NATIONAL ENERGY TECHNOLOGY LABORATORY

Case Study: Interagency Workgroup on Life Cycle GHG Emissions of Alternative Aviation Fuels

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NETL, Office of Strategic Energy Analysis & Planning

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Purpose

- **Existing and Emerging GHG Emissions Regulations**
  - Energy Independence and Security Act (EISA) of 2007: *Life Cycle GHG emissions for alternative fuels contracted by a Federal agency other than for research and testing must be less than or equal to life cycle emissions from conventional fuel from conventional sources*

- **US Air Force Aircraft Fuels Testing Program**
  - Non-petroleum based fuels
  - Focus on conventional petroleum/F-T blends

- **Other Existing and Emerging Federal/State Regulations**
  - US EPA Renewable Fuels Standard
  - California Low Carbon Fuel Standard, etc.

Interagency Workgroup Members

Over 30 Federal, Academia, & Industry Experts

Air Force Research Laboratory

Department of Energy, National Energy Technology Laboratory

Department of Energy Argonne National Laboratory

Federal Aviation Administration

Environmental Protection Agency

Defense Logistics Agency

Department of Transportation, VOLPE Center

University of Texas at Austin

Massachusetts Institute of Technology

University of Washington

Carnegie Mellon University

Georgia Institute of Technology

Princeton University

University of Dayton Research Institute

URS Corporation

Universal Technology Corporation

The Boeing Company

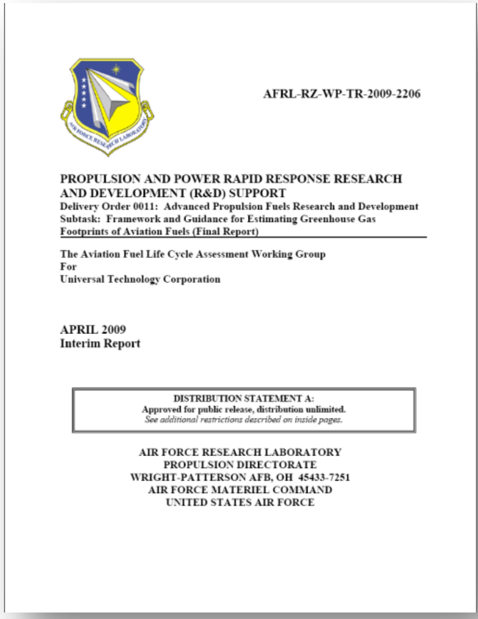
Franklin Associates

RAND Corporation

Workgroup Charge and Progress

- **Develop *guidance* to satisfy EISA §526:**
  - Provide guidance for developing LCAs that satisfy §526 for alternative jet fuels (synthetic paraffinic kerosene) for comparison with a conventional jet fuel baseline
  - Justify with Examples

- ***Step 1: Framework and Guidance for Estimating Greenhouse Gas Footprints of Aviation Fuels (December, 2009)***
  - *www.netl.doe.gov/energy-analyses/pubs/EstGHGFtprntsAvFuels2009.pdf*



AFRL-RZ-WP-TR-2009-2206

PROPULSION AND POWER RAPID RESPONSE RESEARCH AND DEVELOPMENT (R&D) SUPPORT
Delivery Order 0011: Advanced Propulsion Fuels Research and Development
Subtask: Framework and Guidance for Estimating Greenhouse Gas Footprints of Aviation Fuels (Final Report)

The Aviation Fuel Life Cycle Assessment Working Group
For
Universal Technology Corporation

APRIL 2009
Interim Report

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UNITED STATES AIR FORCE

- ***Step 2: Test Framework and Guidance Document on a Case Study example:***
  - *F-T jet fuel made from Illinois No. 6 coal and switchgrass*
  - *External peer review completed July 2011*
  - *Final Report submitted to Air Force for publication/release August 2011*

