IEA Bioenergy
Technology Collaboration Programme

Workshop on Guidelines to overcome barriers for commercialization of advanced biofuels

Learnings in biofuel developments

"Meta-analysis of studies addressing learnings in biofuels

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Project: Lessons learned biofuels
IEA-B Tasks 39, 40, and 45

WP-2 Meta-analysis of existing studies

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Lessons Learned Project

Work Packages

„Lessons learned biofuels I“ (Triennium 2019-2021)

WP 1 | Status quo biofuel projects
T39 (Lead), T45
Overview TRL, capacities of biofuels projects, Wrap up national programs
Existing sustainability / certification schemes

WP 2 | Meta-analysis existing studies
T45 (Lead), T39, T40
Inventory of studies, specifically addressing lessons learned biofuels
Screening with criteria to be defined

WP 6 | Project manag
T39 (Le

WP 3 | Case studies technologies
T39 (Lead)
Success stories for dedicated technologies and regions, (e.g. US, EU, Brazil)

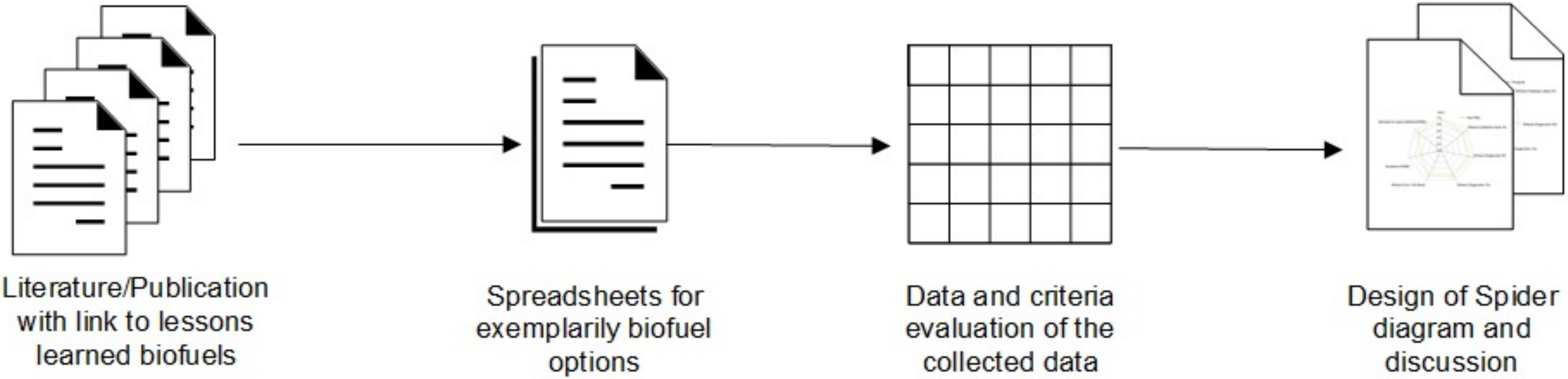
WP 4 | Case studies supply chains
T40 (Lead), T45
Success stories for biomass supply chains

WP 5 | Synopsis / synthesis of key issues
T39 (Lead), T40, T45
Conclusions, guideline „good to know“ for decision makers, identification of required actions for *„Lessons learned biofuels II“*

WP-2 Meta-analysis of existing studies

- Inventory of studies specifically addressing lessons learned biofuels
- Relevant studies were screened, and main findings were summarized
- A set of indicators were established to compare biofuels

WP-2 Procedures



Indicators and grading used to compare biofuels

Biofuel/Biofuel Technology:		Evaluation criteria (point attributed to each answer)
TRL (Technology Readiness Level)	TRL 7 – system prototype demonstration in operational environment	TRL 7 = 1 (integrated in implementation)
	TRL 8 – system complete and qualified	TRL 8 = 2 (integrated in implementation)
	TRL 9 – actual system proven in operational environment	TRL 9 = 3 (integrated in implementation)
Biofuel main use		-
Principle feedstocks:	Type of feedstock	Crop = 1; Residue = 2
	Please indicate if domestic or imported	
	Feedstock availability	Low = 1; Medium = 2; High = 3
	Feedstock yield	Low = 1; Medium = 2; High = 3
	Planted area	Not applicable = 4; Low = 3; Medium = 2; High = 1
	Soil-climate requirements	Not applicable = 4; Low = 3; Medium = 2; High = 1
Products:	If commercial production include output (m3/yr, t/yr, other)	-
	Biofuel yield (per unit feedstock, land, etc.)	-
	Co-products – low value	Yes = 1 (For each product); No =0
	Co-products – medium value	Yes = 1,5 (For each product); No =0
	Co-products – high value	Yes = 3 (For each product); No =0
SDGs	1-17	Yes = 2; Partially = 1; No or Not applicable = 0

Indicators and grading used to compare biofuels (II)

