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Update on the status and prospects of microalgae for biofuels and bioenergy

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innovations kompetenz

Overview

- IEA Bioenergy Inter-Task Report
- Support and funding for algae
- Overview of technology routes
- Biorefineries and bioproducts
- Techno-economic analysis
- Sutainability and LCA
- General trends worldwide
- Situation in Austria
- Key messages

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IEA Bioenergy Report
2016 State of Technology Review – Algae Bioenergy

- **Inter-Task Report** of IEA Bioenergy Task 34, 37, 38, 39, 42
- **Update** to Task 39 report published in 2010
- „Algaehype“ and overly optimistic outlook had been relativized
- **Tremendous progress** in technical feasibility – projects, pilot plants, demo plants

Source: IEA Bioenergy

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Support and funding for algae technology development in North America

- **NAABB** National Alliance for Algal Biofuels and Bioproducts ($44M)
- 3 **integrated biorefinery demonstration plants** ($97M)
  - Solazyme – lignocellulosis to biodiesel and renewable diesel, heterotrophic algae
  - Algenol – light and CO_2 to ethanol, cyanobacteria, development of economic PBR
  - Sapphire – renewable biocrude for upgrading to jetfuel and diesel fuels, 121 ha plant
- Other funded **consortia** (CAB-Comm, SABC, Cornell Marine Algal Biofuels Consortium, ATP^3, RAFT)

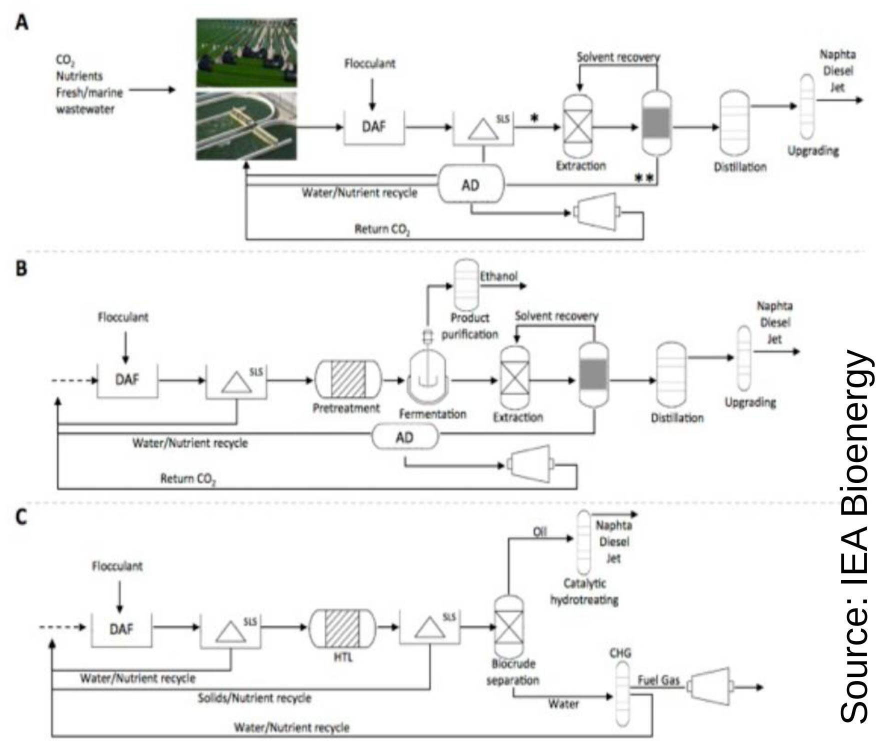
- **Canada**: ACC Algal Carbon Conversion Flagship Program

Support and funding for algae technology development in Europe

- **AQUAFUELS** project (2009)
- **AlgaeCluster** (€31M, each 10 ha)
  - InteSusAl – Combination of photobioreactors and fermentors for production of biofuels (biodiesel)
  - All-Gas – Mixture of algae and bacteria to clean wastewater and produce fuel
  - BioFAT – Coupled production of biodiesel and bioethanol
- **Other EU projects**: AlgaeBioGas, DEMA, D-Factory, EnAlgae, Fuel4Me

