PHASE II:
Large Pilot Testing of Linde-BASF Advanced Post-Combustion CO_2 Capture Technology at a Coal-Fired Power Plant (FE0031581)

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PROJECT OVERVIEW

Funding: $3,736,684
DOE: $2,988,359
20% Cost Share: $748,325
Work Period: Sept. 1, 2019 – Aug. 31, 2020

City Water, Light and Power (CWLP) Springfield, IL

PROJECT OBJECTIVES:

Overall: Design, construct, and operate a 10 MWe capture system based on the Linde / BASF advanced amine-based, post-combustion carbon dioxide (CO_2) capture technology at CWLP Dallman Unit 4, Springfield, IL.

Phase II: Front End Engineering Design (FEED) study along with obtaining necessary regulatory approvals and funds for Build / Operate in Phase III.

Large Pilot Team Management Structure

Well-defined roles based on relevant capabilities

CWLP

- Equipped with SCR, baghouse, WFDG, WESP

ICF
NEPA Contracting

PRIME CONTRACTOR
University of Illinois (UIUC)
Dr. Kevin C. O'Brien
Project management

Commercialization

SUBAWARDEE
Linde Gas North America LLC (Linde)
Makini Byron/Krish R. Krishnamurthy
Design and engineering,
ISBL Components

SUBAWARDEE
Affiliated Engineers Inc. (AEI)
David Guth, LEED AP
Engineering Design,
OSBL Components

SUBAWARDEE
Affiliated Construction Services (ACS)
Greg Larson
Procurement and Construction Management, **OSBL** Components

SUBAWARDEE
Linde Engineering – Region Americas (LERA)
Jim Nazzaro
- Detailed Engineering, **ISBL** Components
- Procurement and Construction, **ISBL** Components

SUBAWARDEE
Linde Engineering Dresden (LEDD)
Torsten Stoffregen
- Basic Engineering, **ISBL** Components

SUBAWARDEE
BASF
John Nichols
- Technology Package
- Manufacturing and Provision of Solvent

