Coal/Biomass-to-Liquid Fuel

Summary Report

ARCADIS

CCAT Connecticut Center for Advanced Technology, Inc.

AVETEC

Sponsoring Agency

DLA Energy
Fort Belvoir, VA

Lindsey H. Hicks, Jose V. Maniwang, Jr.

Project Team

Team Lead

Connecticut Center for Advanced Technology, Inc.
East Hartford, CT

CCAT Team: Tom Maloney, Adnan Foysol, Bruce Karasik, William Leach, Jason Smith, Wayne Sumple, Melanie Wadden, April Willhide

Team Members

ARCADIS U.S., Inc.
Middletown, CT

Arcadis Team: Mark Barmasse, Andrew Danzig, Timothy Shelton, Carl Singer, Tina Summerwood

Avetec, Inc.
Springfield, OH

Avetec Team: Tony Corvo, Jeff Dalton, Ian Halliwell, Rebecca Somers

GeertTech, LLC
Westminster, CO

GeertTech Team: Arie Geertsema

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Fueling America's FUTURE

The U.S. Air Force Strategic Energy Plan calls for a 50% increase in the use of alternative fuels for non-contingency operations by 2025.[1]

BACKGROUND

The Defense Logistics Agency (DLA) Energy and the Connecticut Center for Advanced Technology, Inc. (CCAT) engaged in a contract to determine feasible methods of utilizing our nation's vast coal supply to provide jet fuel for the United States military. The United States holds the world's largest supply of coal and it can be used as a domestic, secure source of alternative fuel.

The demand for alternative military fuel and energy is increasing. The U.S. Air Force Strategic Energy Plan calls for a 50 percent increase in the use of alternative fuels for non-contingency operations by 2025. The U.S. Navy's Great Green Fleet and the U.S. Army's Net Zero Program focus on alternative fuel and power use.

Through these programs and the U.S. Department of Energy's research in alternative fuels, the U.S. Department of Agriculture's Farm to Fleet and Farm to Fly efforts, plus global commercial activities stimulated by the Commercial Aviation Alternative Fuels Initiative, our nation is showing a long-term commitment to work together to establish secure, clean fuels. Technical feasibility and commercial viability for producing alternative fuels must now be established.

OBJECTIVES

The objectives of this work were to investigate, through analyses and testing, the use of domestic coal and biomass to make liquid fuel and electricity for the U.S. military. Technical feasibility and commercial viability for meeting U.S. military alternative fuel use goals in the near- and mid-term time frames, and complying with greenhouse gas (GHG) emissions requirements of Title V Section 526 of the Energy Independence and Security Act of 2007 (Section 526) were examined.

Section 526 requires that GHG emissions from alternative fuels purchased by federal agencies be less than or equal to emissions from conventional petroleum-based fuel. And per the Department of Defense (DoD) Alternative Fuels Policy for Operational Platforms (DoD, 2012), all commercial procurement of alternative fuels must be cost competitive with petroleum-based fuels.

CCAT, ARCADIS U.S. Inc., Avetec Inc., GeertTech LLC, technical advisors, and subject matter experts (the Project Team) worked collaboratively with DLA Energy and a Military Advisory Board to execute this project. The Project Team engaged in a Cooperative Research and Development Agreement with the U.S. Department of Energy National Energy Technology Laboratory and leveraged significantly the capabilities and expertise of existing public and private U.S. test facilities.

For more than half a century, coal has been used to make liquid fuels. To meet required emissions levels, the team chose to investigate mixing biomass with coal.

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[1] U.S. Air Force Energy Strategic Plan, March, 2013

METHODOLOGY

The investigation began with an assessment of the state-of-the-art technologies pertaining to liquid fuel production and electricity/heat generation from coal, including carbon capture utilization and storage (CCUS), carbon reuse, and the potential for conducting demonstration tests at U.S. military installations.

The initial assessment revealed a small number of coal burning facilities (12) at U.S. military installations, using relatively low amounts of coal. Opportunities for CCUS demonstration testing at those installations were limited and CCUS work sponsored by the U.S. government and industry was already in progress at non-military sites. The Project Team determined that minimal benefits would result from testing and analyses for coal-to-electricity/heat plants at DoD installations. Additional examination of CCUS would not contribute significantly to the DoD's future energy goals.

