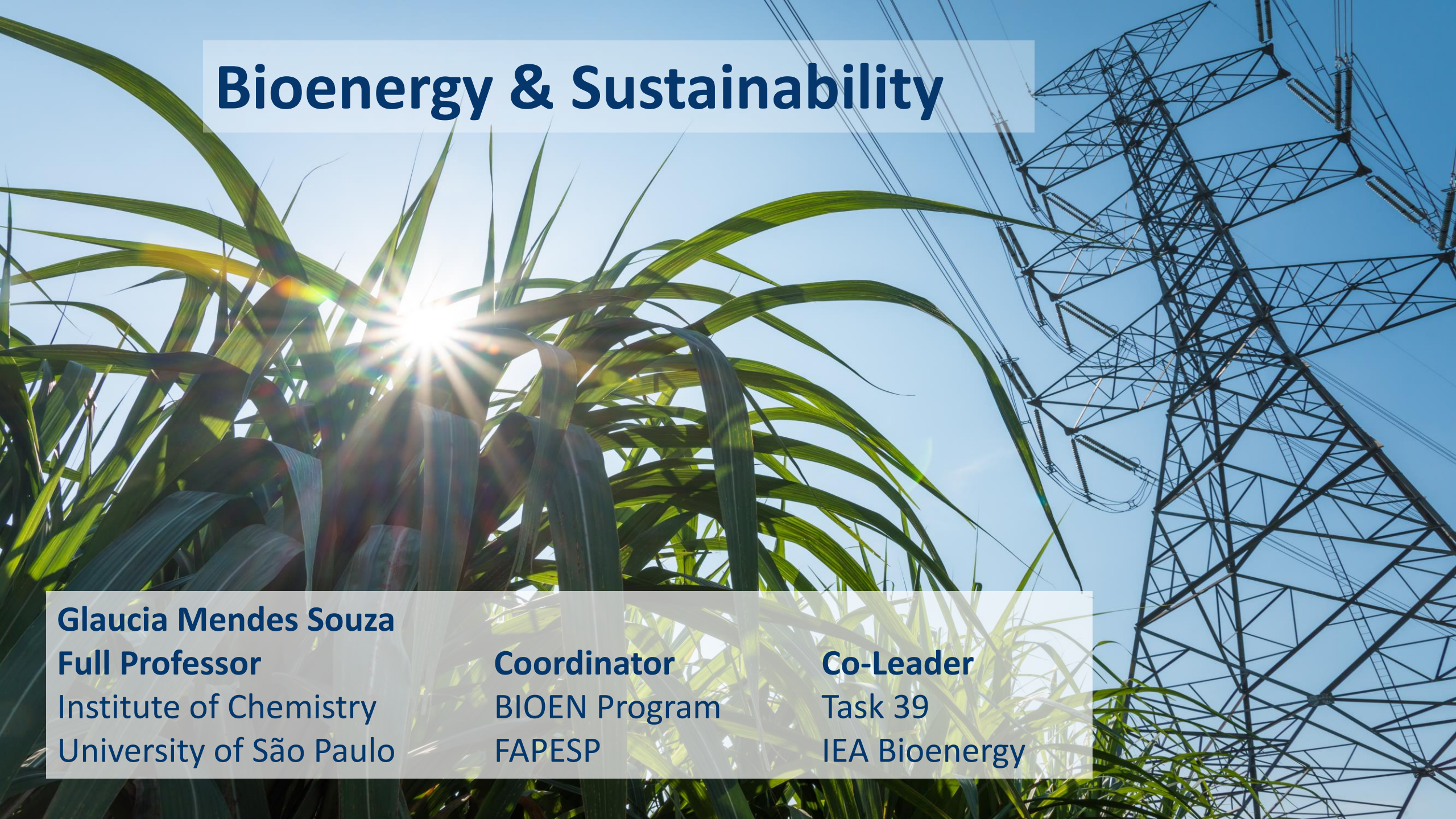
Bioenergy & Sustainability



Glaucia Mendes Souza

Full Professor
Institute of Chemistry
University of São Paulo

Coordinator
BIOEN Program
FAPESP

Co-Leader
Task 39
IEA Bioenergy

Bioenergy & Sustainability

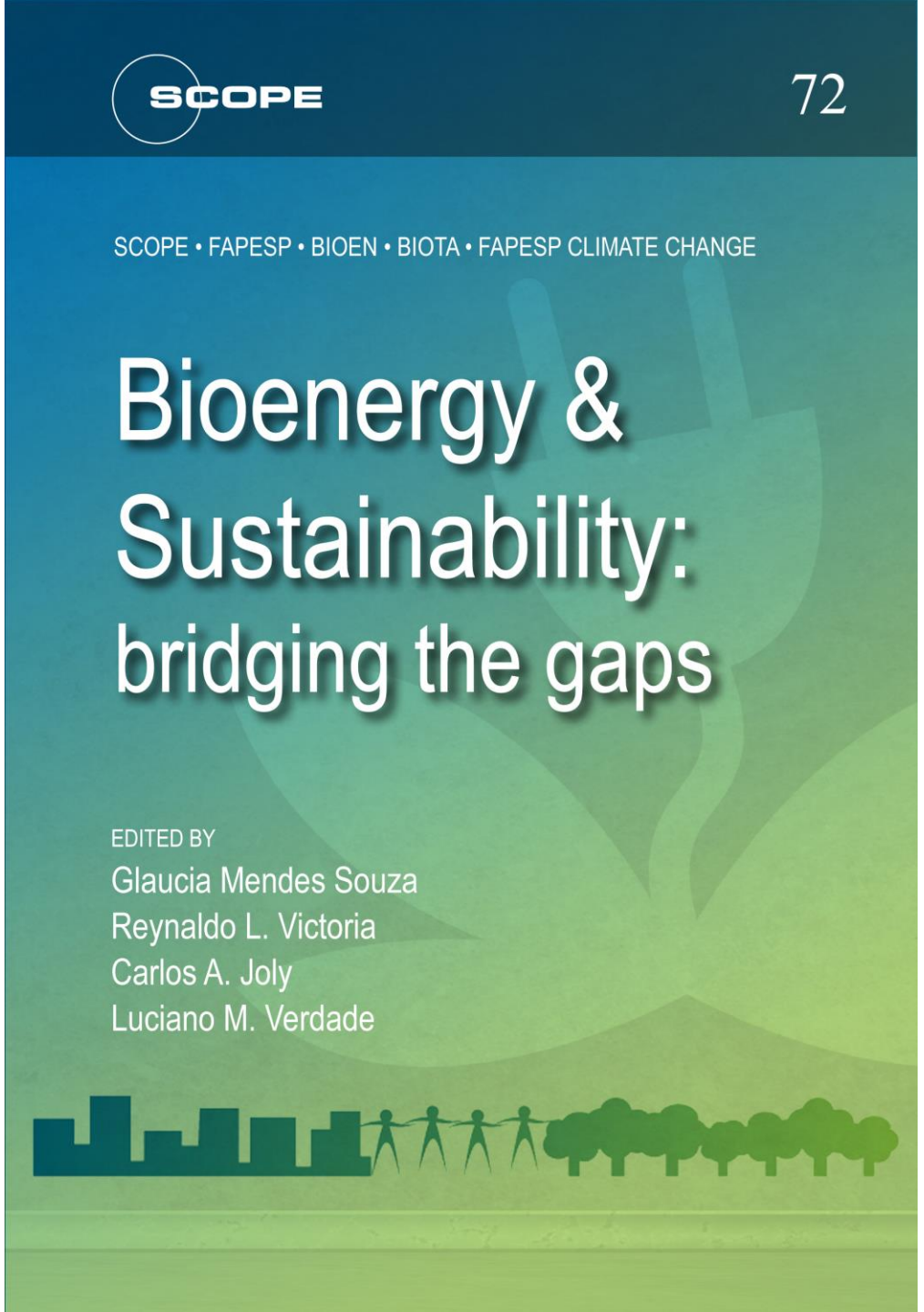
References
Drivers: Sustainable Development and Climate Change
What, Why, How much
Sustainability, Emissions, Pollutants, Water, Soils, Biodiversity, Jobs
Policies to stimulate, insure and reward sustainability
Main Technological routes
Where
Case of success
Innovation
Let’s meet again!