ISBL

OSBL

OASE® blue solvent

Capture Technology Evaluated up to 1.5 MWe

TECHNICAL BACKGROUND

Solvent and System Designed for Improved Performance

Reduced capital costs / energy costs

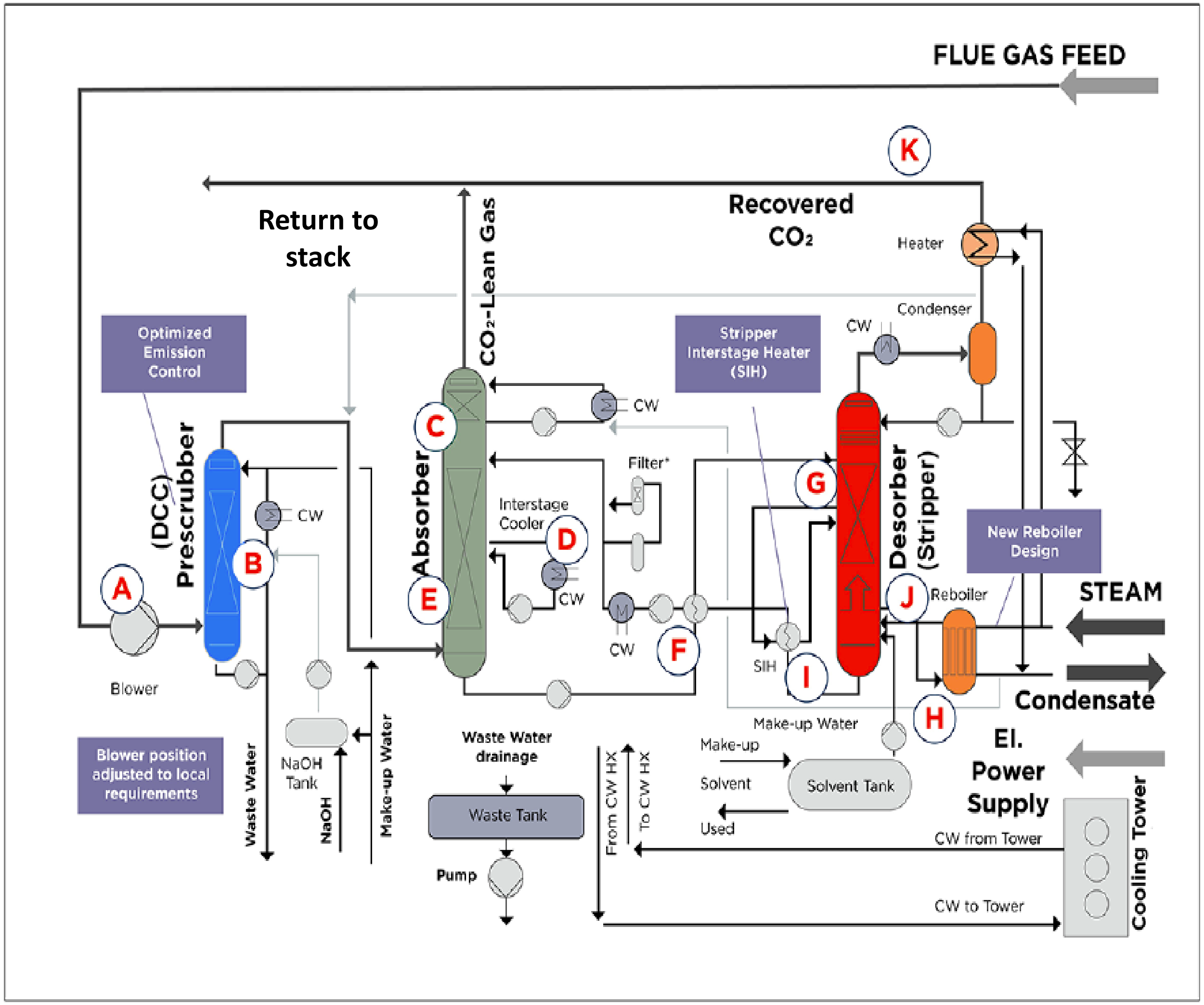
- Optimized BASF OASE® blue solvent
- Efficient CO_2 capture from low-pressure sources
- Longer solvent stability
- Lower solvent circulation rate

Notable Linde process improvements

(C, E) Dry bed water wash design to minimize solvent losses

(G) Stripper regeneration at 3.4 bars reducing CO_2 compressor cost and power consumption

(I) Advanced Stripper Interstage Heater to reduce regenerator steam consumption.



Project Technology Development 2004-present

Development Scale	Year	Size, MWe	Scale-Up Factor*	Development Strategy
Lab scale: mini pilot tests	2004	0.015		Solvent selection and proof-of-concept under laboratory conditions
Bench scale: Niederaussem	2009	0.45	30	Solvent performance validation and emissions control testing under realistic conditions
Small pilot : NCC	2016	1.5	3	Validation of unique process features aimed at reducing capex, such as high structure packing, gravity-driven absorber inter-stage cooler, and unique reboiler design
Proposed large-scale pilot	2020	10	7	Equipment performance validation at commercially relevant scale (i.e., uniform gas/liquid distribution in absorber and inter-stage heating in the stripper)
First commercial plant	2025	100-250	10-25	At scale demonstration of complete CCS value chain (i.e., capture, compression, transport, and storage/utilization)
nth commercial plant	2030+	500+	2-5	Safe, reliable and economical operation in compliance with regulations

*Scale-up assumes PCC capacity of 20 tpd captured CO_2 for every 1 MWe (flue gas has 13% CO_2 concentration).

