Beneficial Uses of CO_2

Technologies and Implications for a Carbon Market

Andrew McIlroy, PhD

Senior Manager for Chemical Sciences

Combustion Research Facility

Sandia National Laboratories

Livermore, CA

with

Mark Allendorf & Ellen Stechel

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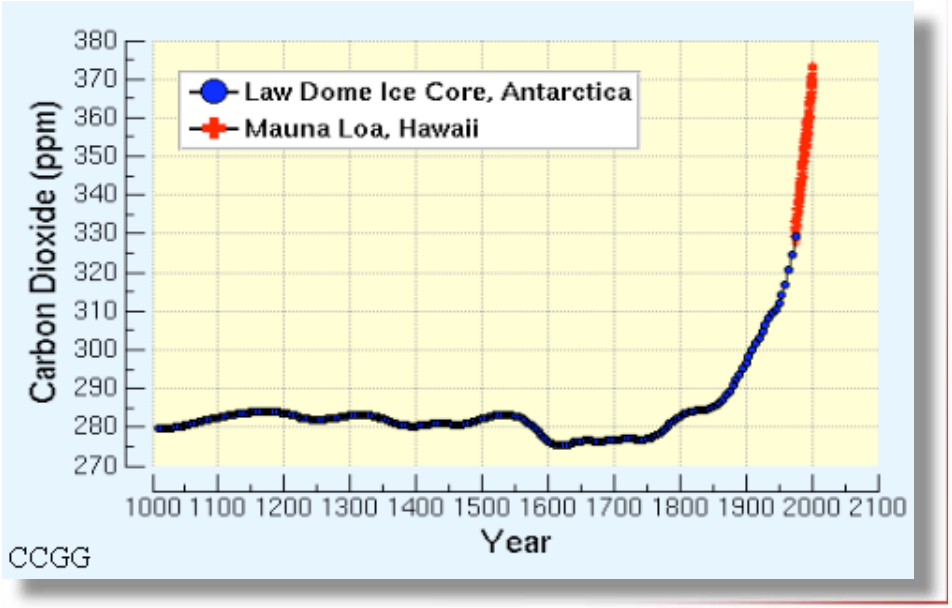
Introduction

- Average preindustrial level = 280 ppm (~2200 Gt)
- Human activity currently adds 2 ppm/yr (15 Gt /yr)
- Current total atmospheric CO_2 = 380 ppm (~ 2900 Gt)
- Primary sources:
  - Electricity production
  - Vehicular transport



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Primary sources of CO_2

Source	US 2000 (Gt)
Fossil fuel combustion [Electricity generation] [Transportation]	5.6 [2.2] [1.9]
Iron and steel production	0.066
Cement manufacture	0.041
Waste combustion	0.022
Ammonia manufacture	0.018
Lime manufacture	0.013
Limestone/dolomite use	0.009
Natural gas flaring	0.006
Aluminum production	0.005
Soda ash manufacture/consumption	0.004

Source: EPA, EIA and SPCC TAR

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CO_2: Pollutant, By-product or Waste?

- Carbon trading, carbon taxes, or other forms of carbon control will put a value on CO_2 as a GHG
- Other waste streams have been found to have value
  - Aluminum cans, glass containers, newspapers, cardboard, etc.
- Four strategies linked to the value of CO_2
  - Reduce
  - **Displace other GHG**
  - Sequester
  - **Convert and reuse**

Global Warming is More Than Just CO_2

Gas	GWP
Carbon Dioxide	1
Methane	23
Nitrous Oxide	296
HFC-23	12,000
HFC-125	3,400
HFC-134a (automotive A/C)	1,300
HFC-143a	4,300
HFC-152a	120
HFC-227ea	3,500
HFC-236fa	9,400
Perfluoromethane (CF_4)	5,700
Perfluoroethane (C_2F_6)	11,900
Sulfur Hexafluoride (SF_6)	22,200

Refrigerants

Source: ICPP Third (2001) Assessment Report

GWP = Global warming potential. GWP(CO_2) = 1

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Displacement: CO_2 Replaces Higher-Impact Greenhouse Gases

- An Example: CO_2 as a replacement for HFC-134a refrigerant commonly used in vehicles
  - HFC-134a GWP = 1300
- Average leakage = 40 g/year/vehicle
- 243 million vehicles in US (2004), ~ 90% have A/C $\rightarrow$ ~ 0.013 Gt/yr CO_2 equivalent emitted
- CO_2 can be a solution, not a problem

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Reuse: Delay the Release of CO_2 to the Atmosphere