These initial assessment results led the Project Team to focus on coal/biomass-to-liquid (CBTL) fuel production. CBTL fuel processes offer significant potential benefits to DoD in producing clean liquid fuel, particularly in gasification of coal/biomass mixtures.

The Project Team determined that gasification of coal and biomass using indirect liquefaction presented the best chance to meet DLA Energy's requirements. Gasification processes convert solid feedstocks such as coal and biomass into product gases. These product gases are then cleaned and conditioned, including the partial capture of CO_2, resulting in synthesis gas (syngas) that can be converted to jet fuel by the well-established Fischer-Tropsch process. Blends of conventional petroleum-based fuels and Fischer-Tropsch-based fuels have already been qualified for use in many military aircraft. The integrated system is referred to as a CBTL plant (Figure 1).

ENVIRONMENTAL IMPACT

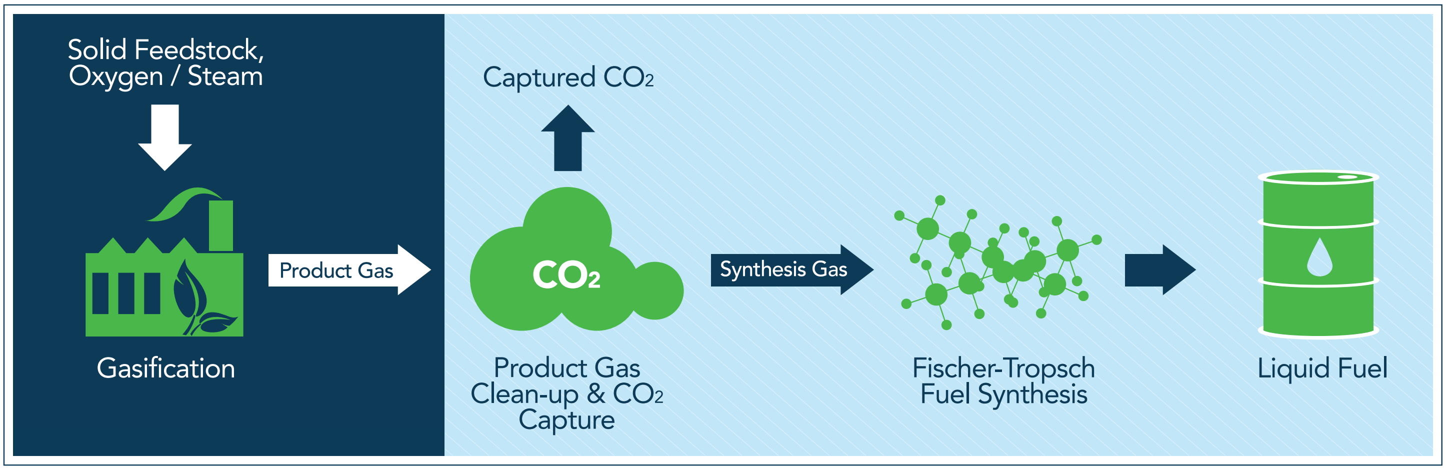
Why coal and biomass? Coal is mined in more than 50 countries with the U.S. controlling the largest coal reserves in the world. Technologies for converting coal into liquids are mature today, as evidenced in South Africa where coal has been used to make liquid fuels for the last 60 years. The use of domestic feedstocks, such as coal and biomass, offers a degree of energy security and can decrease U.S. dependency on petroleum imports.

Because coal-consuming processes emit large amounts of CO_2, the Project Team tested and analyzed the impact of processing biomass mixed with coal to achieve the Section 526 requirements for CO_2. Tests included raw biomass, torrefied biomass, and municipal solid waste—all domestic feedstocks that can reduce CO_2 emissions from CBTL processes.

RESEARCH OBJECTIVES

1. *Evaluate CO2 footprint for generating liquid fuels from domestically sourced solid feedstocks.*
2. *Conduct gasification tests with a wide range of coal and biomass mixtures.*
3. *Examine commercial viability of coal/biomass-to-liquid fuels facilities.*

Figure 1 Simplified Coal/biomass-to-Liquid Plant Block Diagram
Project Team performed extensive tests on gasification processes.