Overview of technology routes

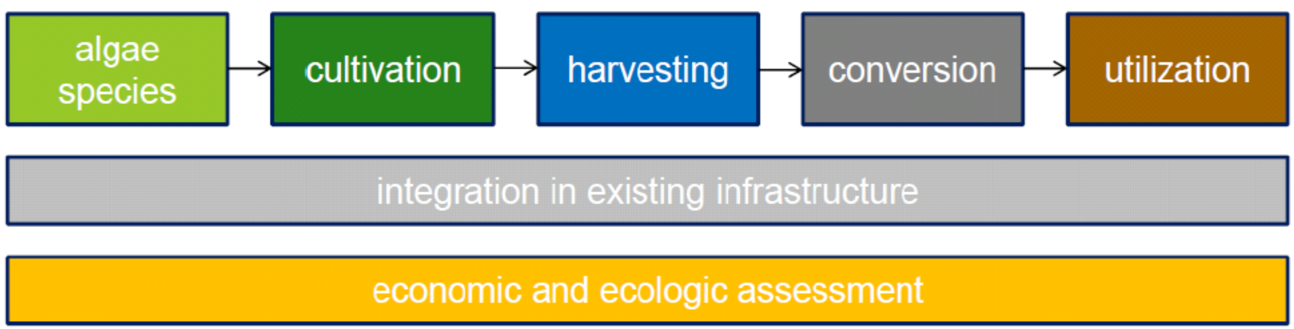
- Biomass production
  - Estimation best case: 280-410 t/ha/a
  - Demonstrated yields: 60-182 t/ha/a
- Biochemical and thermochemical conversion of biomass
  - Biodiesel
  - Renewable diesel
  - Jet Fuel
  - Bioethanol
- **Biorefinery approach**



Source: IEA Bioenergy

Biorefineries and bioproducts

- A **biorefinery** is defined as a facility in which algal biomass can be sustainably processed into a spectrum of bio-based products (food, animal feed, chemicals, and materials) and bioenergy products (biofuels, power and/or heat).
- **Research Programm Framework**
  - Whole Chain Approach



Source: Own compilation

  - Multidisciplinary Approach
  - Bridge from Fundamental Research to Applications

Techno-economic analysis I

- Assessment of **process feasibility** and **commercial viability**
- „What is the cost of algal biofuels?“
- **Complexity** of TEA
  - Many inputs and outputs
  - Inter-relationsships
  - Different algae production processes
  - Constant further development and improvement
  - Unsafe data sources (infancy of technolgies)
  - Biological parameters and reactor design
  - Local conditions (taxes, financial support, …)

Techno-economic analysis II

- List of **important parameters** for algae cultivation

Metric	Unit	Notes
1. Cultivation: Continuous data - weather		
Precipitation	cm/day	Precipitation data (as available from weather events)
Air temperature	°C	Minimum hourly basis
Dew point temperature	°C	Hourly basis
Solar radiation/insolation	W/m^2	Hourly basis
Wind speed	m/s	Hourly basis
Air pressure	mm Hg	Hourly basis
2. Cultivation: Continuous data - culture		
Water salinity	mg/L	
Water pH	pH	
Water temperature	°C	
Dissolved oxygen	mg/L	
Oxidation reductive potential	mV	
Photosynthetically active radiation (PAR)	$\mu mol/m^2$ sec	Hourly basis
3. Cultivation: Installation/logistics		
Land use/cost		Upon installation
Polyethylene consumption	m^3/ha	
Scale of production (pond/cultivation size)	ha	
Days of operation		Steady state/dynamic/culture crash ratio