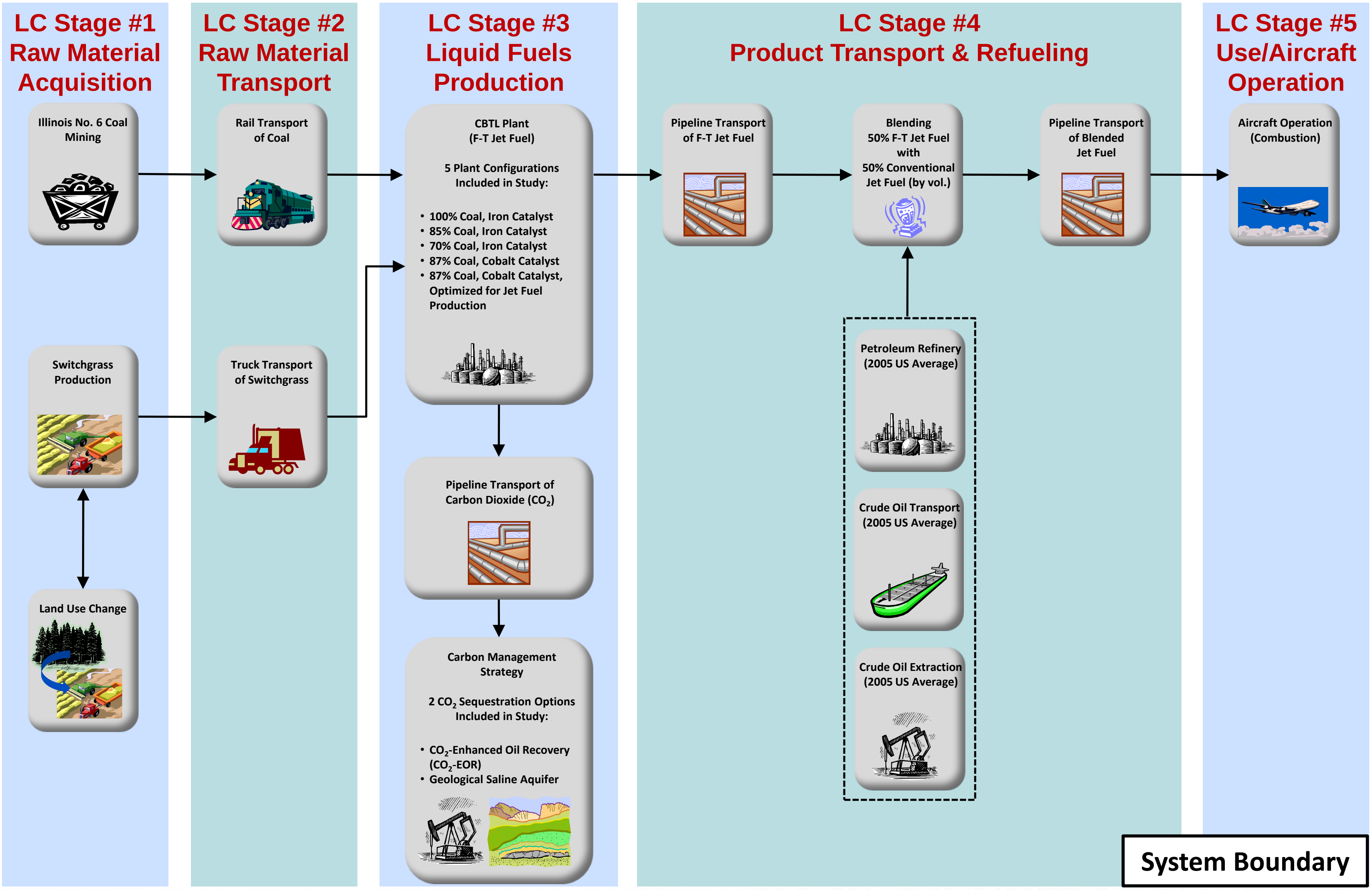
10 Life Cycle Scenarios Evaluated

Scenario	Coal and Biomass to Liquids (CBTL) 30,000 Barrel per Day (bbl/d) Plant Configuration				Carbon Management Strategy
	Illinois No. 6 Coal (% by wt.)	Switchgrass (% by wt.)	Type of F-T Catalyst	CBTL Jet Fuel Production (bbl/d)	
1	100%	0%	Iron	15,940	CO_2-EOR
2	84%	16%	Iron	15,940	CO_2-EOR
3	69%	31%	Iron	15,940	CO_2-EOR
4	86%	14%	Cobalt	17,360	CO_2-EOR
5	86%	14%	Cobalt	23,600	CO_2-EOR
6	100%	0%	Iron	15,940	Saline Aquifer
7	84%	16%	Iron	15,940	Saline Aquifer
8	69%	31%	Iron	15,940	Saline Aquifer
9	86%	14%	Cobalt	17,370	Saline Aquifer
10	86%	14%	Cobalt	23,950	Saline Aquifer

10 Life Cycle Scenarios Evaluated

Scenario	Coal and Biomass to Liquids (CBTL) 30,000 Barrel per Day (bbl/d) Plant Configuration				Carbon Management Strategy	CO_2-EOR Crude Oil Production (bbl/d)
	Illinois No. 6 Coal (% by wt.)	Switchgrass (% by wt.)	Type of F-T Catalyst	CBTL Jet Fuel Production (bbl/d)		
1	100%	0%	Iron	15,940	CO_2-EOR	63,440
2	84%	16%	Iron	15,940	CO_2-EOR	63,440
3	69%	31%	Iron	15,940	CO_2-EOR	63,440
4	86%	14%	Cobalt	17,360	CO_2-EOR	63,440
5	86%	14%	Cobalt	23,600	CO_2-EOR	63,440
6	100%	0%	Iron	15,940	Saline Aquifer	0
7	84%	16%	Iron	15,940	Saline Aquifer	0
8	69%	31%	Iron	15,940	Saline Aquifer	0
9	86%	14%	Cobalt	17,370	Saline Aquifer	0
10	86%	14%	Cobalt	23,950	Saline Aquifer	0