SCOPE-FAPESP
Reporting a global assessment of
Bioenergy & Sustainability
137 experts from 24 countries

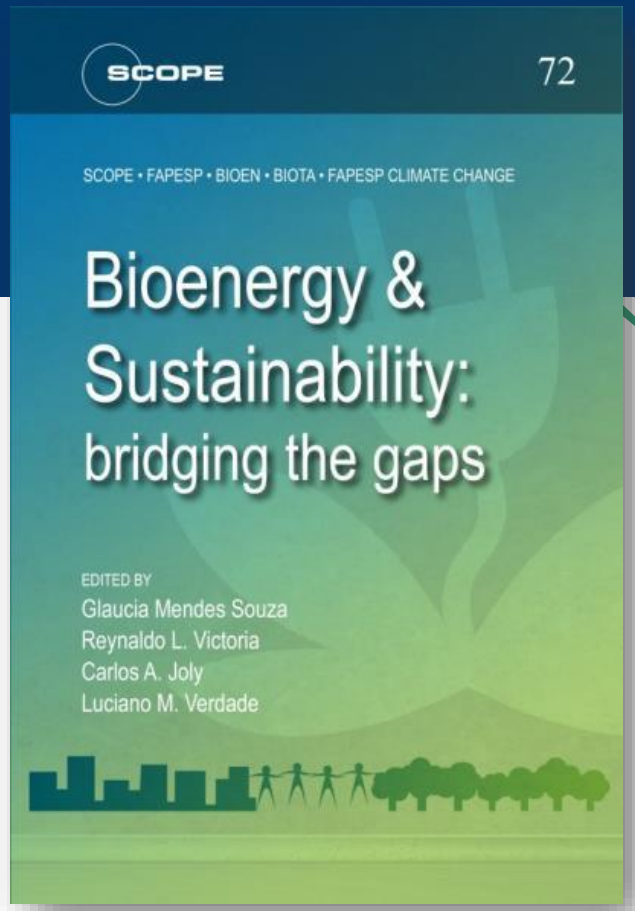
Bioenergy status
Bioenergy expansion
Energy security
Food security
Environmental and climate security
Sustainable development and Innovation
The much needed science