Attractive Techno-Economics for Linde / BASF Process

Baseline case: DOE-NETL supercritical PC power plants

Parameter	DOE-NETL Case B12A	DOE-NETL Case B12B	Linde-BASF LB1	Linde-BASF SIH	Linde-BASF WHR
Description	No CO_2 capture	90% CO_2 Capture w/ Cansolv PCC process	90% CO_2 Capture w/ OASE® blue	90% CO_2 Capture w/ OASE® blue and SIH	90% CO_2 Capture w/ OASE® blue, SIH, and WHR
Net Power Output (MWe)	550	550	550	550	550
Gross Power Output (MWe)	580	642	630.4	629.3	626.3
Coal flow rate (tonne/hr)	179.2	224.8	221.9	218.5	210
Net HHV plant efficiency (%)	40.70%	32.50%	3297.88%	33.40%	34.73%
Total Overnight Cost ($2011) ($/MM)	$1,379	$2,384	$1,970	$1,950	$1,921
Cost of CO_2 captured with T&S ($/MT)*	N/A	$68.00	$53.58	$52.71	$51.31
Cost of CO_2 captured without T&S ($/MT)*	N/A	$58.00	$43.58	$42.71	$41.31
COE ($/MWh) with T&S*	$82.30	$142.80	$127.97	$126.50	123.63
PCC specific reboiler duty (MJ/kg CO_2)	N/A	2.48	2.6	2.3	1.5

* T&S: Transport and Storage

Key Phase I Activity

HOST SITE SELECTION

Example of the Challenge: Selecting the Host Site

Selection process used in recent Large-Scale Capture Pilot (10 MWe)

	Site Selection Criteria
Technical	Flue gas availability
	Flue gas CO_2 concentration
	Aerosol concentration in flue gas
	Steam and utility availability for ISBL
	Design costs for OSBL
	Available plot size for ISBL
	Use of domestic coal
	Existing abatement equipment (FGD, ESP, SCR, etc.)
	Logistics of transportation and lifting
Regulatory and Environmental	Permitting requirements
	Permitting timelines
	Supports NEPA
	Safety culture
Financial and Business Agreements	Cost share commitment
	Contractual terms and conditions
	Site interest
	Sign-off requirements
	Potential for capture system to permanently remain
	Interest in serving as future training site
	Personnel support and responsiveness

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Three Power Plants Evaluated in Phase I

****CWLP was selected for Phase II and Phase III***

Abbott Power Plant : UIUC campus

**City Water, Light and Power (CWLP): Springfield*

Prairie State Generating Company (PSGC): Marissa

City Water, Light and Power (CWLP)

Water and power supplier for City of Springfield

Phase II

PROJECT MANAGEMENT

Project Tasks

Designed for smooth transition to Phase III

Task #	Task
1.0	Project Management and Planning
2.0	Front-End Engineering Design (FEED)
3.0	NEPA / Permitting at Host Site
4.0	Team and Cost Share Commitments for Phase III
5.0	Updated Techno-Economic Analysis (TEA)

Milestones for Phase II

Budget Period	Task Number	Description	Planned Completion Date	Actual Completion Date	Verification Method
1	1	Updated Project Management Plan	8/31/2019		Project Management Plan file
1	2	Finalized FEED study	7/31/2020		Topical Report File
1	3	NEPA and permitting documentation complete	7/31/2020		Topical Report File
1	4	Phase III cost share commitments complete	7/31/2020		Topical Report File
1	5	Updated TEA	7/31/2020		Topical Report File
1	1	Phase II Topical Report Completed	7/31/2020		Topical Report File
1	1	Quarterly RPPR report	Each quarter		RPPR files

Success Criteria : Phase II

- ***Technical Milestone***: FEED study complete with costs and schedules developed and bid-ready documentation;
- ***Regulatory Milestone***: Complete the NEPA process as well as the ability to have permit paperwork ready to be submitted to the appropriate agencies;
- ***Financial Milestone***: Cost share commitment in place for Phase III.

Achieving project milestones with updated techno-economic evaluation enables the project team to smoothly transition to Phase III (Build & Operate).