System Boundary



Modeling Approach

- **Geographic System Boundary:** US Midwest; Permian Basin (Texas) for EOR
- **Temporal System Boundary:** 30-year operations commencing in 2012; 3-year construction
- **Functional Unit:** Quantity of jet fuel to produce 1 MJ (LHV) of combustion energy
- **Allocation:** Energy, volume, mass, system expansion/displacement
- **Life Cycle Inventory Metrics:** Global Warming Potential, carbon dioxide equivalents, IPCC 2007, 100-year time horizon (CO_2e)

Key Model Choices

- **Coal Type:** Illinois No. 6 bituminous coal
- **Coal Bed Methane Emission Rate:** 150 scf/ton
- **Coal Bed Methane Capture Rate:** 40%
- **Land Use Metrics Considered:** GHG emissions
- **CBTL Products:** F-T jet fuel, F-T diesel, F-T naphtha
- **CBTL Facility Capacity:** 30,000 bbl/d
- **CO_2 Losses:** CO_2 EOR (0.5%) and saline sequestration (0.5%)
- **Fuel Blending:** 1:1 / F-T jet fuel and conventional petroleum jet fuel (by volume)
- **Combustion:** jet engine (airplane)

Uncertainty and Allocation

- **Uncertainty Options Included in the Model**
  - System Boundary
    - Baseline System Boundary (shown previously)
    - Modified Baseline System Boundary (displacement of natural CO_2 - boundary ends immediately following CO_2 transport)
  - Co-Product Allocation
    - Energy Allocation
    - Volume Allocation
    - Mass Allocation
    - System Expansion/Displacement