Biofuel/Biofuel Technology:		Evaluation criteria (point attributed to each answer)
Economics:	Economics considered?	-
	Biofuel production costs (or sales cost)?	-
	CAPEX available?	-
	OPEX available?	-
Public policies:	Did any mandate support the introduction?	Yes = 1; No =0
	Does it require subsidies?	Yes = 1; No =0
	Are there relevant laws and regulations?	Yes = 1; No =0
	Does it have public acceptance?	Yes = 2; Partially = 1; No =0
Environmental impact:	GHG Emissions (g CO2e/MJ)	Savings > 85 = 3; Savings > 80 = 2; Savings > 70 = 1; Savings < 70 = 0
	Competition with food?	Yes = 0; Partially = 1; No =2
	Land requirement?	Not applicable = 3; Low = 2; Medium = 1; High = 0
	Air quality impact?	Yes = 1 (Positive effect); No =0
	Water usage?	Yes = 0; Partially = 1; No =2
	Land impact?	Yes = 0; Partially = 1; No =2
	Sustainability issues: additional remarks	-

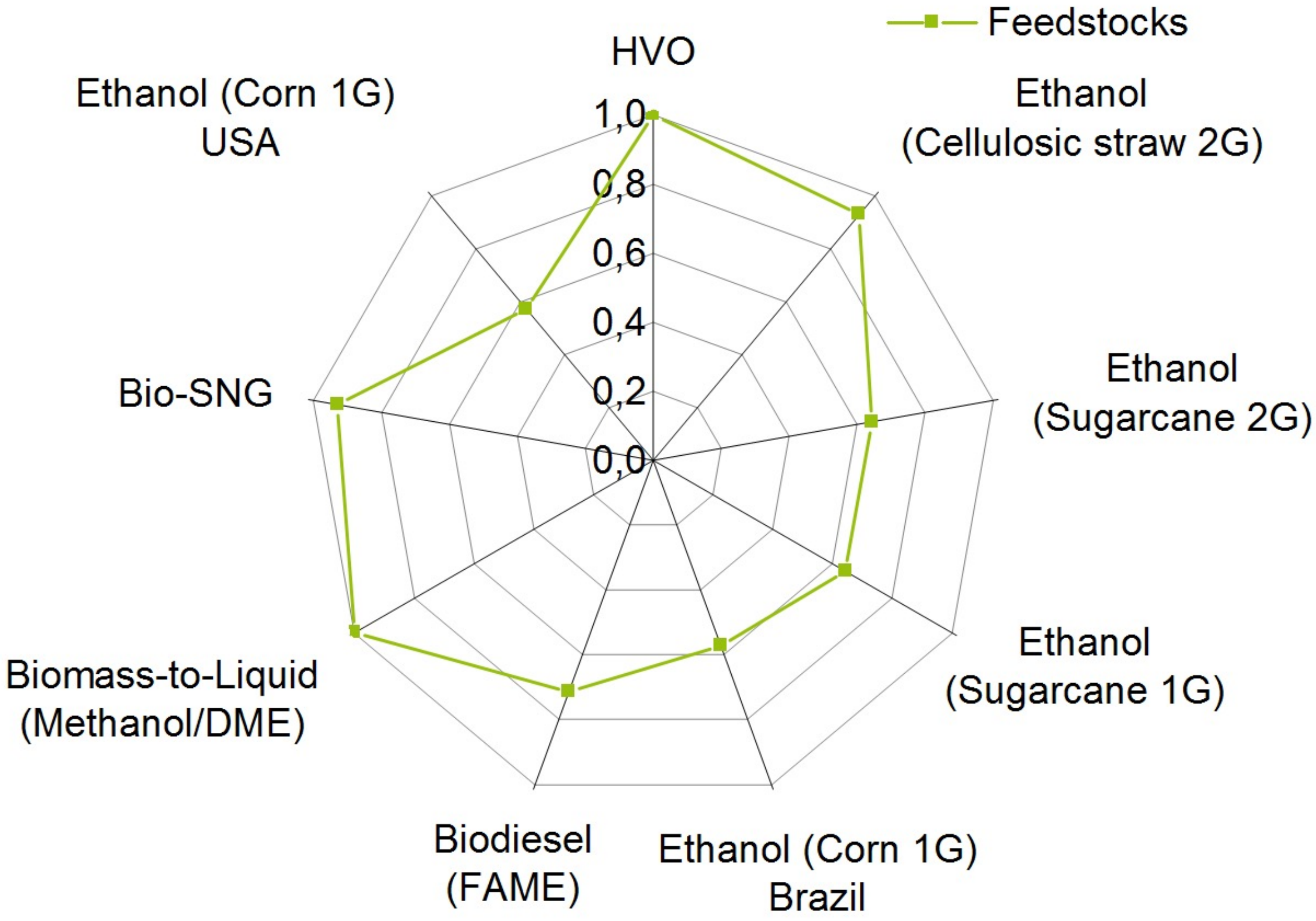
Indicators and grading used to compare biofuels (III)