Probability Impact Matrix : Phase II

Probability of Occurrence	Very Low	Low	Medium	High	Very High
Very High					
High					
Medium			▪ Energy optimization not validated	▪ Project cost overruns ▪ Uncertainty of NEPA determination	
Low			▪ Unknown flue gas contaminants ▪ Wastewater management ▪ Negative stakeholder response	▪ Absorber scale-up ▪ Solvent handling and supply ▪ Uncertainty of time for permits	
Very Low			▪ Integration with host site ▪ Unavailability of operators	▪ Non-availability of flue gas/utilities	

Impact of Risk

Risk & Mitigation Strategy: Phase II

Shown for those Medium Probability or greater, and High Impact

Description of Risk	Probability	Impact	Mitigation and Response Strategy
Project Cost Overruns	Medium	High	More of an issue for Phase III, addressed through clear scope definition, supplier / vendor selection, and completion of full engineering prior to procurement
Uncertainty of NEPA determination	Medium	High	Quotes obtained for both CX and EA from NEPA contractor

Identifying Challenges to Phases II & III

None are insurmountable

Challenge to Phase II and Phase III Execution	Team's Response
Aerosol concentrations in the flue gas	Aerosol measurements taken in Phase I indicate the aerosol formation will likely not be an issue for the 10 MWe project and aerosol mitigation technologies are not necessary.
Limited space available for OSBL connections	The off-take and return lines will be made 150 feet above the ground. These factors have been accounted for in OSBL costs from Phase I
Location of flue-gas offtake relative to Continuous Emissions Monitoring System (CEMS)	CEMS inside the stack and access to flue gas after the CEMS requires breach of fiberglass. Therefore, the plan is to return captured gas to the stack where it can be monitored. Discussions with IEPA will continue during Phase II for acceptance.
Permitting timelines	Strong relationships between the applicant and all relevant regulatory agencies will be leveraged for expediency. All permit-related paperwork for Phase III will be completed during Phase II.
Host site commitment	Bipartisan support has been obtained from elected officials at the local, state, and federal level. UIUC has presented at public forums and will continue to engage the public on the progress of the pilot.
Cost share from the state of Illinois	The previous success in obtaining a financial commitment for a large-scale pilot in Illinois demonstrates the willingness of the state to support such a project. Discussions have already been initiated with state and federal elected officials regarding the need for this cost share support. They appreciate the importance of a large-scale capture pilot and see value not only in having the pilot in Illinois, but at a location close to the state Capital.

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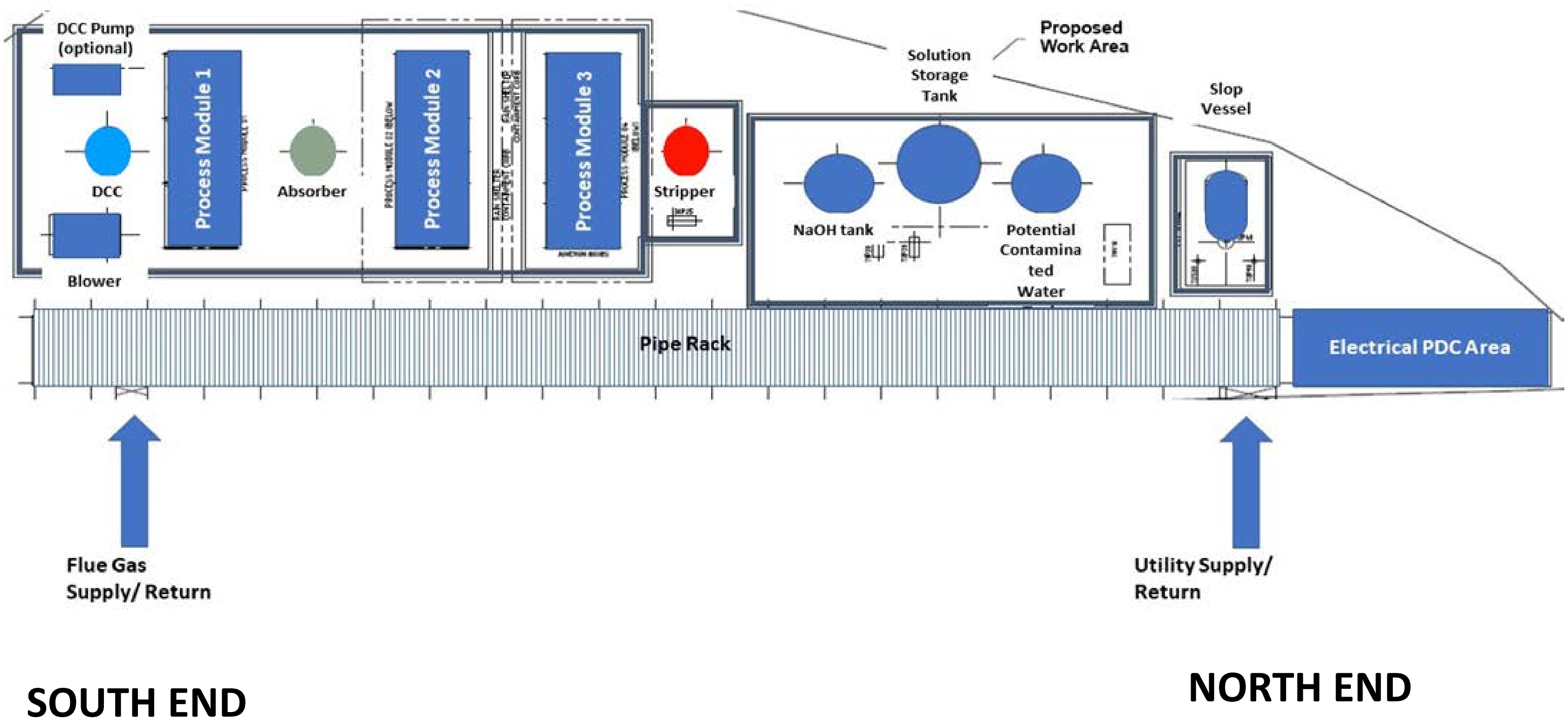
Phase I