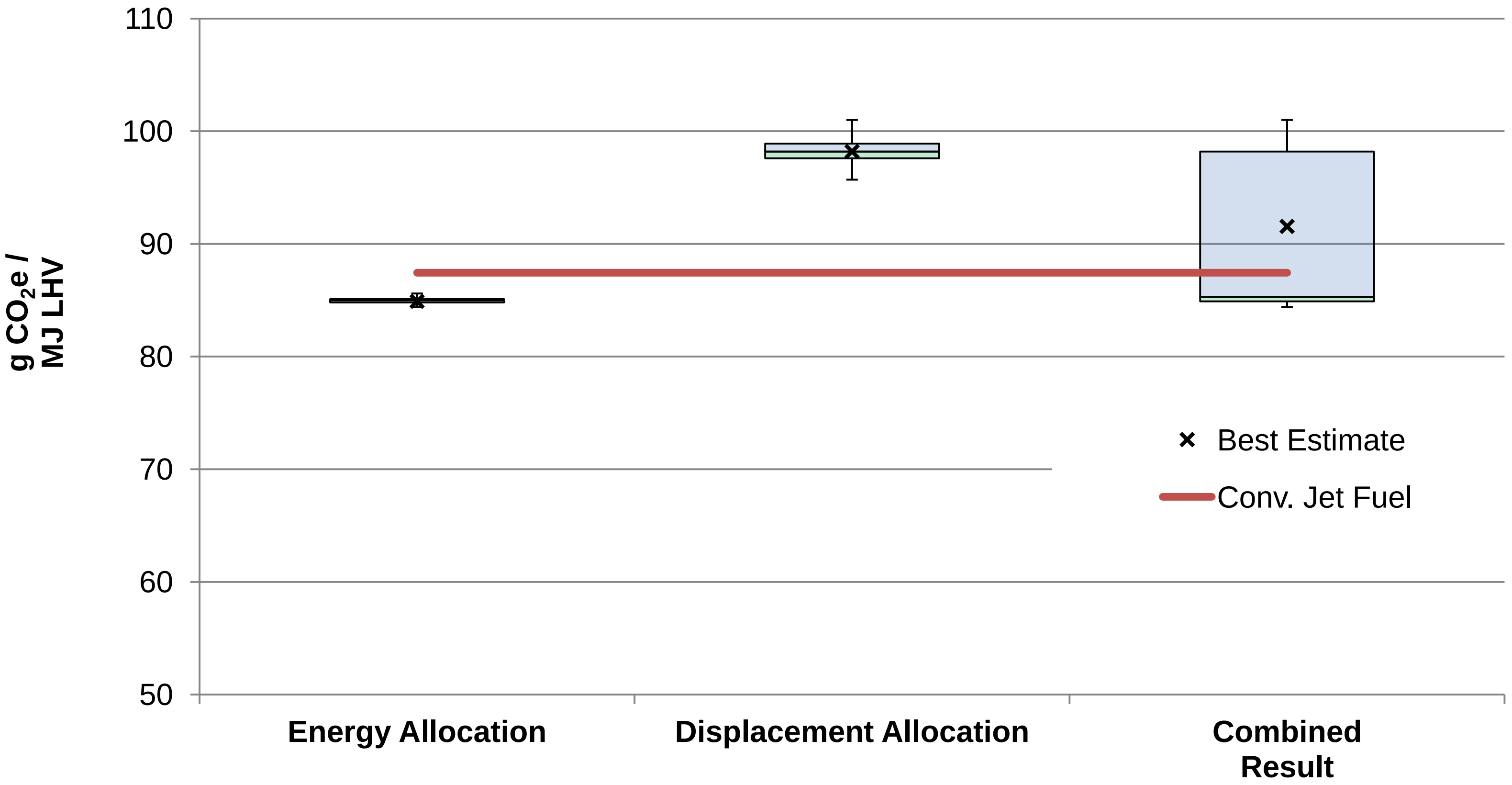
Scenario 1: Deterministic Results

(100% Coal, 0% Switchgrass, Iron F-T Catalyst, EOR)

Life Cycle Stage Sub-Categories	Unallocated Global Warming Potential (CO2e)		Energy Allocation Global Warming Potential (CO_2e)		Displacement Allocation Global Warming Potential (CO_2e)	
	g/MJ	%	g/MJ	%	g/MJ	%
Stage 1a: Coal Acquisition	5.2	4.3%	0.8	0.9%	2.4	2.4%
Stage 2a: Coal Transport	0.9	0.7%	0.1	0.1%	0.4	0.4%
Stage 1b: Switchgrass Prod.	0	0.0%	0	0.0%	0	0.0%
Stage 1c: Direct Land Use	0	0.0%	0	0.0%	0	0.0%
Stage 1c: Indirect Land Use	0	0.0%	0	0.0%	0	0.0%
Stage 2b: Switchgrass Transp.	0	0.0%	0	0.0%	0	0.0%