Biofuel/Biofuel Technology:		Evaluation criteria (point attributed to each answer)
Employment:	If available, describe jobs created and/or indication of employment number related to a project	-
Implementation potential:	indicate if it is low, medium or high and if this is at local/regional, national or international level	Low = 1; Medium = 2; High = 3
		Nacional = 1; International = 2
Replication potential:	indicate if it is low, medium or high and if this is at local/regional, national or international level	Low = 1; Medium = 2; High = 3
		Nacional = 1; International = 2
Scale-up potential:	indicate if it is low, medium or high and if this is at local/regional, national or international level	Low = 1; Medium = 2; High = 3
		Nacional = 1; International = 2

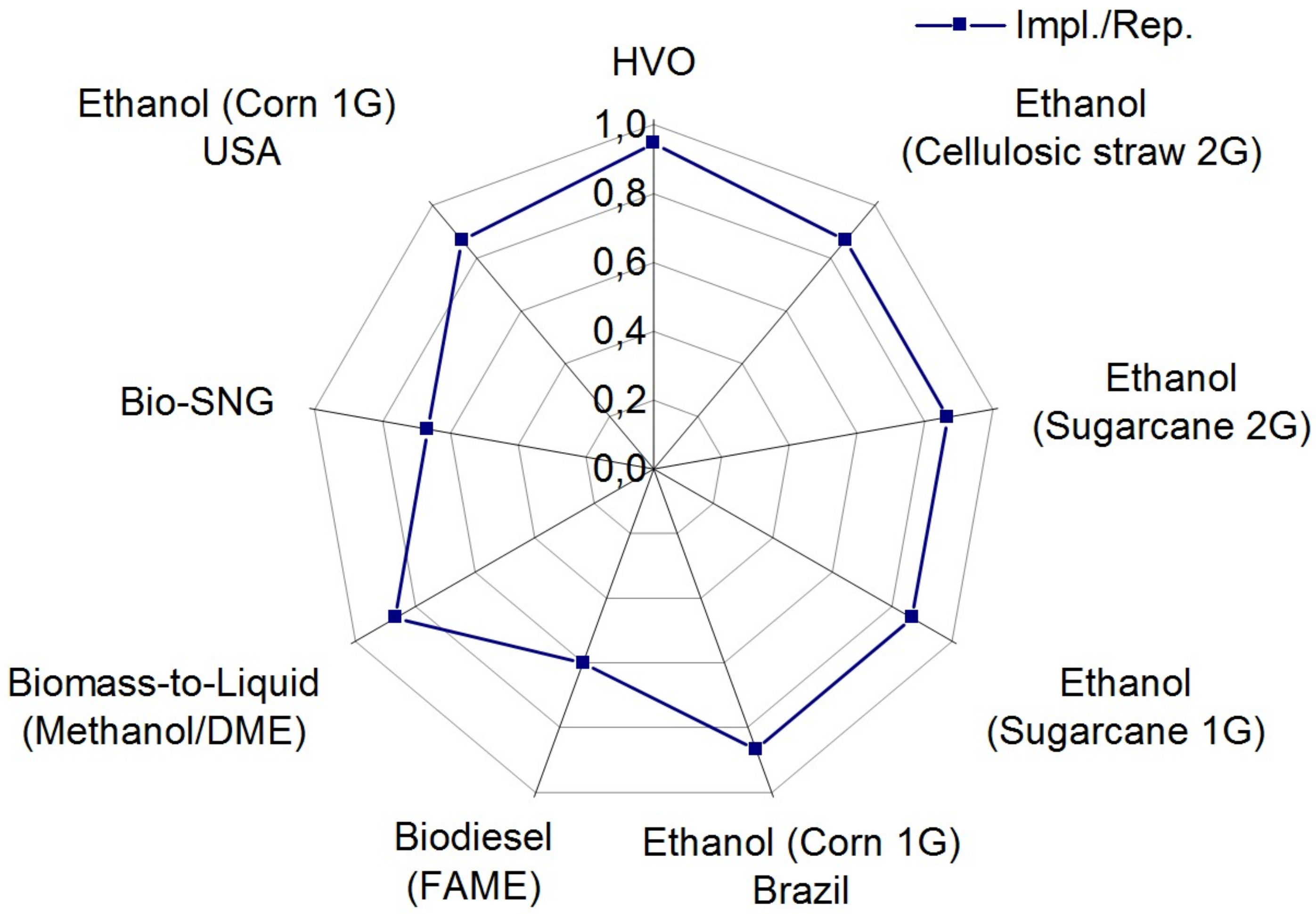
Biofuels included in the study

Biofuel	Country /Region
Ethanol (Sugarcane 1G)	Brazil
Ethanol (Sugarcane 2G)	Brazil
Ethanol (Corn 1G)	Brazil
Ethanol (Corn 1G)	USA
Ethanol (Cellulosic 2G)	Europe
Biodiesel (FAME)	Brazil
HVO	Europe
Biomass to Liquid /Methanol or DME	Europe (Sweden)
Biosynthetic Natural Gas (Bio-SNG)	Europe (Sweden)