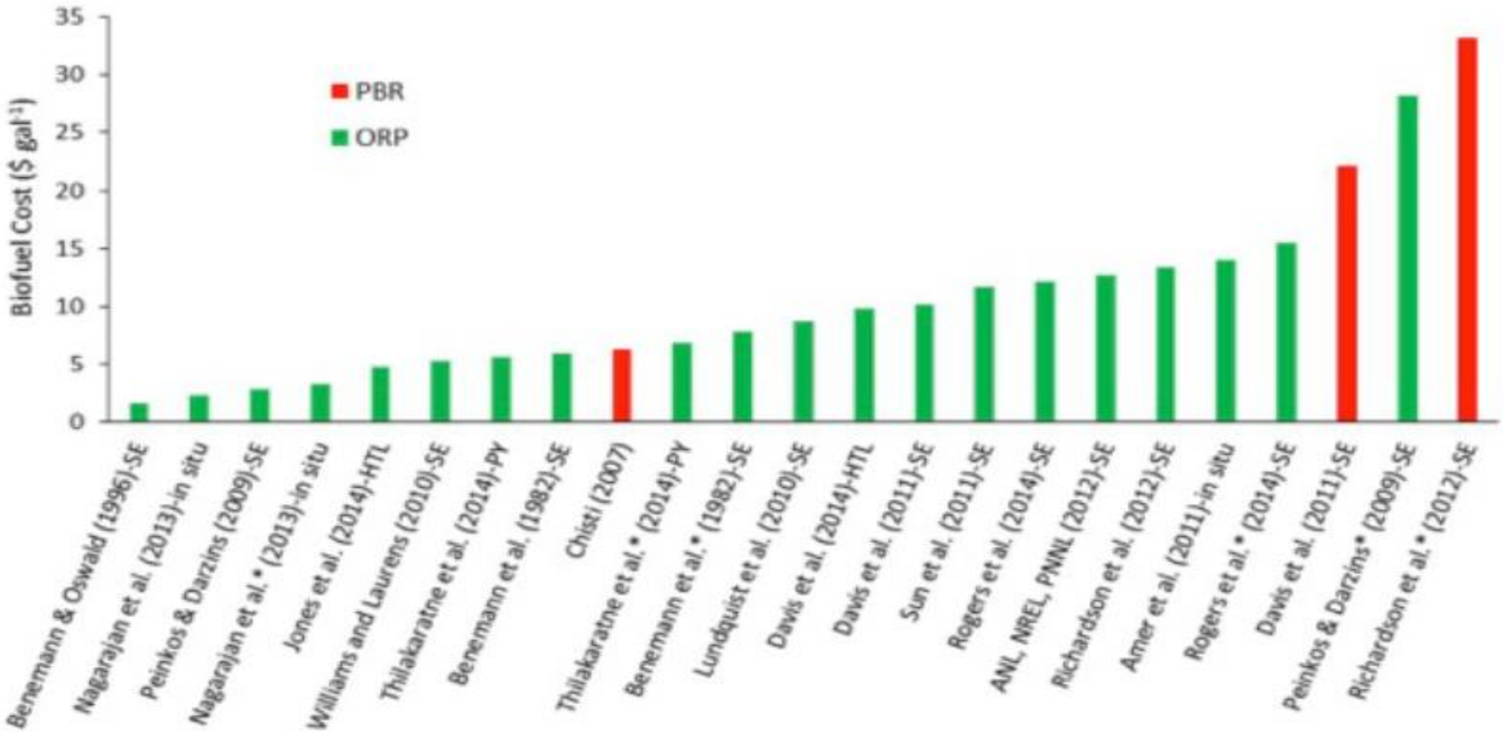
Source: IEA Bioenergy

Techno-economic analysis III

- **Sensitivity analysis**:
  - Highest impact factor over the entire process are algal strain-specific biological parameters
    - Specific lipid content
    - Growth rate
  - Further possibilites for optimization:
    - Operating days per year
    - Degree of nutrient recycle
  - Production of algae biomass accounts for 65-85 % of total production costs of algal biofuel
    - Cost range: 541 $/t (OP, Arizona) to 10.177 $/t (PBR, Niederlande)