Stage 3a: CBTL Facility	8.4	7.0%	1.3	1.5%	3.9	4.0%
Stage 3b: Supercrit. CO_2 Transp.	0.8	0.7%	0.1	0.1%	0.4	0.4%
Stage 3c: EOR	27	22.1%	4.1	4.8%	12.5	12.7%
Stage 3d: CO_2 Sequestration	0	0.0%	0	0.0%	0	0.0%
Stage 4: F-T JF Transport	0.1	0.1%	0.1	0.1%	0.1	0.1%
Stage 4: Conv. Jet Fuel LC	6.9	5.7%	6.9	8.1%	6.9	7.0%
Stage 4: Blended JF Transport	0.1	0.1%	0.1	0.1%	0.1	0.1%
Stage 5: Jet Fuel Use	71	59.2%	71	84.1%	71.4	72.7%
Life Cycle Total:	**121**	**100%**	**84.9**	**100%**	**98.2**	**100%**

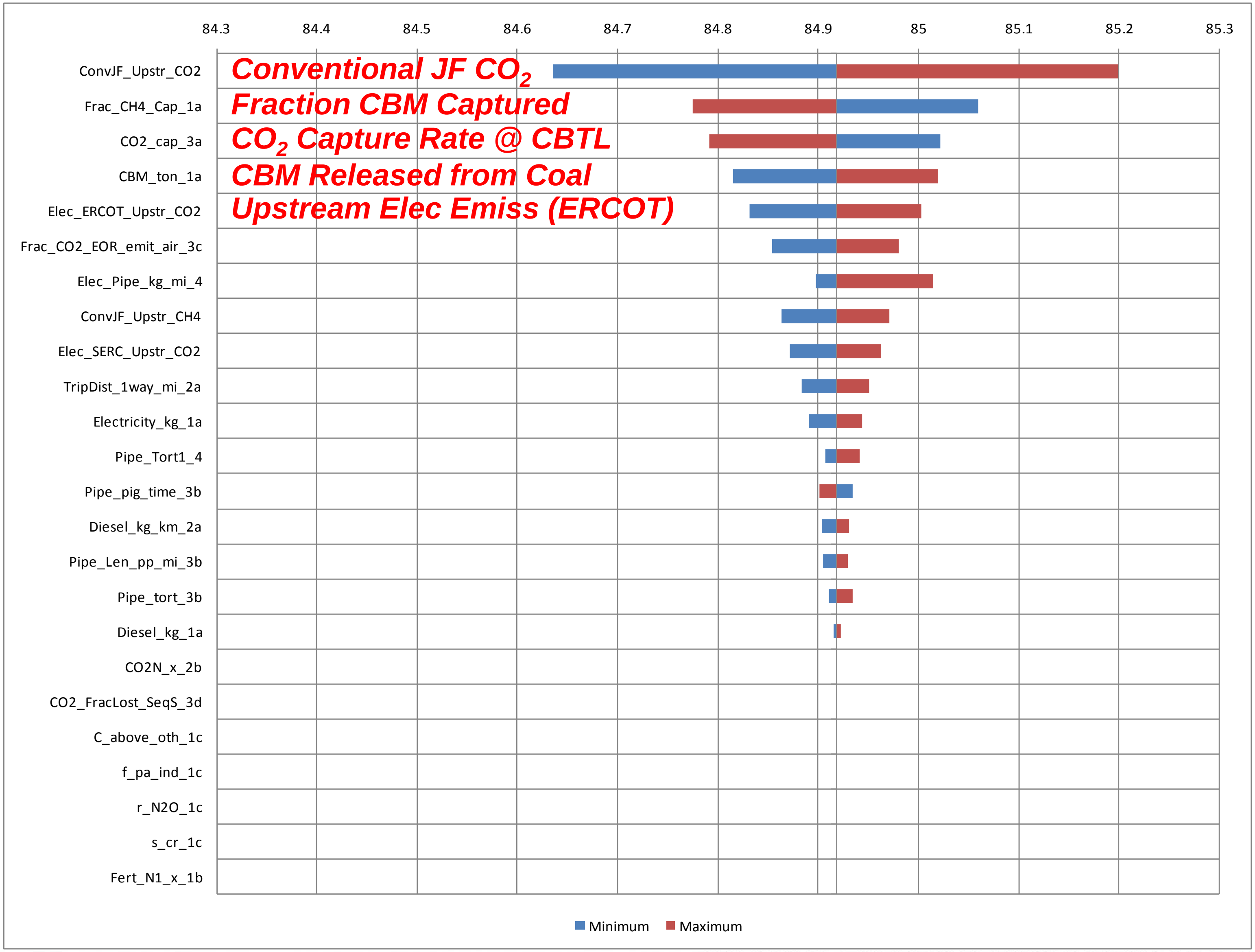
- **Conventional Jet Fuel Life Cycle Emissions:**
  - *87.4 g CO_2e/MJ LHV*

