Beneficial Uses for CO_2 Within the State of California

Research Roadmap for Carbon Sequestration Alternatives

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Outline of Presentation

Past, present, future trends

- Background on Energy Commercialization
- One year ago
  - Beneficial Use Analysis
- One year later
  - Results from study / future needs
- One year in the future……

- Emphasis on Identifying Market Impacts
- More than an Academic Study
- Requires Consideration of Technology, Regulatory, & Market Drivers

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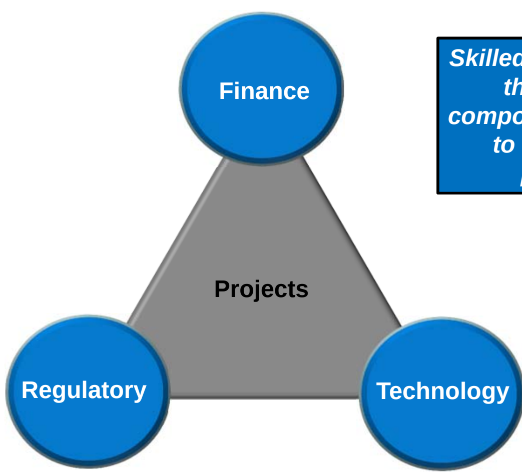
Energy Commercialization Bio

C-Level execs experienced in energy and reducing operating expenses

- Limited Liability Corporation within the state of California
- Certified small business within the state of California
- Accounting system designed to meet DCAA / DOE requirements
- Experienced working with the Department of Energy (DOE)
- Most of team +30 years experience
- Active in Middle East and Southeast Asia
- Skilled at forming teams to deploy energy technologies
- Project developer for +20 MW projects in US and internationally
- Understand PPA, FIT, and other factors affecting energy deals

Driving and Managing Energy Projects

Energy projects enabled when combining all three components



Skilled at integrating these three components in order to implement projects

Westcarb 2010 :Beneficial Use of CO_2

Based on financial, regulatory, environmental climate in 2010

	Building Materials	EOR	Algae & Bioconversion	Chemical Conversion	Geothermal	Water production	CFC Replacement	Consumer	Conventional CCS (aquifers)
Geographic Constraints	L	H	M	L	H	L	L	L	H
Backend Liability	L	M	L-M	?	M	M	L	L	H
Difficulty of Lifecycle Analysis	L	L-M	H	H	L	M	M	H	L-M
Sensitivity of Market Economics (Local: H; Regional: M; Global: L)	M	L	L	M	M	M	H	H	M

What has Happened Since?

One year later…..

Worldwide trends in CCS projects:

- Modest growth in large-scale integrated projects from 64 in 2009 to 77 in 2010 and now 74 in 2011
- Projects in construction have increased from two in 2009, to four in 2010 and is now at six in 2011
- Projects are moving forward but building a viable business case is proving to be a complex and time consuming process

Per Global CCS Institute October 2011

Pricing carbon:

- Australia carbon tax
- California passes Cap and Trade

"a lot of people didn't expect us to be here. We surprised a lot of people"

Tim Lincecum, SF Giants

The Roadmap…

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Purpose of Study

Required by legislation

- **Designed to provide future R&D guidance**
- **Focus on technologies with potential to assist CA in meeting GHG emissions goals (*per Governor's Executive Order S-3-05 in 2005 and Assembly Bill 32*)**
- **In-state industrial sources:**
  - **Refineries, cement plants and natural gas power generators**
- **Out-of-state sources:**
  - **Large coal-fired power plants importing power into the state**
  - **High-carbon fuel stocks for refineries**
- **Recommended technologies**
  - **Reach commercialization commensurate with the time frames for California's emissions goals in 2020 and 2050**
  - **Have the potential to make significant contributions to GHG reduction**

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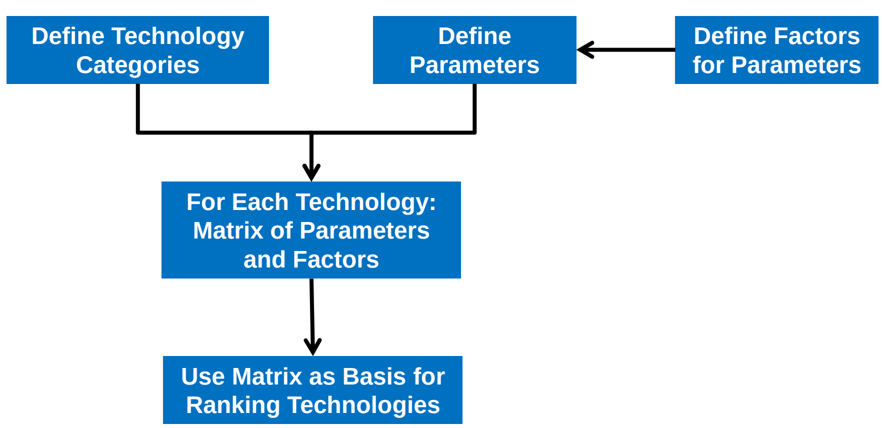
Defining Beneficial Use