Techno-economic analysis IV

- High range of results in literature



Source: IEA Bioenergy

- → **Harmonisation** is of tremendous importance

Techno-economic analysis V

- 2 big challenges:
  - **Harmonization** and **standardization** of the models and methodologies
  - **Model Validation** - Accessibility to pilot and demonstration experimental data from different locations

Sustainability and LCA I

- Life Cycle Assessment = tool to quantify environmental impacts
- LCA highly dependent on **system boundaries** and assumptions
- **ISO LCA standard** – selection of system boundaries and functional units variable
- → comparison of different LCA studies difficult
  - System boundaries, co-products, assumptions, infancy of technology, extrapolation of lab and pilot plants

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Sustainability and LCA II

- **Set of indicators** for assessing sustainability of algal biofuels

Category	Indicator	Unit	Potential environmental effects
Soil quality	Bulk density	g/cm^3	Water holding capacity, infiltration, crop nutrient availability
	Terrestrial acidification	kg SO2 equivalent to air	
	Terrestrial ecotoxicity	kg 1,4 dichlorobenzene to industrial soil	
Water quantity	Peak storm flow	L/s	Erosion, sediment loading, infiltration
	Minimum base flow	L/s	Habitat degradation, lack of dissolved oxygen
	Consumptive water use (incorporates base flow)	feedstock production: m^3/ha/day; biorefinery:m3/day	Availability of water for other uses
Water quality	Nitrate concentration in streams (and export)	concentration (mg/L, ppm); export kg/ha/yr	Eutrophication, hypoxia, potability
	Total phosphorus (P) concentration in streams (and export)	concentration (mg/L, ppm); export kg/ha/yr	Eutrophication, hypoxia
	Salinity	Conductivity (no unit)	water composition change
	Fresh/Marine water eutrofication	kg P and N equivalent	
	Water ecotoxicity	kg 1,4 dichlorobenzene	
Greenhouse gases	CO_2 equivalent emissions (CO_2 and N_2O)	kg C eq/GJ	Climate change, plant growth

Land use	Agricultural/Urban land occupation	m^2 x year of land	
	Natural land transformation	m^2 x year of natural land	
Resource depletion	Mineral resource depletion	kg Fe equivalent	
	Fossil resource depletion	kg oil eq	
Biodiversity	Presence of taxa of special concern	presence	increased or decreased biodiversity
	Habitat of taxa of special concern	ha	increased or decreased biodiversity
	Abundance of released algae	number/L	increased or decreased biodiversity
Air quality	Tropospheric ozone	ppb	human and plant health
	carbon monoxide	ppm	human health
	Total particulate matter less than 2.5 um diameter (PM2.5)	µg/m^3	visibility and human health
	Total particulate matter less than 10 um diameter (PM10)	µg/m^3	visability and human health
	Ozone depletion	kg CFC-11 equivalent	
	Human air toxicity	kg 1,4 dichlorobenzene to urban air	
	Photochemical oxidant formation	kg NMVOC compound equivalent to air	
Productivity	Primary productivity or yield	gC/L/year or based on chlorophyll a	Climate change, soil fertility, cycling of carbon and other nutrients