Scenario 1: Probabilistic Uncertainty Analysis
(2,000 Model Runs)

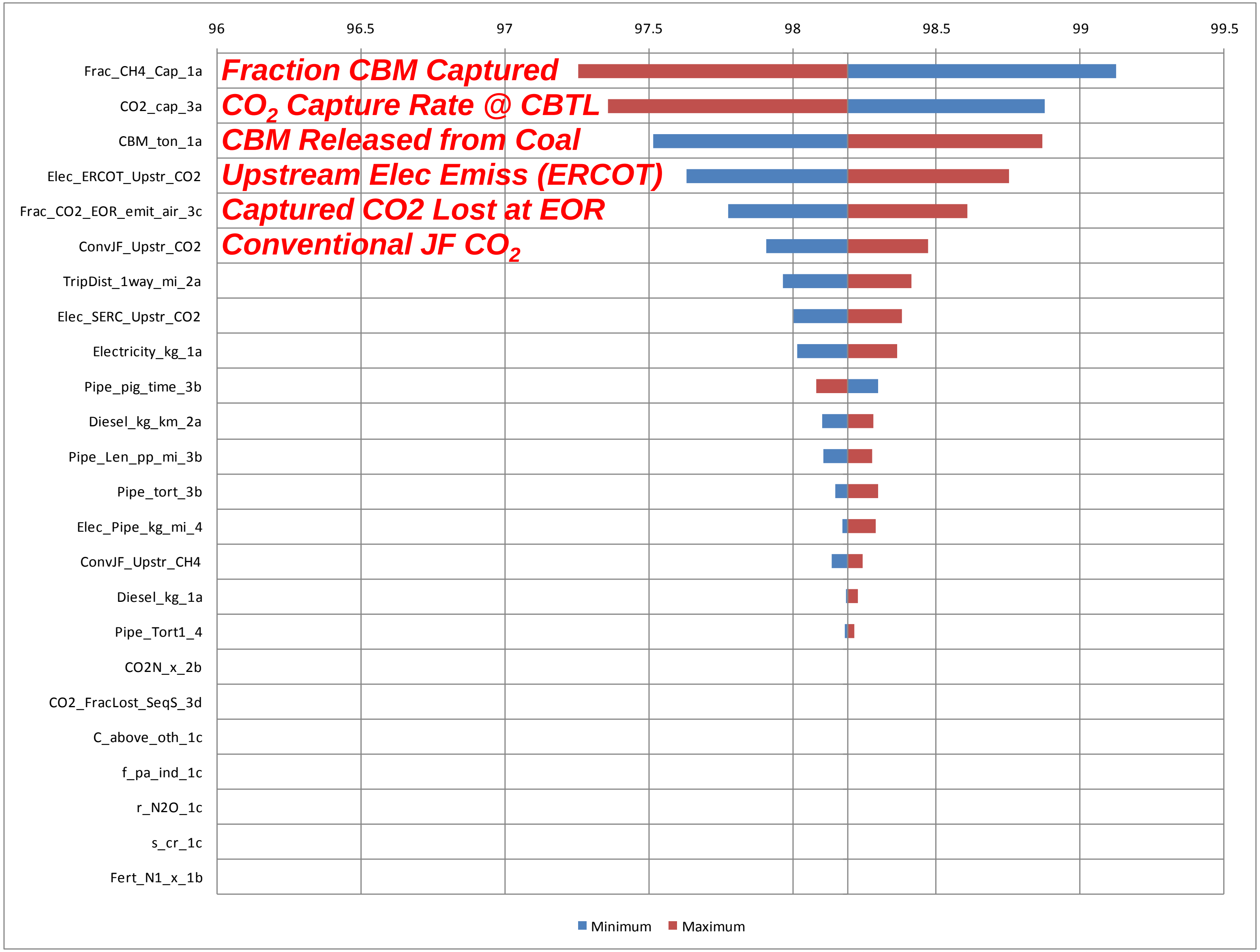


<u>Boxplot Key:</u> center line = median; top/bottom box = 75th/25th percentile; whiskers = min/max; x = study best estimate

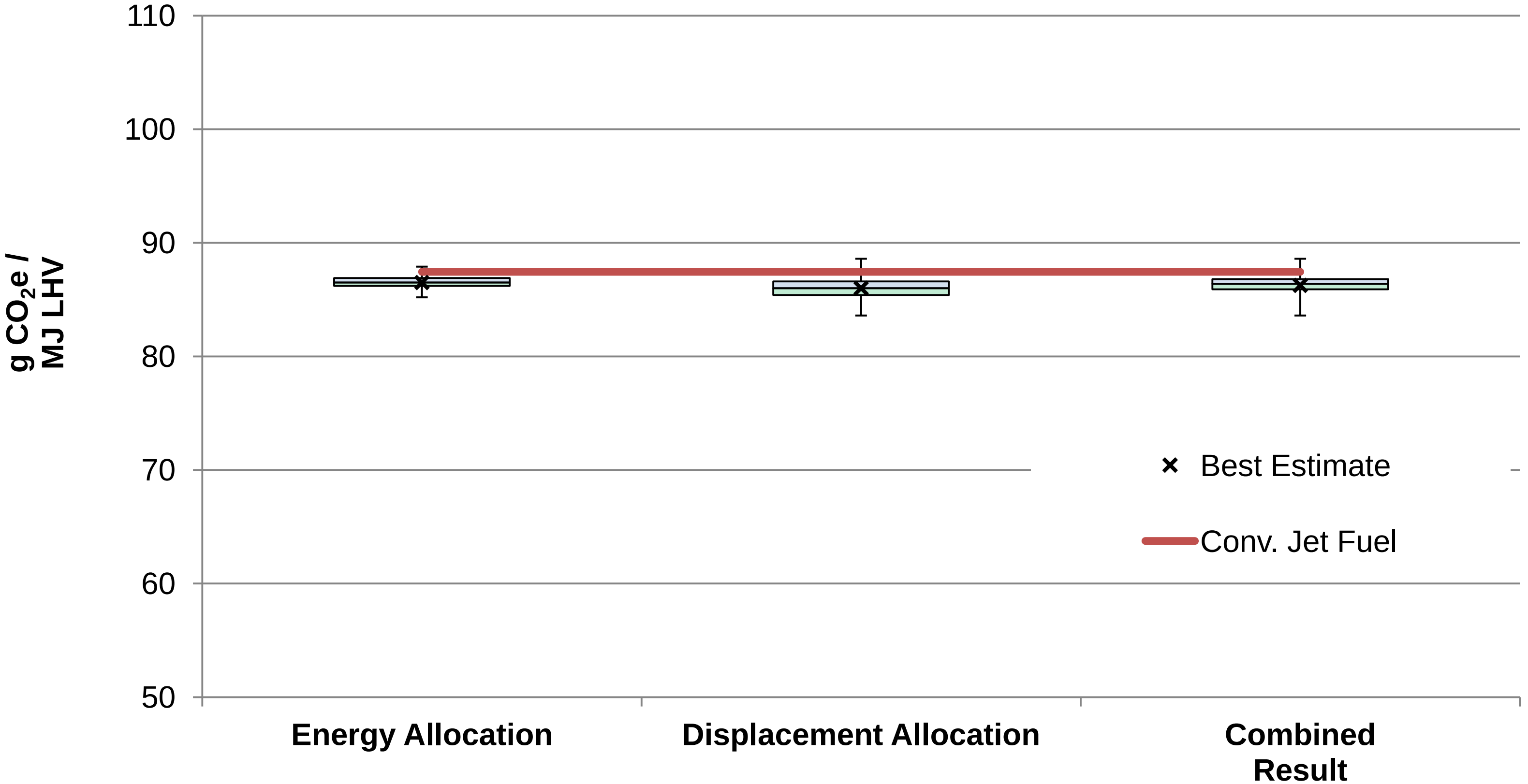
Scen. 1: Sensitivity Analysis, Energy Allocation