Must involve producing a product

- Technologies that produce a useful product directly from captured anthropogenic CO_2 or in connection with the processes of capture or sequestration of CO_2.
- Capture technologies are ***out-of-scope*** unless they produce a product as part of the capture process
- Geologic sequestration not included ***except*** in cases where something of value, such as additional oil, gas, geothermal heat, or water, is a byproduct.

Systematic Process Used

Enables comparison of a variety of technologies



Five Key Factors Addressed

Looks beyond CA border

1. **State of R&D**
2. Lessons learned and synergy with other efforts
3. Technology barriers and knowledge gaps
4. Role of CO_2 Utilization in Climate Change Mitigation in California
5. Recommendations on Funding through the State of California

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Categories of Technologies Examined

Casting a wide net for analysis

CATEGORIES	TECHNOLOGY DESCRIPTION
CO_2 as a working fluid	• Enhanced oil recovery (EOR) • Enhanced gas recovery (EGR) • Enhanced coal bed methane recovery (ECBM) • Enhanced geothermal systems (EGS)
CO_2 for Building Materials Manufacture	• Carbonates and other construction materials
Biochar	• Pyrolysis of biomass
Fuel and Chemical Production	• Chemical Conversion • Biological Conversion
Power Generation Applications	• Super critical CO_2 for Brayton Cycle Turbines • Working fluid / cushion gas for energy storage
CO_2 as a Solvent	• Supercritical fluid extraction and other food processing applications • Dry cleaning
CO_2 in Agriculture and Biomedical Applications	• Greenhouse atmosphere additive • Grain silo fumigant • Sterilization for biomedical applications
Miscellaneous Industrial Applications	• Fire extinguishers • Shielding gas for welding • Refrigeration and heat pump working fluid • Propellant • Rubber and plastics processing - blowing agent • Cleaning during semiconductor fabrication
Water from displaced aquifer fluids	• Water purification • Extraction of Value Added Solids from Water

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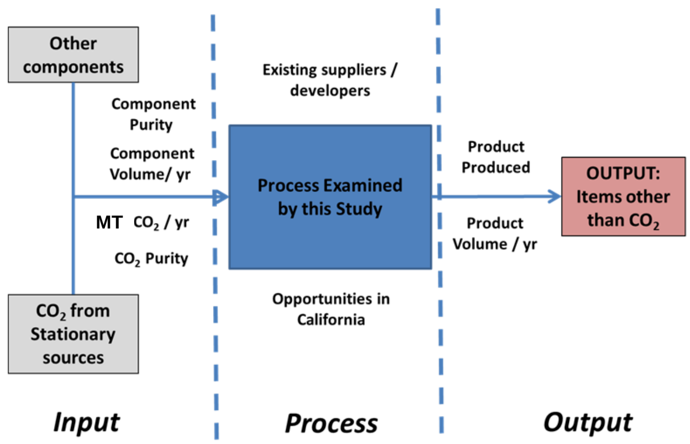
Methodology Used in Study

Systems approach focused on the needs of California



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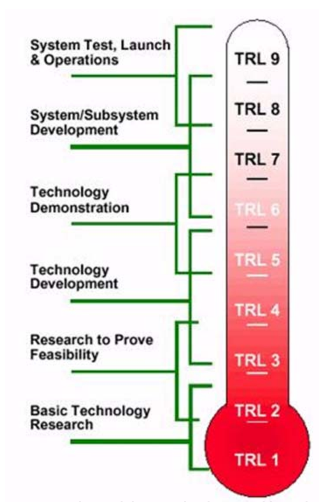
Method to Measure Maturity of Technology

Many studies done on determining TRL and developing R&D portfolios



- **Technology Readiness Levels (TRLs) : scale for assessing the maturity of a particular technology**
- **Developed by NASA, now wider use in DoD and other agencies**
- **Viewed as one component of a risk-reduction measure***
- **Creates "common language" that facilitates the integration of technologies from universities and research labs (e.g. NRL, ARL)***
- **Recent versions include market related risks, e.g. COSYSMO****