IDENTIFYING CHALLENGES

ENVIRONMENTAL

The large CO_2 footprint from coal use is a primary negative factor for converting coal into liquid fuel. To implement coal use, CO_2 emissions must be mitigated. CO_2 footprint of CBTL processes can be lessened by mixing biomass or municipal solid waste with coal and by capturing and sequestering CO_2. By design, most CO_2 generated by CBTL plants must be captured for the plant to operate properly. Sequestration or utilization of the captured CO_2 is the key to meeting environmental regulations.

TECHNICAL

Blends of conventional petroleum-based fuels and Fischer-Tropsch-based fuels have already been qualified for use in many jet aircraft. CBTL plant processes that convert coal/biomass-to-liquid fuel already exist today. Advances to processes such as biomass feedstock preparation (drying, torrefying, grinding), the production of pure oxygen, gasification technology, and Fischer-Tropsch methods will lead to more efficient, affordable, and cleaner plants.

ECONOMIC

Alternative fuels will be competitively procured and thus must compete with petroleum-based fuels in the long-term. Estimated prices of fuel generated by CBTL plants are high. Several considerations for modifying CBTL plants may improve the economics. Use of positive revenue feedstocks such as municipal solid waste and nuisance plants, favorable CBTL plant financing, and monetary credit for sequestering or utilizing the captured CO_2 will improve economics. Cost reduction for small-scale CBTL plants, about 3,000 barrels-per-day or less, will allow for higher percentages of biomass use and open possibilities for integrating CBTL plants in high value installations for secure, assured energy scenarios. In the long term, petroleum-based fuel prices may increase such that fuel from CBTL plants will be cost competitive.

TESTING

The Project Team executed gasification testing and analyses of 150 coal-biomass feedstock tests. Testing was performed with partners and facilities at Energy and Environmental Research Center (EERC), U.S. Department of Energy National Carbon Capture Center (NCCC), Westinghouse Plasma Corporation, ThermoChem Recovery International, Inc., and Emery Energy Company. Analyses for technical feasibility and commercial viability were performed by the Project Team and subject matter experts.

Pictured right: Project Team in lab at the Energy and Environmental Research Center (EERC).

Table 1 Summary of 150 Gasification Tests with Coal/biomass Mixtures

Biomass Type	Coal Type				Gasifier Technology Type				
	PRB	Lignite	IL No. 6	Biomass Only	Entrained Flow	Transport Reactor	Fixed Bed	Steam Reformer	Plasma
Coal Only (No Biomass)	17	3	4		10	13	1		
Raw Wood	27	1	2		12	16	1	1	
Torrefied Wood	25		2	1	12	16			
Switchgrass	3				0	3			
Shale Gas	6	8			6	8			
Natural Gas		9			0	9			
Methane	5				5				
Railroad Ties	7				0	7			
Raw Corn Stover	5		2		4	3			
Torrefied Corn Stover			3		3				
Filamentous Algae	6				4	2			
Water Hyacinth	3				1	2			
Water Lettuce	4				1	3			
Water Lettuce/Hyacinth Blend	3				3				
Municipal Solid Waste	2	1		1	0			1	3
Total	**113**	**22**	**13**	**2**	**61**	**82**	**2**	**2**	**3**

TESTING FACILITIES

Energy and Environmental Research Center (EERC) - *Grand Forks, ND*

- 0.1-6.1 tons-per-day feedstock
- 129 tests performed with a range of coal, biomass and shale gas blends
- Entrained flow and transport gasifiers, tar reformer

National Carbon Capture Center (NCCC) - *Wilsonville, AL*

- 50 tons-per-day feedstock
- 14 tests performed with Powder River Basin coal and raw or torrefied pine blends
- Transport gasifier

Westinghouse Plasma Corp. (WPC) A wholly-owned subsidiary of Alter NRG - *Madison, PA*

- 10 tons-per-day feedstock
- 3 tests performed with Powder River Basin coal and municipal solid waste blends
- Westinghouse Plasma Arc™ gasifier

ThermoChem Recovery International, Inc. - *Durham, NC*

- 4 tons-per-day feedstock
- 2 tests performed with lignite coal, woody biomass, and municipal solid waste blends
- TRI steam reformer/carbon trim cell

Emery Energy Company - *Laramie, WY*

- 2.5 tons-per-day feedstock
- 2 tests were performed with Powder River Basin coal and raw biomass
- Fixed bed gasifier and Ceramatec plasma tar reformer

Molten slag, seen flowing from the bottom of a plasma gasifier, is quenched and granulated upon exiting the gasifier, resulting in vitreous granules that are used for beneficial purposes, such as aggregate.