Comparing biofuels – Feedstock



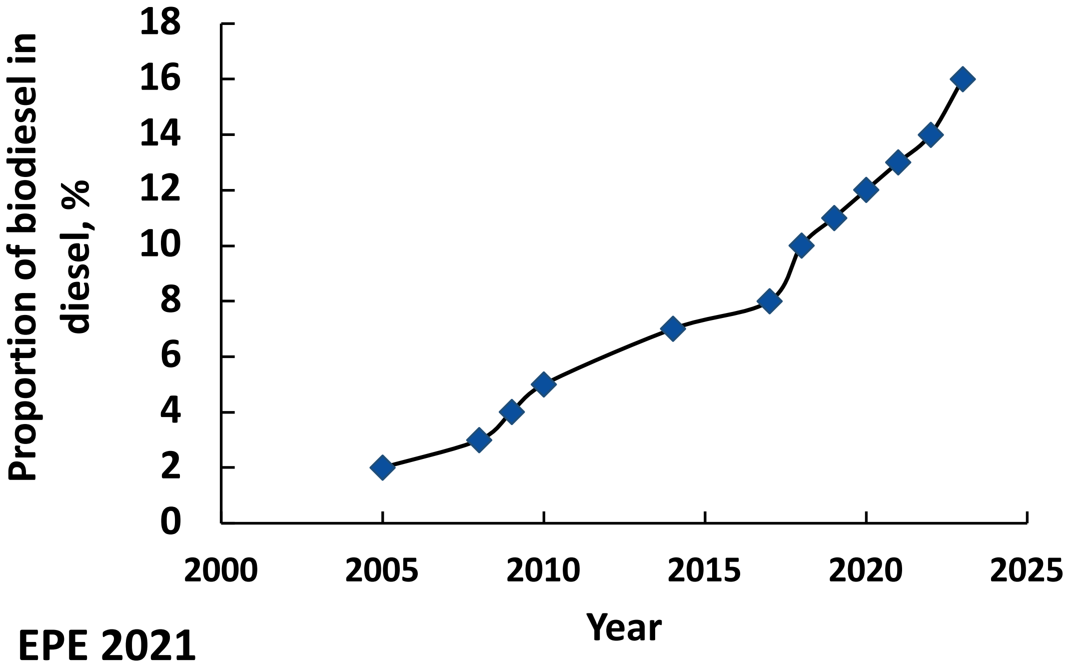
Comparing biofuels - Implementation/Replication potential



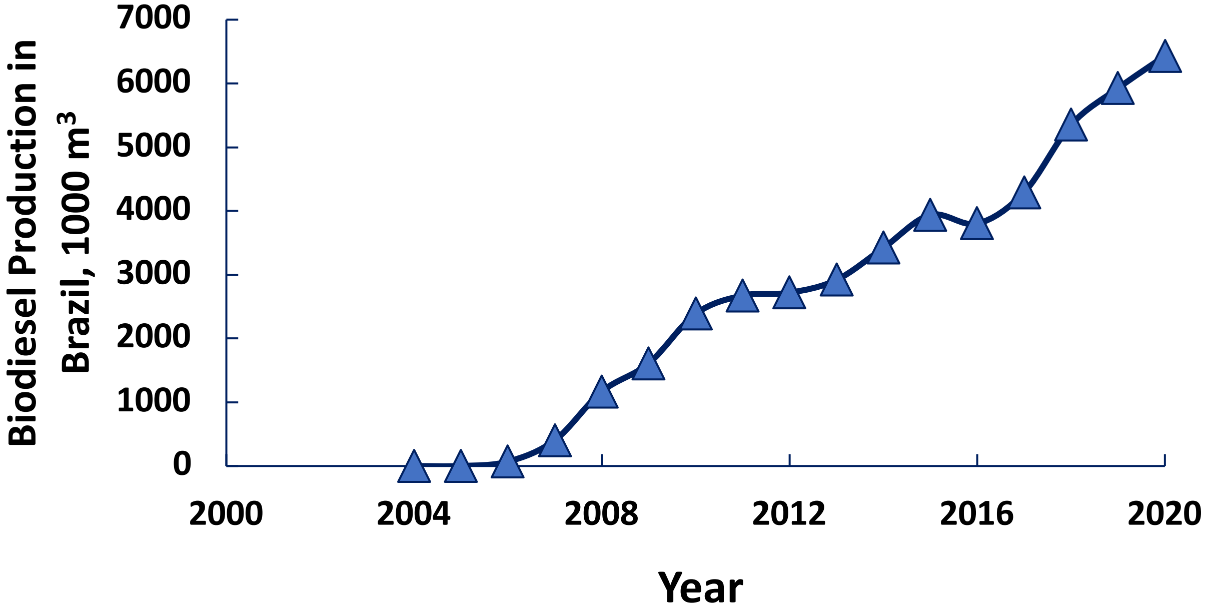
Summary of indicators for selected biofuels.