*Graettinger, C; S. Garcia, J. Siviy; R. Schenk; P. Syckle, Using the "Technology Readiness Levels" Scale to Support Technology Management in the DoD's ATD/STO Environments", conducted for Army CECOM, CMU/SEI-2002-SR-027, August 2002
**Valerdi, R; R. Kohl, An Approach to Technology Risk Management, Engineering Systems Division Symposium, MIT, March 2004

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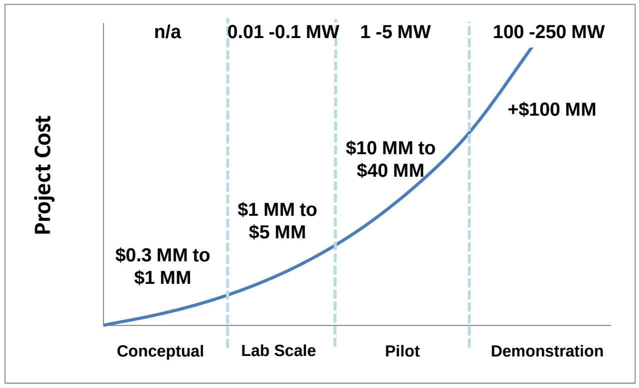
Commercialization Pathway

Requires significant capital, talent, and knowledge of stakeholder needs



- **Drives type of investor relative to technology maturity**
- **Field testing begins at pilot scale**
- **Often failures in transition from lab scale to pilot**

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Parameters Used in Technology Evaluation

Factors defined to describe each parameter

Parameter	Factors
Technology Maturity	Technology Readiness Level (TRL)
Input to Process	Attributes of CO_2 required, especially amount of CO_2 utilized by process
	Attributes of additional components, especially indicating any water usage
Output from Process	Attributes of Product Produced
Time Frame for Commercial Viability	Less than 10 years
	Greater than 10 years
Environmental impacts	Potential impact on air emissions, disposal of used components, etc.
Economic Benefit	Job creation / growth of new or existing industries in California
Federal Investment	Status of previous and existing federal investment in RD&D of technology
Barriers to deployment	Example: Technology / Regulatory / Economic based factors that limit deployment of technology
Knowledge gaps	Knowledge or know-how hindering the removal of barriers
Suppliers	Existing developers / suppliers for the technology

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Sample Characterization of Technologies

Shown for Working Fluid Category

	Tech. Maturity (1-9)	Estimated Amnt of CO2 Utilized	Attributes of CO2	Other Components and their Attributes	Product produced	Time to Commercialize (<10 years; > 10 years)	Environmental Impacts on California	Projected Economic Benefit to California	Federal Investment in technology?
Working fluids									
Enhanced oil recovery (EOR)	9	L	- Sulfur content may enhance EOR, but must maintain pipeline specs for CO2 transport - CO_2 Purity	Water, surfactants	oil / natural gas	already commercial	Minor (relative to impact of existing oil field)	Jobs & economic stimulus in vicinity of well field, locally generated fuels, royalties to state	Yes
Enhanced Gas Recovery (EGR)	3-5	M	Pipeline specs	water	natural gas	<10 years	Minor (relative to impact of existing gas fields)	Jobs & economic stimulus in vicinity of well field, locally generated fuels, royalties to	Yes
Coal bed methane recovery (ECBM)	6	negligible in CA	- CO2 Purity > 90%	Water removed from seam to enable methane to more readily	natural gas	< 10 years	Coal beds not common in California	Not much direct benefit since coal not a significant resource in California	Yes
Geothermal working fluid (Enhanced Geothermal Systems)	4	M	- CO2 Purity > 90%	Water	electricity	< 10 years	Moderate - similar to new geothermal field development	Electrical power that displaces fossil fuel use; stimulates local economy	Yes

S denotes estimated to be less than 0.5 million metric tons/year
M denotes estimated to be between 0.5 and 5 million metric tons/year
L denotes estimated to be greater than 5 million metric tons/year

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Five Key Factors Examined

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Summary of Federal Funding

Significant ARRA funding

- Six federal programs accounting for +$300 Million
- Primarily for large scale demonstration projects
- California recipients:
  - Calera Corporation: $20 million;
  - Consortia of research institutions involved in the Fuels from Sunlight Hub: $122 million (Joint Center for Artificial Photosynthesis (JCAP))
- Many projects, especially those involving algae and biodiesel, provide processes for economic conversion of point-source CO_2 emissions

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Increasing Flow of Federal Funds into CA

Opportunities exist if CA teams with others

- Provide state funds to meet the requirements for matching funds for federal project
- Encourage teaming of outside institutions and organization with California-based companies, in particular biotechnology companies
- Allow California sites to be used as demonstration facilities for beneficial use technologies

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Common Barriers & Knowledge Gaps

Impacts all technology options

- Need for CO_2 Life Cycle standard
- Monitoring CO_2 Levels, especially for cap and trade considerations
- Permitting, Regulatory, and Legal Hurdles.