Source: IEA Bioenergy

Sustainability and LCA III

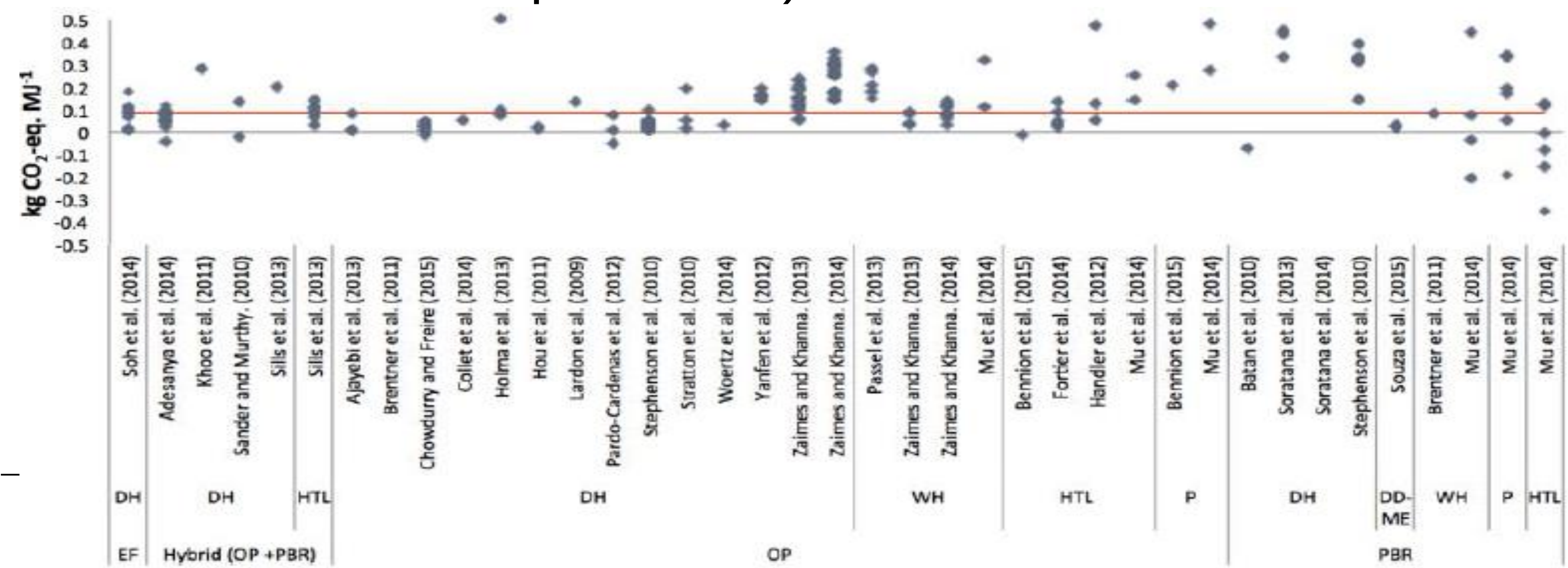
- Identified **major sustainability concerns** (NRC Report):
  - Quantity of water and quantity of freshwater addition
  - Supply of key nutrients for algal growth (N, P, CO2)
  - Appropriate land area with suitable climate and resources
  - Energy return on Investment (EROI)
  - GHG emissions over the life cycle of algal biofuels

Sustainability and LCA IV

- **Comparison** of 29 LCA studies (2009-2015)
  - Results of each study were converted to 1 MJ as the functional unit
  - **Systems vary** in terms of cultivation, harvesting, extraction and conversion processes, assumed growth rates and lipid content
  - Productivities: 2 g DM m-2 day-1 to 65 g DM m-2 day-1
  - Lipid Content: 7% to 50%