Sensitivity Analysis: Displacement Allocation

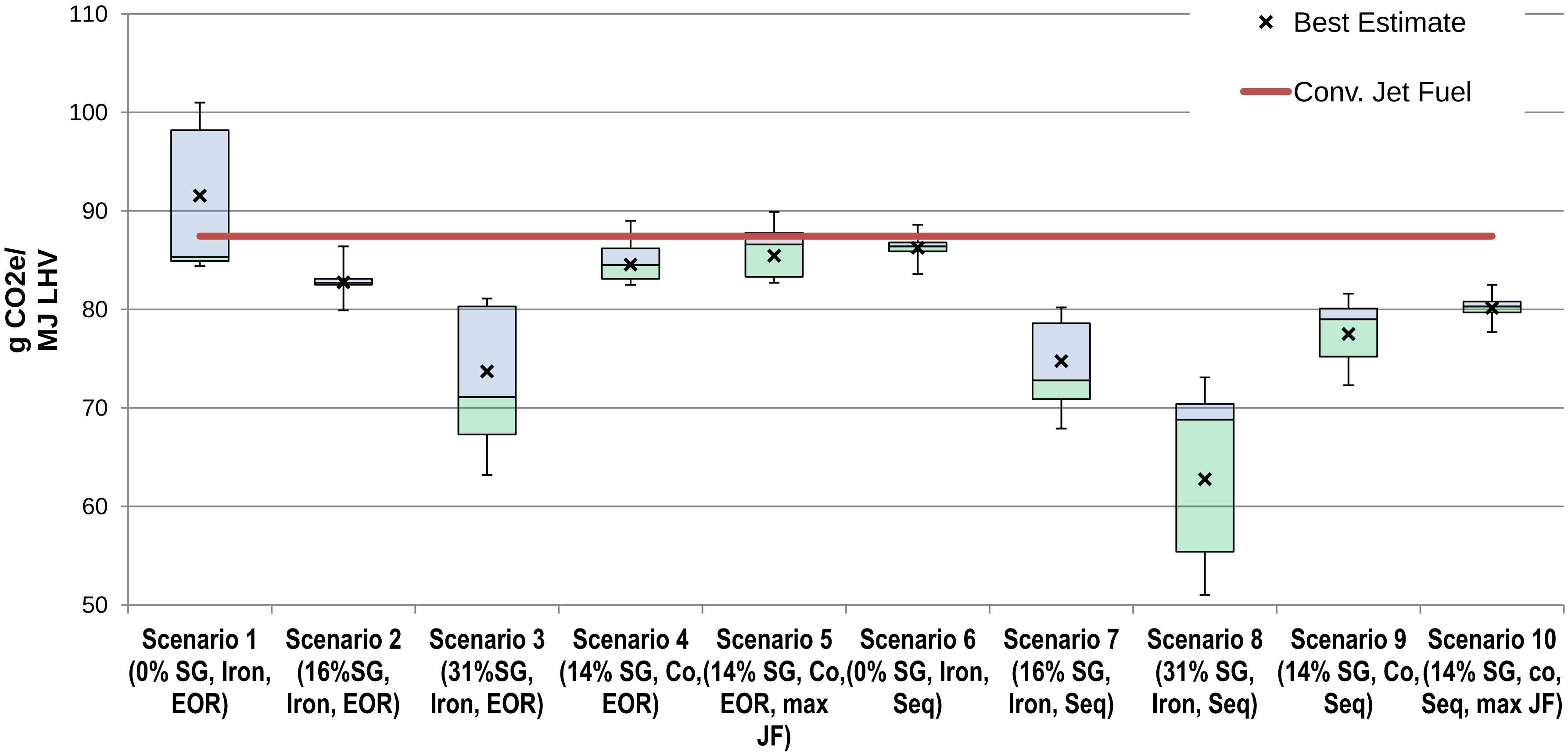


Scenario 6: Probabilistic Uncertainty Analysis
(100% Coal, 0% Switchgrass, Iron F-T Catalyst, Saline Seq.)



