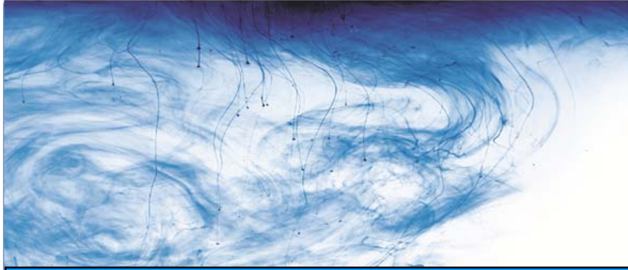
For each non-sequestration option listed above:

- Technologies available or developing are discussed.
- Key players are identified.
- Regulatory and commercial considerations that apply to $CO_2$ use in these industries are highlighted
- The extent to which $CO_2$ might be utilized in the global market is estimated (i.e., supply/demand on a global basis, as well as U.S. and China regional breakdowns).
- Costs of production estimates (including capital investment required) for the following have been evaluated:
  - Commercial dimethyl carbonate and polycarbonate processes that already use $CO_2$
  - $CO_2$ utilization in urea production.
  - Speculative economics are given for the potential of ethanol production from algae utilizing $CO_2$.

  For the manufacture of the products above from $CO_2$, detailed cost tables are given, and include a breakdown of the cost of production in terms of raw materials, utilities consumed (electrical energy, cooling water, fuel etc.), direct and allocated fixed costs, by unit consumption and per metric ton and annually, as well as contribution of depreciation to arrive at a cost estimate. Capital costs are broken down according to inside battery limits (ISBL), outside battery limits (OSBL), other project costs, and working capital.

- For other processes, the economics for the conventional commercial (non-CO2 consuming process) to manufacture the product are given; and high level comments on the economics with respect to the potential of the alternative developing $CO_2$ consuming process to the product are given (but production cost estimates are not attempted in these cases due to the lack of reliable information to make a credible assessment).

The report concludes with a brief analysis of global carbon emission policies and standards. Global attitudes toward $CO_2$ emissions are particularly relevant, since carbon credits and the spread of emissions trading platforms could help render some non-sequestration $CO_2$ technologies economically justifiable.



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