Present Primary Industrial Uses of CO_2

	Market (Gt/yr)	Lifetime
Fertilizer (urea)	0.090	Six months
Methanol	0.024	Six months
Inorganic carbonates	0.008	Decades to centuries
Organic carbonates	0.003	Decades to centuries
Polyurethanes	0.010	Decades to centuries
Technological	0.010	Days to years
Food	0.008	Months to years

"A large proportion of all CO_2 recovered is used at the point of production to make further chemicals of commercial importance, chiefly urea and methanol" *IPCC* report 2005

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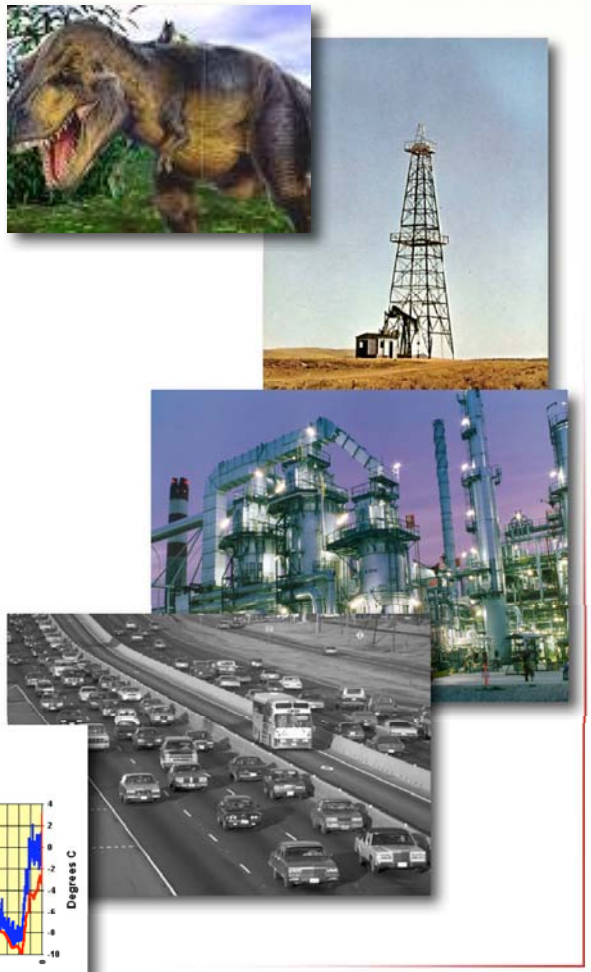
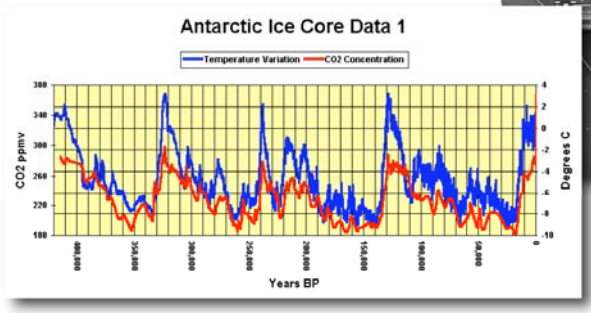
Convert and Reuse:
Only Fuel Scales to CO_2 Problem

- 'Problem' CO_2 came from fuels
- In principle, it can be recycled
- BUT, where does the energy come from to convert CO_2 back to fuel?
  - Solar (biofuels… or something better)
  - Nuclear





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How to capture the CO_2?

- Two major possibilities
  - Capture it at the source
    - Most practical for stationary sources
    - Easiest with pure oxygen combustion
    - Demonstrations now underway
  - Remove it from the atmosphere
    - Challenging, but not impossible
    - Wind naturally moves vast quantities of air
    - Feasible to build scrubbers that to pull CO_2 directly from air
    - Potential to disconnect capture from source
    - Not yet demonstrated at scale or in field

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Solar Driven CO_2 to Fuel

Biofuels Without the Biology

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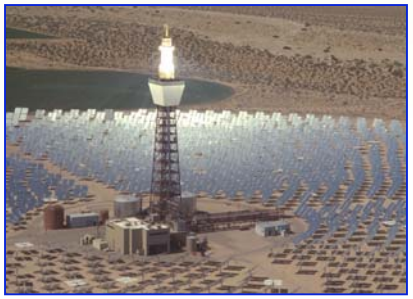
Solar Heating



CO_2

H_2O

Energy Input
(Reduction)