Biofuel	Country	TRL	Feedstock	Feedstock Yield	Planted area	Biofuel Output	Biofuel Yield	GHG emission	Price/Cost	Mandate
				t/ha	ha	m^3/y	m^3/ha	g CO_{2e}/MJ	US$/L	
Ethanol (Sugarcane 1G)	Brazil	9	Sugarcane	80	10 M	33 M	6.8	23	0.53	Yes
Ethanol (Sugarcane 2G)	Brazil	8	Sugarcane	16+10	10 M	0.12 M	0.231 m^3/t (6.0 m^3/ha)	11,8	1.33	Yes
Ethanol (Corn 1G)	Brazil	9	Corn	5.5	19 M	3.0 M	2.3 m^3/ha	23	?	Yes
Ethanol (Corn 1 G)	USA	9	Corn	10.5	33 M	55 M	4.4	52	?	Yes
Ethanol (Cellulosic various 2G)	Europe	7	Straw (wheat)			55 M t (potential)	0.2 m^3/t	14	?	Yes
Biodiesel (FAME)	Brazil	9	Soybean	3.5 (grain) 740 l/ha (oil)	38.3 M	6 M	0.68 m^3/t oil (x m^3 /ha)	15.8	US2/GJ	Yes
HVO	Europe	9	UCO	-	-	0.5 Mt	0.77 t/t feedstock	16	?	Yes
Biomass to Liquid (BTL)/DME	Sweden	7	Black liquor	-	-	-	0.25 MWh/t black liquor	-	?	Yes
Biosynthetic Natural Gas (SNG)	Sweden	7	Multiple	-	-	20 MW	0.57 MW CH_4/MJ dry feedstock	18.8	?	Yes

Biodiesel production & Blending in Brazil: 2004-2020



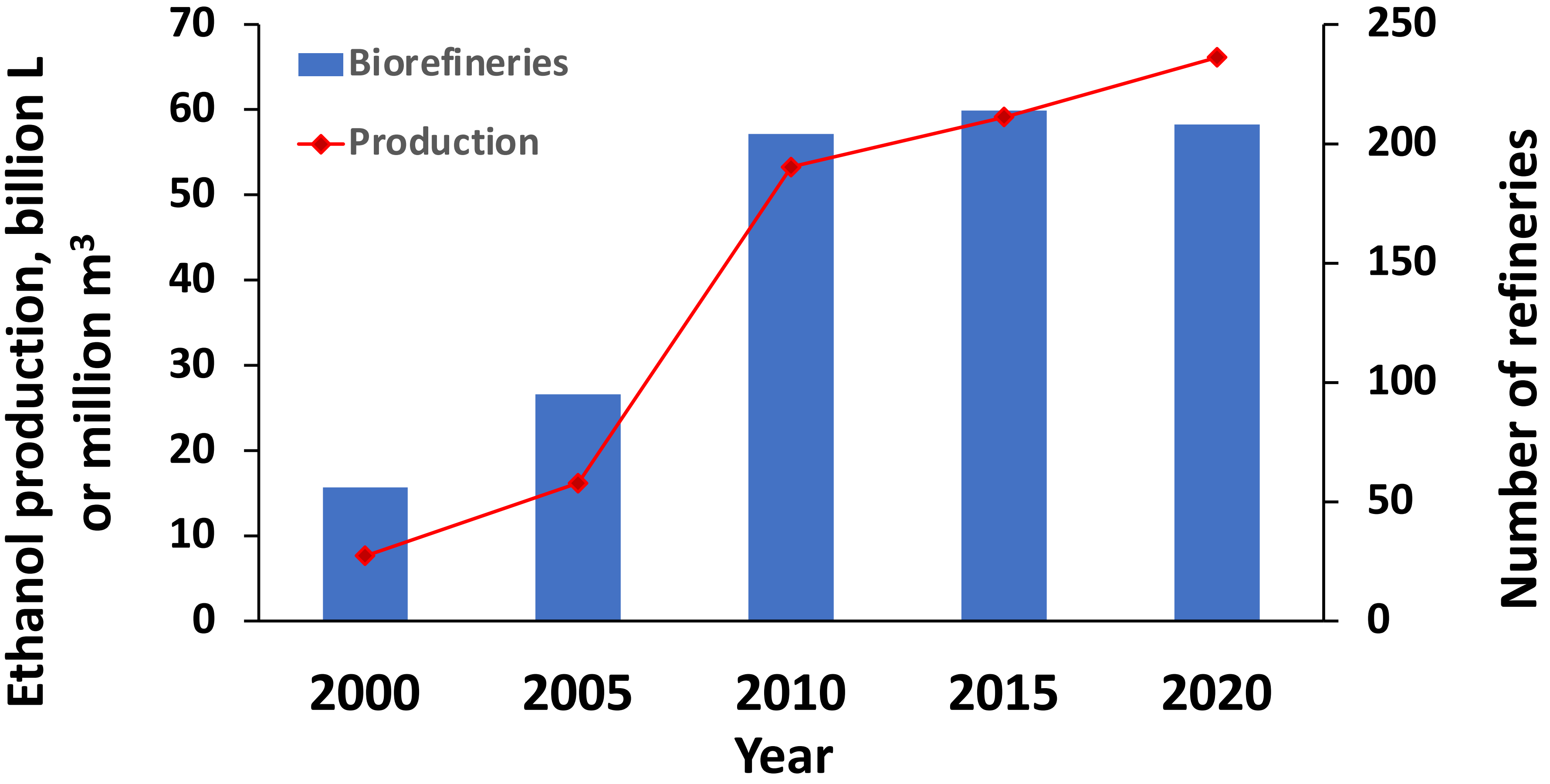
EPE 2021



Success story in a nutshell: Biodiesel (example of Brazil)

