

EXPANDING THE BIOECONOMY

Date: Wednesday, 11 July 2017 Venue: SHERATON PENTAGON CITY, Washington, DC

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Bioeconomy 2017: Domestic Resources for a Vibrant Future

Beyond Biofuels: Leveraging the Bio-economy to Manage Carbon, Open Markets, and Increase Global Economic Efficiency

> *ASU campus wide initiative on light inspired research for energy and sustainability, impact and scale

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REFRAMING THE FUTURE OF CARBON IN SOCIETY:

"Every problem has in it the seeds of its own solution. If you don't have any problems, you don't get any seeds." Norman Vincent Peale (1898 - 1993), American Author

"Each problem has hidden in it an opportunity so powerful that it literally dwarfs the problem. The greatest success stories were created by people who recognized a problem and turned it into an opportunity."

Joseph Sugarman, American Author

"We can't solve problems by using the same kind of thinking we used when we created them." - Albert Einstein

"Inventing is seeing the same problem that everyone around the world is seeing, but looking at it differently." Dean Kamen, Most Known as the Inventor of the Segway





TOO MUCH OF A GOOD THING CAN BE BAD -- SOURCES EXCEED SINKS

2040 \pm 310 GtCO₂ 1750-2011 \rightarrow 880 \pm 35 additional GtCO₂ Problem: Increasing content in the atmosphere & surface ocean



We could actively mine the excess CO₂ in the atmosphere as a resource 1300 Gt-CO₂ at \$10 per tonne profit would be \$13T.

~3100 GtCO₂ total in the atmosphere Was ~ 2200 Gt pre-industrial Beyond ~3500 Gt is considered too much >450 ppmv **Proven fossil reserves:** ~2800 Gt potential CO₂ emissions Cumulative budget left < 900 GtCO₂ ~4.25% yoy decrease in net 30% in 8 yrs and 50% in 16 yrs

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THINKING DIFFERENTLY ABOUT CO₂

Managing as a resource rather than waste to just get rid of or worse a pollutant

REDUCE, REUSE, DOWN-CYCLE, <u>RECYCLE</u>, DISPOSE WHAT'S LEFT ONLY AS A LAST RESORT

Automobiles are the most recycled consumer product in the world today. There are >9,000 vehicle recycling facilities around the US. \$32B/yr in sales; >140,000 employed.



"Automotive recycling has evolved into a sophisticated market and technology-driven industry that constantly changes to keep abreast of innovations in automotive technology and manufacturing techniques." Automotive Recyclers Association





RECYCLING CO₂ INTO THE PRODUCT IT CAME FROM: NO SUCH THING AS WASTE ONLY WASTED RESOURCES

- **MINOR DISTINCTION WE DO HAVE DECARBONIZE PRIMARY ENERGY**
- WE DO NOT HAVE TO DECARBONIZE THE ENERGY SYSTEM
- TODAY'S PRIMARY ENERGY IS REALLY STORED ANCIENT SUNLIGHT AND SEQUESTERED CARBON
- **BIOMASS IS STORED MODERN SUNLIGHT AND FIXED CARBON**









- Prehistoric biomass, processed for millions of years: ancient stored solar energy
- Accelerate the natural process to make new energy carriers from modern sunlight: i.e., Solar fuels and materials.

LIQUID HYDROCARBONS ARE ENERGY DENSE AND CONVENIENTLY STORED AND TRANSPORTED ECONOMICALLY OVER LONG DISTANCES, TRILLIONS OF \$ OF INFRASTRUCTURE

THE QUESTION WE SHOULD BE ASKING IS WHAT WILL BE THE ENERGY CARRIERS OF THE FUTURE? (H₂, CO, CH₃OH, NH₃, DME, OME, CH₄)

ELECTRICITY IS BEST USED AS IT IS PRODUCED – BUT NOT EASILY STORED ESPECIALLY FOR SEASONAL SHIFTS







REFRAMING: CREATING VALUE FROM AND SINKS FOR THE EXCESS CO₂ IN THE ATMOSPHERE

Economically viable carbon-based innovation ecosystem in a few decades – in addition to – not instead of, not part of decarbonizing primary energy?

	Decarbonization Energy Efficiency Renewables for Primary Energy	Adaptation Managing Impacts of Climate Change	Capture, Reuse, and Recycle Transforming into Valuable Products	Capture and Disposal Long-Term Sequestration	
		Climate Change	Bioeconomy	瓜	
r	Progress but Not Fast Enough, nostly in electricity	Increasingly Necessary but expect suffering	Seeking added value, Impact transportation & Manufacturing Can also address "overshoot"	Verified, Safe and Secure Disposal	
	Multi Gt-CO ₂ /yr scale industry: steel, concrete, agriculture, coal, oil, and gas, and plastic is getting close				
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NET NEUTRAL: CLOSING THE CYCLE; RESTORING THE CARBON BALANCE



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NET NEGATIVE: CARBON IS THE MOST VERSATILE OF ALL THE ELEMENTS



Essential for life, ensures a livable climate via the GH effect of CO₂, stored energy that we have been exploiting, greatest number of compounds more than any other element except hydrogen, superior properties. Expect cost breakthroughs on carbon composites from 3D printing.



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SOLAR THERMOCHEMICAL STORAGE AND SPLITTING OF WATER OR CO₂





THE ADVANTAGE OF PRODUCING SYNGAS (CO & H_2)



Source: P.L. Spath and D.C. Dayton, Preliminary screening—technical and economic assessment of synthesis gas to fuels and chemicals with emphasis on the potential for biomas-derived syngas, National Renewable Energy Laboratory, NREL/TP-510-34929, December, 2003.

- Can serve as a universal intermediate
- Can unite fossil and biomass with direct solar technologies
 - Bridge old energy to new energy
 - Make more product for the same feedstock – no process CO₂

e.g. Solar reforming of CO₂ and natural gas (or biogas)

Solar gasification of biomass

Directly splitting water and CO₂, thermochemical, electrolysis, photo-electro-chemical, thermoelectro-chemical

Aim for high carbon atom efficiency and a smoothed transition

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Coccolithophores produce an exoskeleton made of CaCO₃ plates (i.e., 'coccoliths').

- One celled marine plants
 - Very widely distributed globally
 - Leading calcite producers in the ocean
 - Ideal system for secure biomineralization of CaCO₃



Kevin Redding and Bruce Rittmann



ARIZON

WE CAN COUNT ON THE MIRACULOUS LEARNING CURVE



If start at 0.1 Mt/yr If grow at 25%/yr Then 41 years to hit 1 Gt/yr Or ~13 doublings If 16% learning Fall 90%

Not long ago people were still saying solar is niche and always will be. Direct air capture and direct conversion should be able to get on similar learning curves.



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LET'S TOGETHER CREATE A SUSTAINABLE CARBON-BASED FUTURE WITH AND WITHOUT BIOLOGY

The best way to predict the future is to create it.

Peter Ducker

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I skate to where the puck is going to be and not where it has been. Wayne Gretzky



Thank you the audience for your attention and Dave Babson for the kind invitation Grateful acknowledgments to colleagues Gary Dirks, Klaus Lackner, James Miller, Bruce Rittmann, and Elisa Graffy, and many more