RESULTS FROM PRELIMINARY ENGINEERING

OSBL Challenge at CWLP

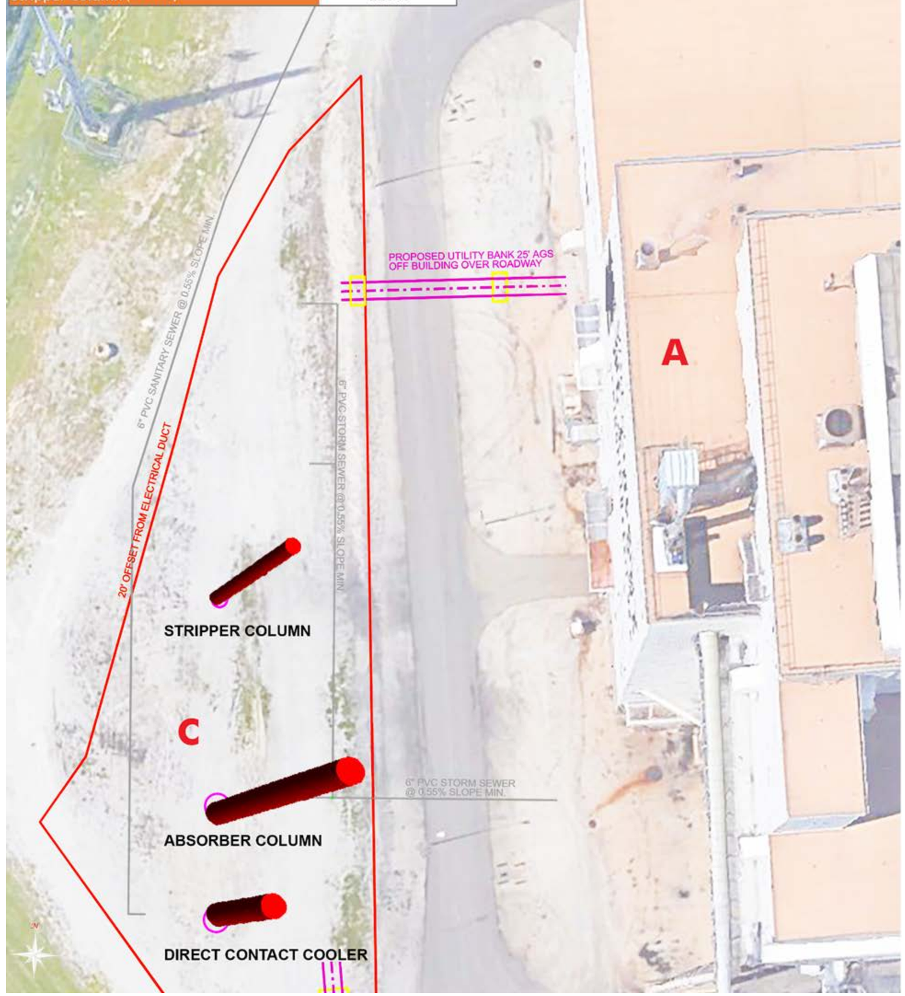
Layout of 10 MWe Capture Plant at CWLP



Overview of Plant Layout at CWLP: South End

Overview of Plant Layout at CWLP: North End

Elevations of the three main vessels	Estimated top of vessel elevation
Direct Contact Cooler (10T10)	90 ft
Absorber Column (20T10)	190 ft
Stripper Column (30T10)	120 ft



Projected Views of Absorber, Stripper, and DCC Columns from Interstate 55

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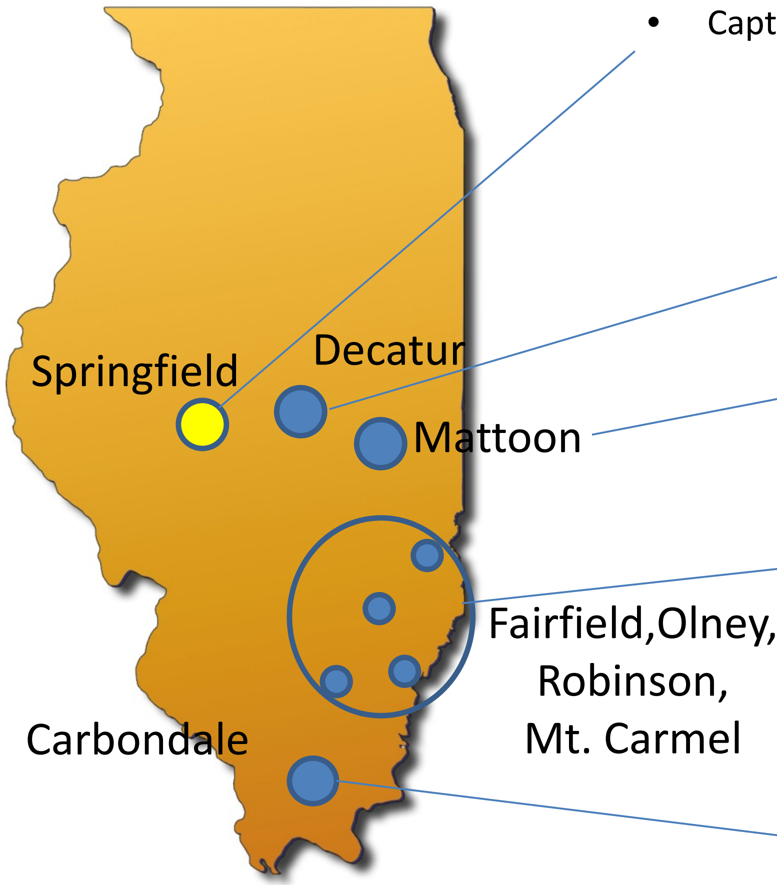
Regional & Global Test Bed for CCUS

Concentration of natural resources and intellectual capital



- Capture of CO_2 : DOE Project Phase II
- Storage of CO_2 : ADM Project
- Utilization of CO_2 : Enhanced Oil Recovery (EOR)
- Operator Training
- Coal combustion

Acknowledgements

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John Nichols	BASF
David Guth	Affiliated Engineers Inc (AEI)
Greg Larson	Affiliated Construction Services (ACS)

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