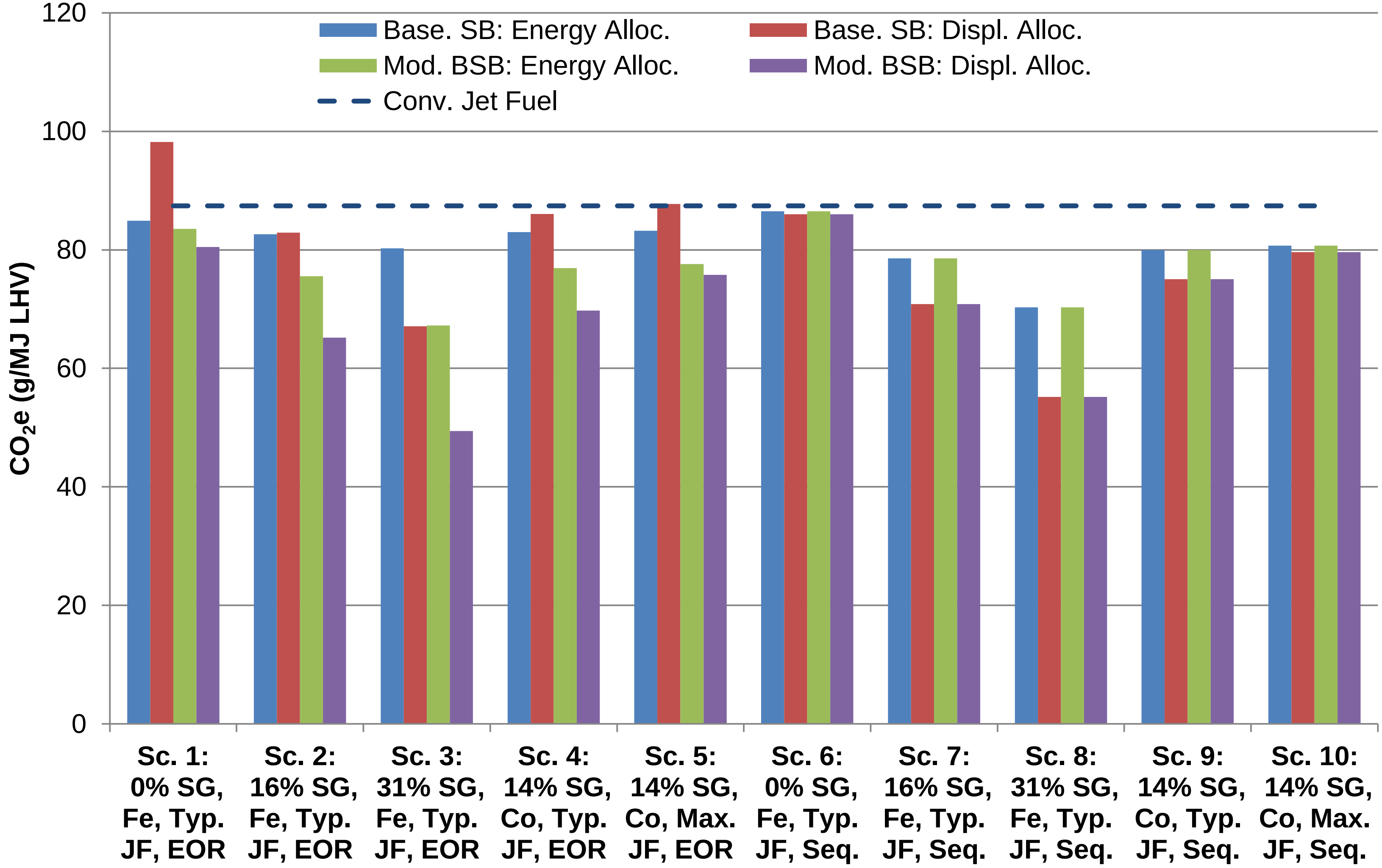
<u>Boxplot Key:</u> center line = median; top/bottom box = 75th/25th percentile; whiskers = min/max; x = study best estimate

CO_2e Emissions, All Scenarios
(g CO2e/MJ LHV)



Boxplot Key: *center line = median; top/bottom box = 75th/25th percentile; whiskers = min/max; x = study best estimate*

Comparison of Allocated CO_2e Emissions
(g CO2e/MJ LHV)



Study Conclusions

- **Coal to Liquids (0% biomass) viable with carbon capture and sequestration in a saline formation**
- **Factors that Substantially Affect Results:**
  - Biomass feed rate (0%-31%)
  - Coal Bed Methane emission rate (150 scf/ton)
  - Coal Bed Methane capture rate (40% capture rate)
  - Carbon Capture Rate (91% at CBTL Facility)
  - Carbon Management Strategy (saline sequestration vs EOR)
  - Allocation methods (Energy, Displacement, etc.)

Study Conclusions

- **Factors that Minimally Affect Results:**
  - F-T catalyst (iron or cobalt);
  - Switchgrass harvesting practices;
  - Facilities/equipment construction;
  - Finished fuels transport options
- **Most Env. Competitive Options**
  - 31% Switchgrass (Scenarios 3 and 8)
  - Saline sequestration over EOR (Scenario 8)
  - However: costs, siting, feasibility issues need to be addressed

Fighter Jet Hits Mach 2 on Synthetic Fuel Blend

By Noah Sachtman, August 21, 2008
Source: www.wired.com

[excerpt] An Air Force F-15 Eagle flew twice the speed of sound this week, using a synthetic fuel blend. The service has already flown some of its bigger, heavier aircraft — like the C-17 cargo plane and B-52 bomber — on the 50-50 blend of synthetics and standard JP-8 jet fuel. A B-1 even broke the sound barrier, using the mixture. But this is the first time a maneuverable, high-performance fighter has been powered by the stuff.

Thank you!

Questions?

For additional information about the IAWG-AF Jet Fuel Study contact:

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