Indicator	Data/grade	Obs.
TRL	9	Known technology, multiple feesdock, produced in most countries
Economics	6 billion L	Mandate: Presently B-12; Price: US$0.4 to US$1.0/L 264 100 jobs in biodiesel chain (2019) (plus 200 000 indirect jobs) More than 50 countries with mandates
Feedstock	Soy (70%) Tallow (9%), UCO (1.2%)	High feedstock availability Only 16% of soy used for biodiesel; 740 L/ha; Soy meal and glycerin are valuable co-products. No land/food competition (Brazil)
Environment	15.8 g CO_{2e}/MJ	70 to 90% avoided GHG compared to diesel. Reduction in S air pollution. Soy is rainfed. No land/food competition (Brazil)
Replication & Scale up	High	Mature technology; various feedstocks possible, including fat residues (adapted to most countries), many large plants operating in the world
Limitations	Regulation	Food/feed crops not allowed in some regions
	Availability	Relatively small blending in most countries; Mandates occasionally waived because of feedstock availability, bad weather, cost issues, and others

Evolution of corn ethanol capacity and number of biorefineries in the USA from 2000-2020



Source: RFA - Renewables Fuel Association, 2021

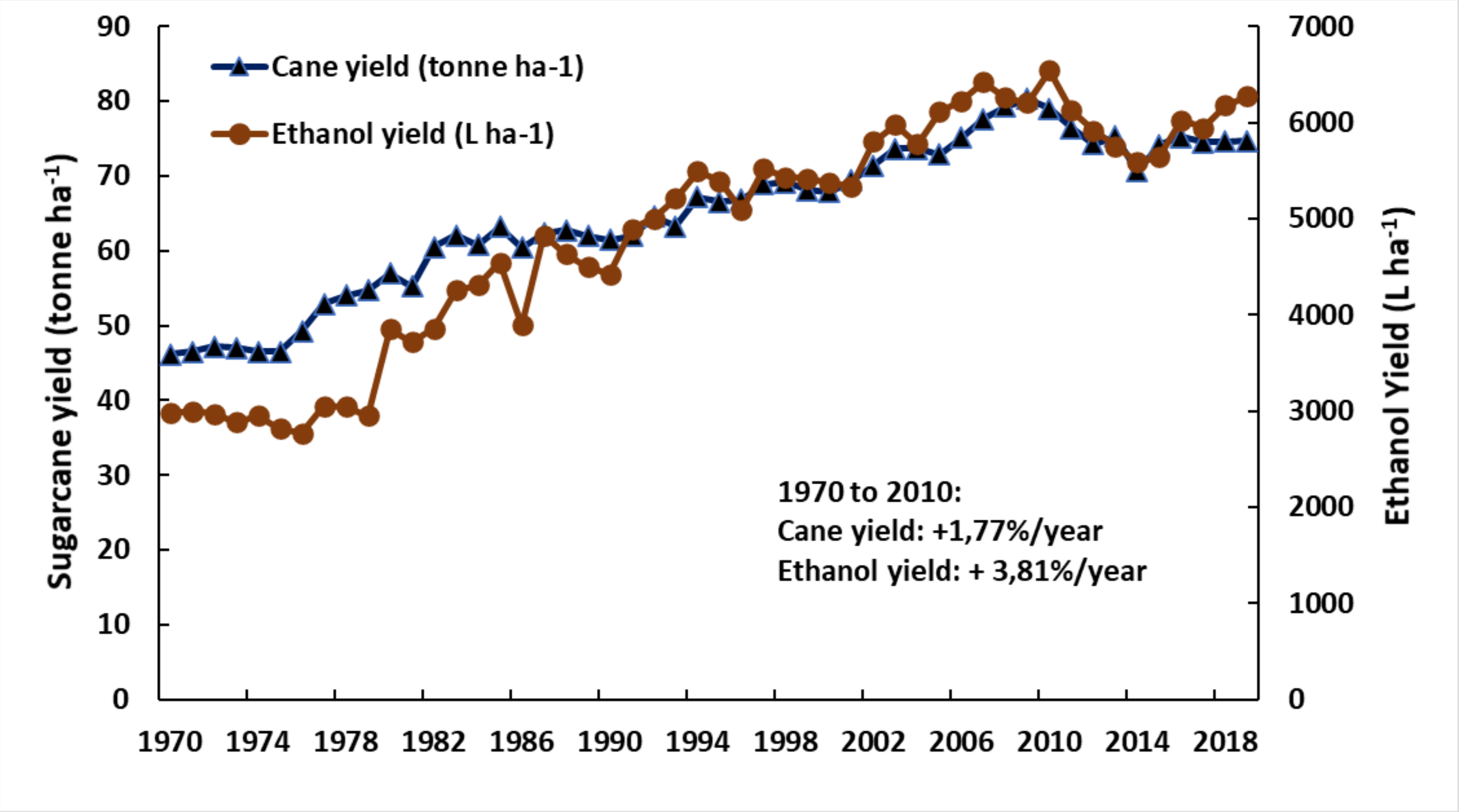
Success story: 1G corn ethanol (example of USA)