CO_2
H_2O

Fuel
O_2

Energy Recovery
(combustion)

Transportation Fuels (Gasoline, Diesel, Jet Fuel)
Natural Gas (CH_4)
Chemical Precursors

O_2

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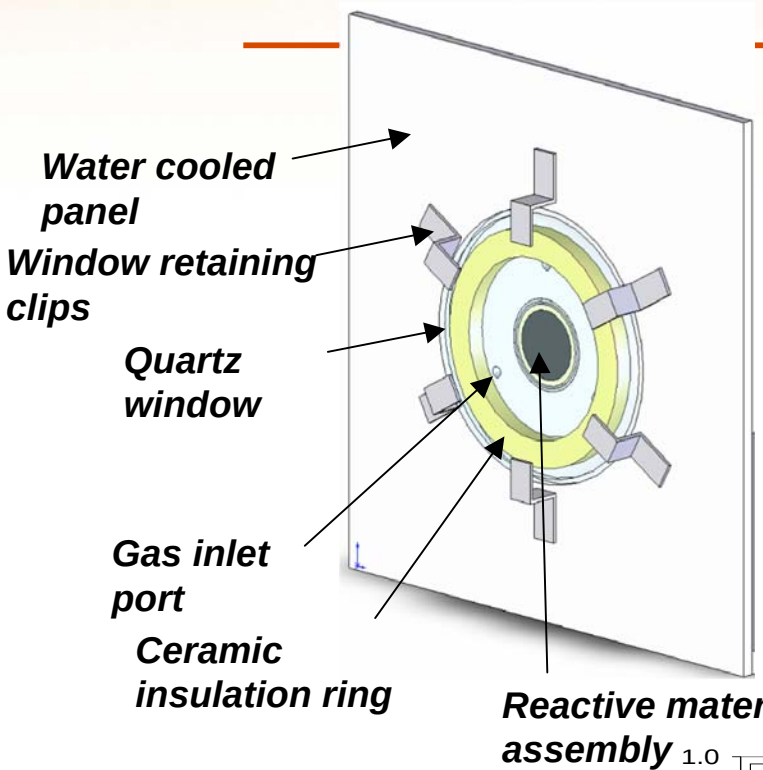
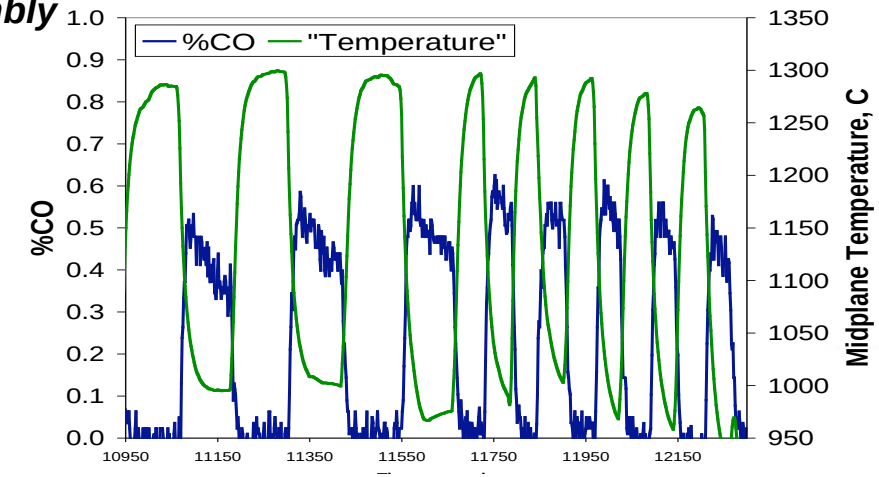
CO_2 Splitting Shown Feasible



- **Two types of catalysts have demonstrated the ability to split both H_2O and CO_2:**
  - **$2H_2O \rightarrow 2H_2 + O_2$**
  - **$2CO_2 \rightarrow 2CO + O_2$**
- **H_2 and CO combine to produce Syngas**
- **Syngas can be converted to any hydrocarbon fuel**



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Technically Possible: Moving CO_2 From Waste to Resource

- Technology development needed
  - CO_2 capture development
  - CO_2 to fuel efficiency improvements
- Regulation needed
  - True cost of CO_2 occurs on a timescale incompatible with market forces
  - Regulation is needed to connect these costs on a more immediate timescale

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Market Questions

- How does capture, convert and reuse change the carbon market?
- How long a delay must be realized to earn a carbon credit?
- Can today's market mechanisms spur investment in the recycle of CO_2?

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