IMPORTANT ASPECTS OF TESTING

A key objective of the investigation was to evaluate gasification test data when utilizing various biomass and coal feedstock combinations. The following factors should be considered for CBTL processes for both small-scale and larger-scale facilities.

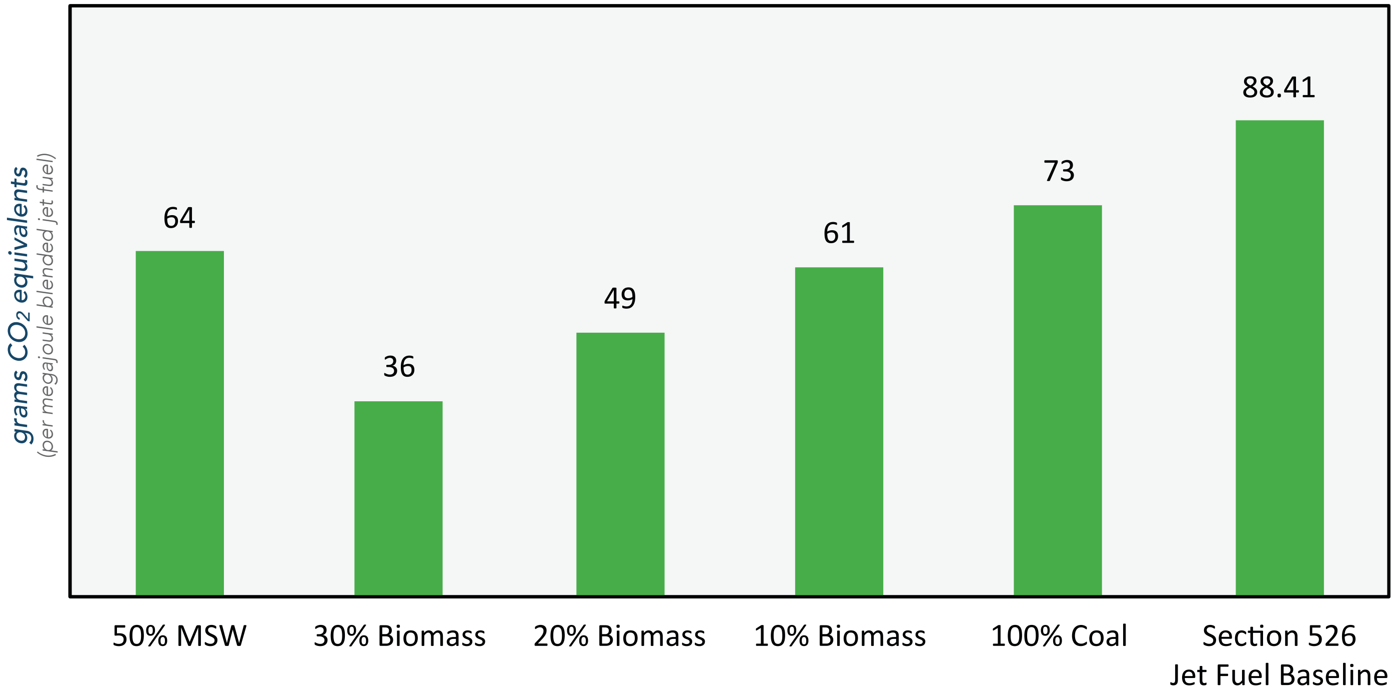
Feedstock Preparation: In order to limit problems during the gasification process, the handling properties of the feedstock should be carefully considered. Particle size, flowability and density are all factors in preventing issues during the feeding process. Coal is generally simple to prepare for gasification. Biomass must be harvested, transported, dried, and chipped/ground in order to be easily mixed with coal. Those operations are energy intensive and add to the CBTL CO_2 footprint. Torrefied biomass can be sized and densified to allow for more efficient handling and mixing with coal. This will result in a lower CBTL CO_2 footprint compared to raw biomass.

Small-Scale Gasifier Operation: Evaluating experimental data from small-scale gasifiers to predict commercial scale performance is an important challenge. For the small gasifiers that were utilized, the Project Team accounted for process variations and scrutinized data for mass and energy balance closure as well as carbon conversion and cold gas efficiency. Data analyses of exhibited trends and additional studies are needed for definitive, commercial-scale performance predictions.