Indicator	Data/grade	Obs.
TRL	9	Known technology
Economics	66 billion L	Legislation variable (among States); 208 plants in operation 62 180 direct jobs and 242 600 indirect jobs (2021). Household income US18.6 billion per year. More than 50 countries with mandates
Feedstock	Corn	High feedstock availability. High yields (>10 tonne grain/ha); 4.4 m^3 ethanol/ha; >30%% of corn used for ethanol; 740 L/ha; corn meal, DGS, and pure CO_2 are valuable co-products. Since the inception of the corn ethanol in the USA other countries increase corn production.
Environment	51.8 g CO_{2e}/MJ (93-101 g CO_{2e}/MJ gasoline)	40 to 50% avoided GHG compared to gasoline. **Significant reductions in C intensity in the USA in the past 15 years** due to improvements in all areas (yield, reduction in fertilization, in energy use in ethanol plants, process improvements etc
Replication & Scale up	High	Mature technology; various grain/starch sources produced in most countries, many large plants operating in the world
Limitations	Regulation	Food/feed crops not allowed in some regions
	Availability	Relatively small blending in most countries; Mandates occasionally waived because of feedstock availability, bad weather, cost issues, and others

Success story: 1G corn ethanol (Brazil)

Indicator	Data/grade	Obs.
TRL	9	Known technology
Economics	3 billion L	4 plants in operation and several planned or under construction
Feedstock	Corn	High feedstock availability. Medium yields (>5.5 tonne grain/ha); Many indicators similar to those of USA (ethanol plants usually built by/with American companies). Low cost of corn in Central Brazil. Usually 2nd harvest corn (after soybean) with low fertilization (N)
Environment	23 g CO_{2e}/MJ (51 g CO_{2e}/MJ in the USA)	>60 % avoided GHG compared to gasoline. Low C intensity in Brazil because of less fertilizer and use of renewable energy (planted wood, sugarcane bagasse) instead of natural gas in the industry.
Replication & Scale up	High	Mature technology; various grain/starch sources produced in most countries, many large plants operating in the world
Limitations	Regulation	Food/feed crops not allowed in some regions
	Availability	Relatively small blending in most countries; Mandates occasionally waived because of feedstock availability, bad weather, cost issues, and others

Lessons Learned: evolution of sugarcane and ethanol yields in Brazil: 1970-2020



EPE, 2021, MAPA, 2021

Success story: 1G sugarcane ethanol (Brazil)