Barrier & Gap Analysis

Shown for Working Fluids Category

	Technical Barriers to Deployment	Regulatory and Other Barriers to Deployment	Knowledge gaps	Notes
Working fluids				
Enhanced oil recovery (EOR)	- Proximity of wells to CO_2 sources - Need for more large scale systems studies	-Access to oil fields and economic price for CO_2 relative to oil price forecasts; - Methodology for monitoring potential CO_2 escape - Permitting process in CA exists, but ambiguities storage accounting and Class II v. VI	-Monitoring of injected CO_2 - Details of long term sequestration	EOR is a mature technology. The amount of CO_2 that is truly sequestered is not known; barriers to deployment in California are mainly the lack of an available CO_2 source. None of the existing CO_2 pipelines bring CO_2 into California. EOR will generate additional fossil fuel for burning, thus adding to the problem that beneficial re-use is trying to address. DOE-NETL report estimates 7.5GT CO_2 could be used between now and 2020 for EOR applications in the U.S. (DOE/NETL 402 1312-02-07-08)
Enhanced Gas Recovery (EGR)	-Requires proof-of-concept field studies - Proximity of wells to CO_2 sources - Need for more large scale systems studies	-Access to gas fields and economic CO_2 price relative to forecast natural gas prices; - Requires methodology for monitoring potential CO_2 escape - Permitting process in CA exists, but ambiguities wrt storage accounting and Class II v. VI	Effectiveness of CO_2 displacement of CH_4 in field studies	EGR is not a mature technology. While the displacement of CH_4 by CO_2 has been demonstrated as has gas drive in hydrocarbon recovery, field demonstrations are lacking to prove sweep efficiency and other economic parameters. Many gas fields in CA are natural water drive, so it is unclear what residual gas ssturations remain and wehther they could be removed by repressuring with CO_2
Coal bed methane recovery (ECBM)	Need for more large scale systems studies	Permitting process	-Monitoring of injected CO_2 - Details of long term sequestration	CO_2 can be used to displace methane bound to coal surfaces. This technology is analogous to EOR and EGS.
Geothermal working fluid (Enhanced Geothermal Systems)	- optimized turbine technology - methods for reservoir optimization - avoiding fast path fluid flow	prediction of potential CO_2 leakage	- Subsurface chemical evolution of CO_2 working fluid, - CO_2 capture flux	CO_2 can be used instead of water as a working fluid in geothermal systems. Over long time periods, the CO_2 will carbonate the rocks, using the intrinsic alkalinity of the rocks to form carbonate minerals. This enhances the rate of mineral trapping, a desirable outcome in conventional CCS systems in terms of reducing the risk of long-term CO_2 confinement.

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CO_2 Utilization: Many Benefits to CA

Provides value beyond just GHG reduction

- Integrated projects where capture provides a CO_2 supply for CO_2 utilization facilities which provide local community benefits such as jobs, while the bulk of the captured stream may still require geologic sequestration
- Replacement of fossil fuel use with CO_2 neutral products
- Potential to address disperse sources which in aggregate may provide significant GHG mitigation volumes

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Ranking Categories

Important to identify focus

RANK	COMMENT
A	High potential for application in CA (either by volume of CO_2 used or based on other factors that might make the technology important for the state); investment in R&D has potential to lead to a commercially deployable technology in CA to meet 2020 goals
B	Moderate potential for CA (based on volume or other factors that would make it important to the state); investment in R&D has potential to be commercially deployable to meet 2020 or 2050 goals
C	Low potential for CA or investment in R&D is high risk with commercialization unlikely to meet 2020 or 2050 goals
D	Not significant to the state (remove from further consideration)

Highest Ranking Technologies

Based on factors listed previously

RANK	TECHNOLOGY
A	• Biological Conversion • Treatment of displaced aquifer fluids • EOR and EGR • Building materials • Working fluids for energy storage
B	• Geothermal working fluid • Chemical conversions • Working fluids for energy generation

Key Conclusions from Analysis

Recommendations for future work

- Need to develop a robust lifecycle analysis applicable to all categories
- Need more quantitative means to assess the combination of regional economic impact coupled with environmental impact
- Need more quantitative study of **A** and **B** ranked technologies