ESTIMATED GREENHOUSE GAS EMISSIONS FROM CBTL PROCESS

Life cycle analysis results indicate that all cases satisfy Section 526 when up to 90 percent of CO_2 emissions are captured and stored.

Figure 2: CO_2 Life Cycle Analysis Results



KEY FINDINGS

Using test data, the Project Team and NETL performed Life Cycle Analyses (LCA) and techno-economic modeling for a commercial scale, 50,000 barrel-per-day CBTL plant to address Section 526 CO_2 emission requirements and commercial viability. This scale CBTL plant will satisfy the stated alternative jet fuel needs of the USAF for non-contingency operations.

- ***All CO_2 footprint projections of alternative jet fuel made from solid feedstocks tested were below the petroleum baseline for blended jet fuel (50% alternative fuel + 50% petroleum-based fuel), thereby satisfying Section 526.***

- ***When coal was the sole feedstock, the CO_2 footprint was the largest and required the most capture.***

- ***Increasing percentages of biomass in the solid feed generally resulted in lower CO_2 footprints and smaller amounts of required capture.***

- ***Feedstocks:***
  - *Torrefied wood offers advantages in blending with coal and lowering the CO_2 footprint for the CBTL plant.*
  - *Municipal solid waste and biomass (considered to be "nuisance plants" in areas where they are abundant) may be economically feasible for use as feedstocks.*
  - *Feedstock preparation and feed system design are critical to the successful development of a large-scale CBTL project.*

- ***Environment:***
  - *Electricity generation and CO_2 displacement credits from CBTL are significant contributors to lower GHG emissions.*
  - *Biomass/coal feedstock ratios with respect to Section 526 compliance:*
    - ***30% biomass** - 38-62% below the baseline*
    - ***10% biomass** - 13-33% below the baseline*
    - ***0% biomass** - 2-18% below the baseline*

- ***Economics:***
  - *Rough order of magnitude cost estimates using the techno-economic model for a 50,000 barrels-per-day CBTL plant with an entrained flow gasifier or transport gasifier showed average required selling price (RSP) of jet fuel (on a crude oil equivalent basis) ranged from approximately $134 to $170 per barrel.*
  - *Instances where coal was the sole feedstock resulted in the lowest RSP.*
  - *Increasing the percentages of raw biomass in the solid feed generally resulted in a higher RSP.*
  - *Using torrefied rather than raw biomass resulted in a lower RSP.*
  - *Capital costs and financing are the major factors influencing the RSP.*

Municipal solid waste at Westinghouse Plasma Corp.

Secure, domestic feedstocks can fuel America's future.

CONCLUSIONS

The testing program met the project objective of demonstrating the viability of gasifying coal/biomass mixtures. All coal/biomass mixtures were successfully fed to the gasifiers and stable operation was achieved for most of the tests.

Composition of the product gas produced in different gasifiers tested was influenced by a wide range of factors. In general, tests showed that product gas compositions could produce liquid fuels using a variety of feedstocks, after shifting of the H_2:CO molar ratio to that required for the Fischer-Tropsch process.

Using data from the wide spectrum of tests conducted, the Project Team concluded that blending various grades of coal with biomass presents a credible approach for reducing carbon dioxide emissions and producing alternative jet fuel.

Improving Commercial Viability

Several factors can improve the commercial viability of CBTL plants:

- Utilization of municipal solid waste as a positive revenue feedstock, for example, can reduce the financial burden of buying feedstock and instead provide plant revenue.
- Optimization of a CBTL plant designed for a particular feedstock blend may allow for less than 90 percent CO_2 capture and still meet Section 526 requirements, thereby improving capital and operating cost and lowering the required selling price.
- Alternative financing, based on a government DOE loan guarantee scenario (40 percent equity, 4.56 percent interest) rather than private financing (50 percent equity, 8.00 percent interest), can result in approximately a 23 percent per barrel reduction in the required selling price.

Additional detailed process engineering and cost analyses are necessary to determine more accurate costs and required selling prices for CBTL plant development.