Sustainability and LCA V

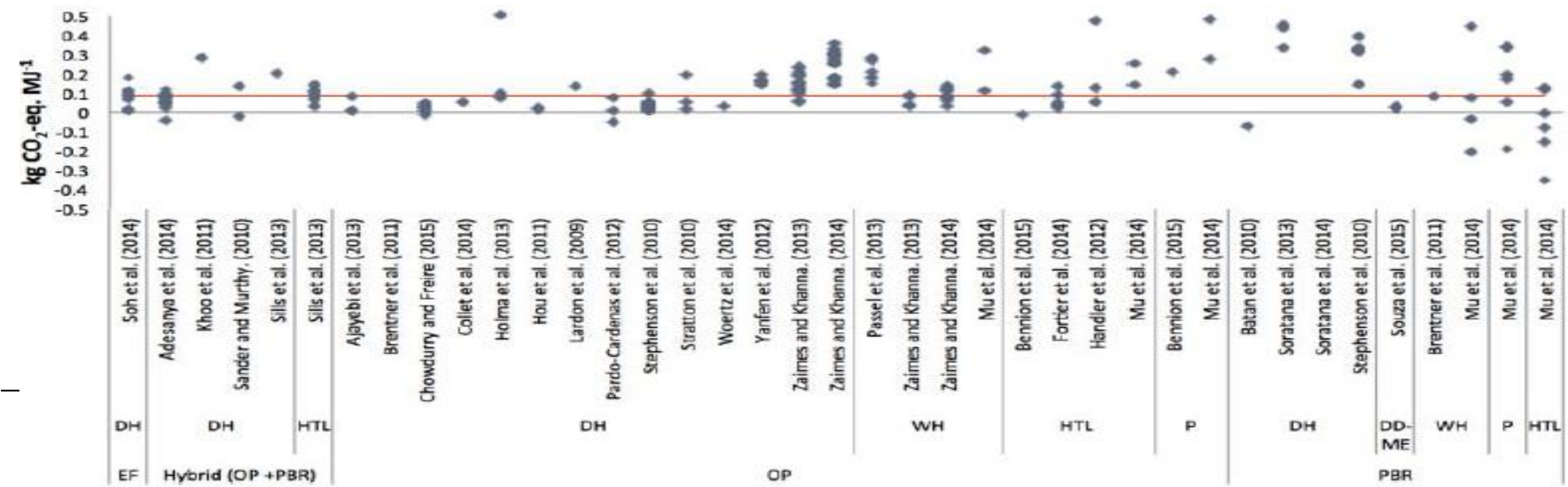
- **GHG emissions** varied from -2,6 to 7,3 kg CO2eq MJ-1
- > 85% between -0,35 and 0,5 kg CO2eq MJ-1
  - Reasons for differences: Modelling choices (handling co-products, alternative cultivation, harvesting, extraction processes)



Source: IEA Bioenergy

Sustainability and LCA VI

- 7 studies reported **negative GHG emissions**
  - Reasons: handling co-products via substitution, exclusion of combustion from system boundary
- > 60% reported emissions **higher than fossil diesel**
  - Reasons: energy-intensive technologies for cultivation and harvesting



Source: IEA Bioenergy

Sustainability and LCA VII

- Important for **future LCA studies** and for reduction of GHG emissions of microalgae biofuels:
  - Development of less energy-intensive technologies for cultivation and harvesting
  - Resource Assessment (RA) for algae operations
  - Conduction of uncertainty assessment
  - Future LCA studies on commercial systems

General trends worldwide

- **Redirecting focus** to food, feed and speciality products
  - Solazyme → TerraVia
  - Solix Biofuels → Solixalgredients
  - Petroalgae → Parabel
  - HR Biopetroleum → Cellana
- **USA**: Great amount of business activities
- **Asia**: focus on production of seaweed as food crop
- **Europe**: many funded research projects, focus on microalgae for biofuels and cosmetica

Situation in Austria

- **Network Algae** since 2013
  - Funded by Austrian Ministry for Transport, Innovation and Technology
  - Next Workshop February 2017
  - First focus on biofuels – changed to high value products
  - Many projects and research in Austria
  - Some companies as technology provider for cultivation systems
  - Variety of production routes

Summary and key messages

- Significant progress in algae cultivation and conversion with demonstrated deployment since 2010
- Low petroleum price challenges cost-competitve production of algal based fuels
- Algae-based industry greatly expanded including development of higher value products
- Algal biofuels not economically viable in the near to intermediate term
- Nearer term opportunity: **Integraded Biorefinery**

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