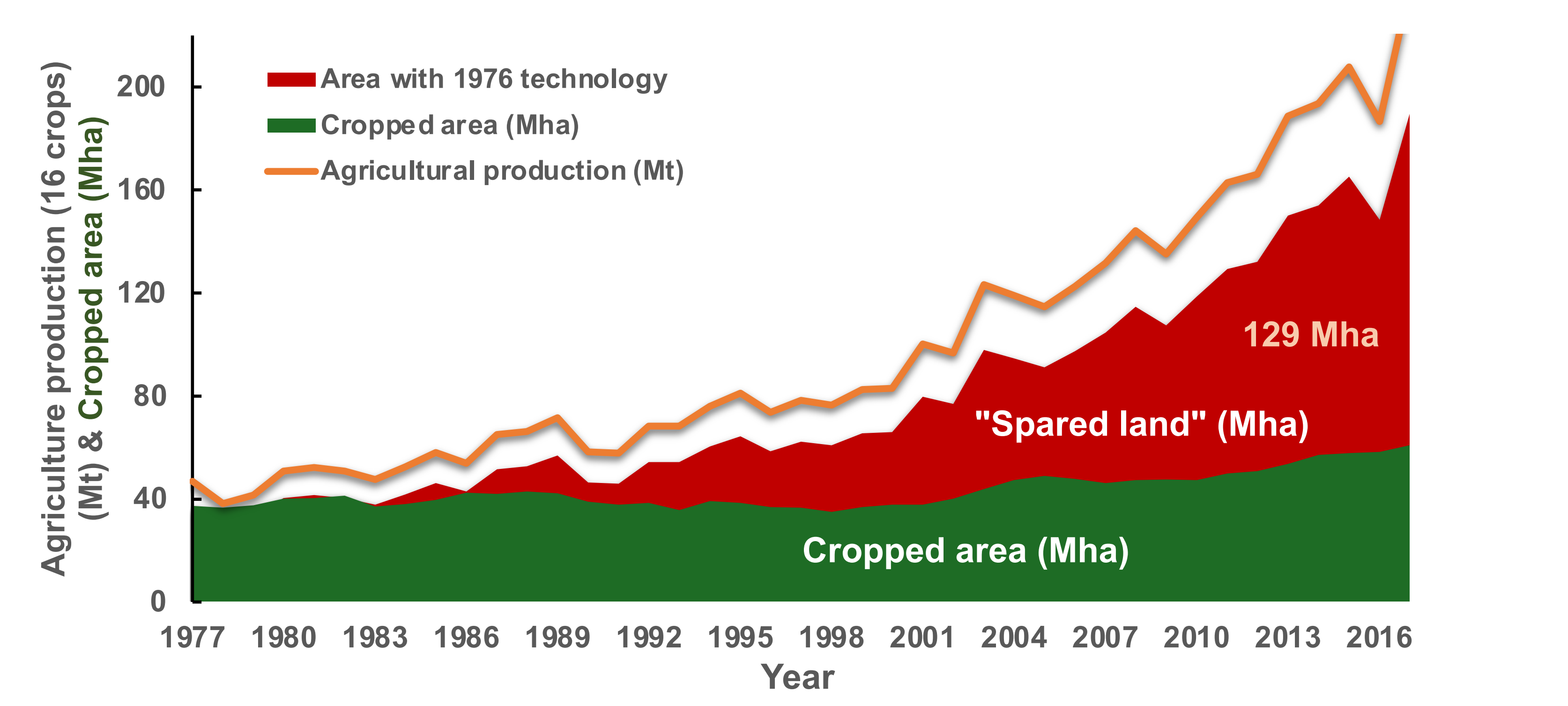
Indicator	Data/grade	Obs.
TRL	9	Known technology
Economics	32 billion L	>300 plants in operation. Price at the mill: US$0.33 to 0.50; it varies with gasoline price. More than 1 000 000 jobs (2012)
Feedstock	Sugarcane	High feedstock availability (10 million ha). Average yields (>80 tonne stalk/ha); Long learning curve (40 to 80 tonne/ha sugarcane & 2 600 to 6 800 L/ha). Most plants produce food (sugar) biogas, bioelectricity and other products; valuable co-products vinasse, bagasse)
Environment	23 g CO_{2e}/MJ	70-90 % avoided GHG compared to gasoline. Low C intensity in Brazil because of high biomass yields, low fertilization, and co-products. High blending in Brazil (minimum 27%; E-100 also available in any gas station)
Replication & Scale up	High	Mature technology, many large plants operating in the world; ~100 countries cultivate sugarcane.
Limitations	Regulation	Food/feed crops not allowed in some countries
	Replication	Many countries do not have the good infrastructure and scale of the Brazilian ethanol industry, partially responsible for relatively low prices

Success story???: 2G ethanol

Indicator	Data/grade	Obs.
TRL	7-9	Finally taking off? Gathering data is a problem in any study
Raizen (Brazil)		
Economics		Raizen (Brazil): 20 million L (2020). New plant (82 million L) to start operation in 2023. Overcoming technical problems: replication and scaling up possible
Feedstock	Sugarcane straw, bagasse	High feedstock availability (10 million ha). Average yields (>80 tonne stalk/ha); Long learning curve (40 to 80 tonne/ha sugarcane). **Operation combined with 1G sugarcane brings relevant synergies**
Environment	11.8 g CO_{2e}/MJ (or less)	50% reduction compared with already good 1G ethanol (23 g CO_{2e}/MJ). No food/feed crop restriction.
2G Europe (Clariant)	14 g CO_{2e}/MJ	Starting operation. Feedstock: straw (several crops); 0.1 t ethanol/t feedstock; designed to produce 50 million tonne ethanol/y) . License agreements to build plants in other countries (Bulgaria, Poland, and China)
Replication & Scaling up	Regulation	Feedstock is crop residues (no food/feed restrictions). May overcome public restrictions to biofuel (but land use remains); If technology is mature and cost-competitive replication may be easy because of the variety of feedstock available

Evolution of agriculture output in Brazil:

Production of 16 grain crops & spared land: 1977 to 2016



	2016/2017	Increase in 40 years
Grain production	239 Mt	+ 408%
Cropped area	61 Mha	+63%
Average yield	3,9 t/ha	+211%

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Source: ANDA/IBGE/CONAB (uptdated DRF & HC)

Final comments - I

- Conventional biofuels (1G ethanol, biodiesel) from grain & sugarcane have gone through great improvements in the past decades
  - Feedstock yield & production
  - Process performance
  - Reduction of C intensity
  - Scale of production
  - In some case, became cost-competitive
- Therefore, they set a standard against which new or “advanced” biofuels are measured
- They may continue to play an important role in transport decarbonization
- Regulations (food/feed feedstock) limit access to some markets

Final comments - II

- 2-G ethanol seems to finally reach the market
  - Price still a limitation
  - Low C intensity, public acceptance, and diversity of feedstock are strong points

- Proper public policies and incentives may lead other coming biofuel options through the learning curves & improved performance of traditional biofuels

Thank you

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On behalf of all authors