Based on the projected required selling prices and life cycle assessments, future techno-economic evaluations should address alternative CBTL process configurations that minimize project capital costs by: (1) optimizing coal/biomass feedstock blends; and (2) capturing/sequestering only enough carbon to satisfy Section 526 requirements.

RECOMMENDATIONS FOR FUTURE STUDY

The need for secure, clean, affordable alternative jet fuel is of increasing importance. Technology to convert diverse types of domestic solid feedstocks (coal, biomass, municipal solid waste) into alternative jet fuel suitable for the military exists today. To help ensure that Section 526 air emissions requirements are met and price points for the alternative fuel are competitive, the following actions are recommended:

- *Improve* gasification efficiency for utilizing mixed coal-biomass feedstocks, including novel gasifier designs.
- *Increase* efficiency for preparing domestic feedstock mixtures (drying, torrefying, grinding).
- *Pursue* improvement of CBTL designs to optimize biomass content, CCUS, and plant capital costs so that Section 526 compliant fuels are more cost competitive to produce. Develop solutions to decrease cost, minimize the water footprint, and increase efficiency of key CBTL plant sub-processes, such as tar reforming and replacing conventional oxygen supply via air separation with newer technology.
- *Reduce* component costs for small-scale (1,000-3,000 barrels-per-day) distributed CBTL plants as smaller scale requires smaller amounts of feedstocks, allowing for a more practical and affordable harvesting radius for biomass and waste as feedstocks.
- *Consider* the integration of CBTL plants, which generate fuel and electricity, with microgrids and waste management as part of a resilient strategy for installation energy security that includes an assured fuel supply.

*Future work should continue **collaboration** and **leveraging** among public-private partners.*

Acknowledgments

Military Advisory Panel

Pete Stemniski, P.E., Director, Environmental Technology, Office of the Assistant Secretary of the Army for Installations, Energy and Environment; **Michael K. Hathaway**, Office of the Assistant Secretary of the Army (IE&E) DASA ESOH Environmental Technology Office; **Daniel F. Kowalcyk**, USAF Support Contractor, Office of the Deputy Assistant Secretary of the Air Force (Environment, Safety and Occupational Health); **Lynda Turner**, Quality Division Head, NAVSUP Energy, Naval Supply Systems Command; **Kenneth J. Henz**, Quality Team Lead, APC, US Army Materiel Command G3/4 Current Ops

Test Facility and Analytical Experts

Dan Driscoll, Dirk Link, Mike Mosser, George Richards, Eric Shuster, Tim Skone, Tom Tarka, Chuck Taylor, Jenny Tennant - **U.S. DOE/NETL**

Jay Almlie, Mike Holmes, Peter Letvin, Josh Stanislowski, Mike Swanson, Christopher Zygarlicke - **Energy and Environmental Research Center (EERC)**

Carson Brown, John Northington - **Southern Company Services, Inc., National Carbon Capture Center**

Alex Gorodetsky, Bill Grichin, Ronald Klatt, Bruce Leonard, Ray Mahaney, Sean Rabiei, Jim Santoianni, Allison Yeckel - **Westinghouse Plasma Corp.**

Dan Burciaga, Ravi Chandran, Chris Doherty, Daniel Leo, Justin Miller, Dave Newport, Sean Whitney - **ThermoChem Recovery International**

Ben Phillips, Collin Dickson (INL), Corrie Nichol (INL), Nick Soelberg (INL) - **Emery Energy**

Subject Matter Experts

Richard Altman, George Bollas, Hanna Breetz, Gregory Cooney, Andrew Davis, David Fairman, Tom Filburn, Joe Genovese, David Gray, Howard Herzog, Vello Kuuskraa, Joe Marriott, Trent Molter, Bill Morgan, Ray Necci, Jordan Peccia, Matt Ranelli, Daniel Schrag, Chungyan Shih, Prabhakar Singh, Ioulia Valla, Sam Venneri, Charles White III

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- Back Cover: C-17 Globemaster III approaches the boom of a KC-135 Stratotanker during aerial refueling practice. (U.S. Air Force photo/Tech. Sgt. Shane A. Cuomo)

C-17 Globemaster III approaches the boom of a KC-135 Stratotanker during aerial refueling practice.

For more information, please contact:

Connecticut Center for Advanced Technology, Inc.
222 Pitkin Street – Suite 101 | East Hartford, CT 06108
860.291.8832 | www.ccat.us

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