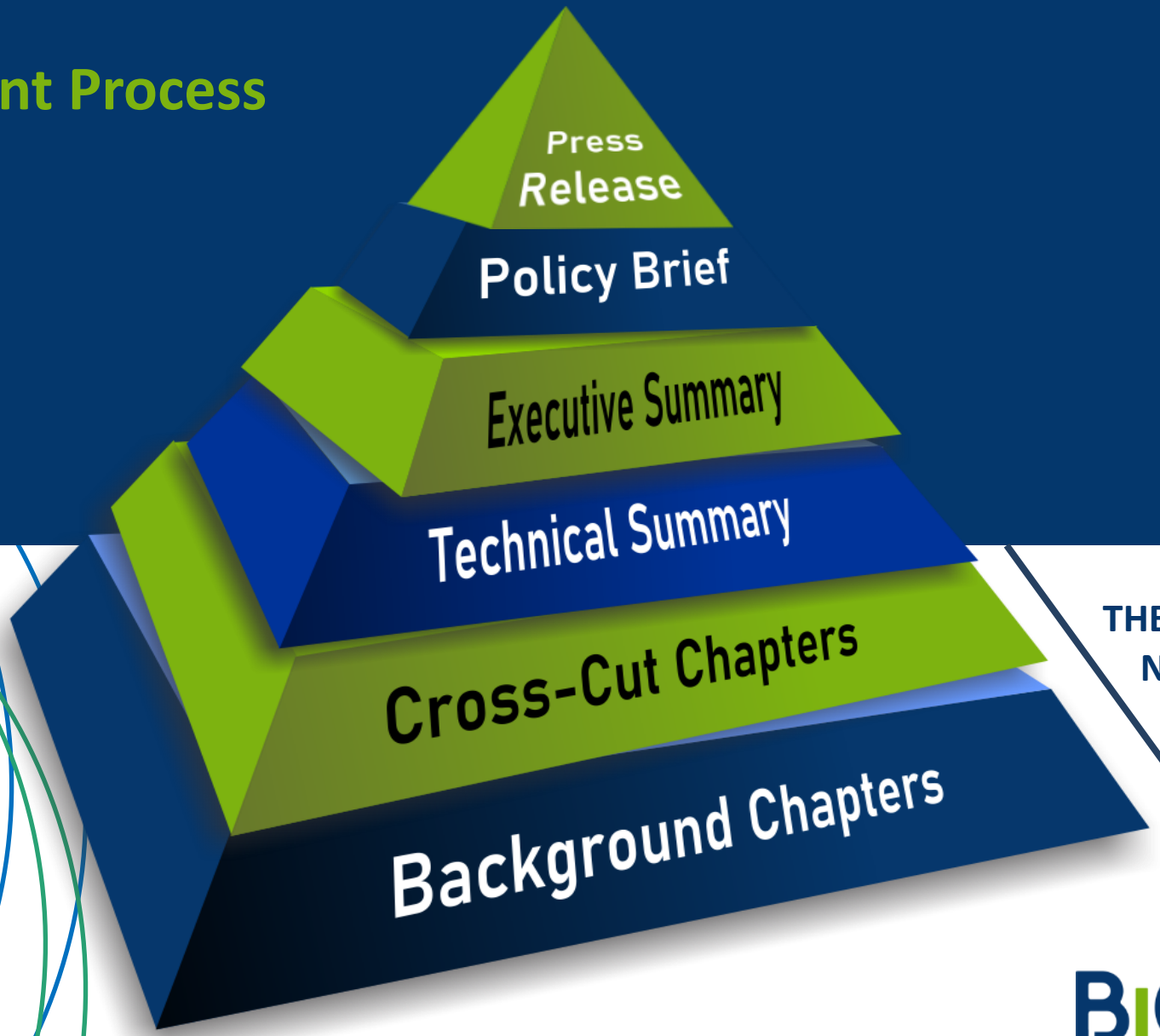
Developed and developing regions
Numbers, cases, issues, solutions
2012-2018

779-page Ebook
Download at http://bioenfapesp.org



SCOPE Rapid Assessment Process





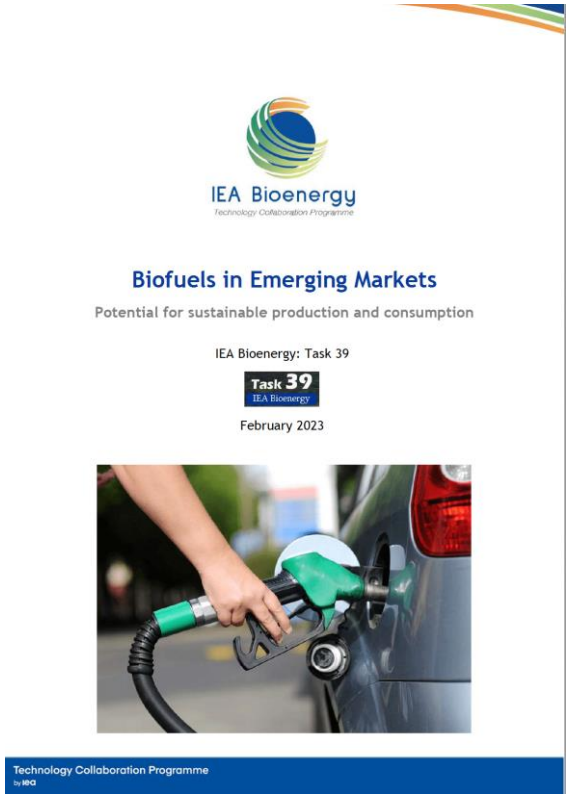
THE MUCH NEEDED SCIENCE

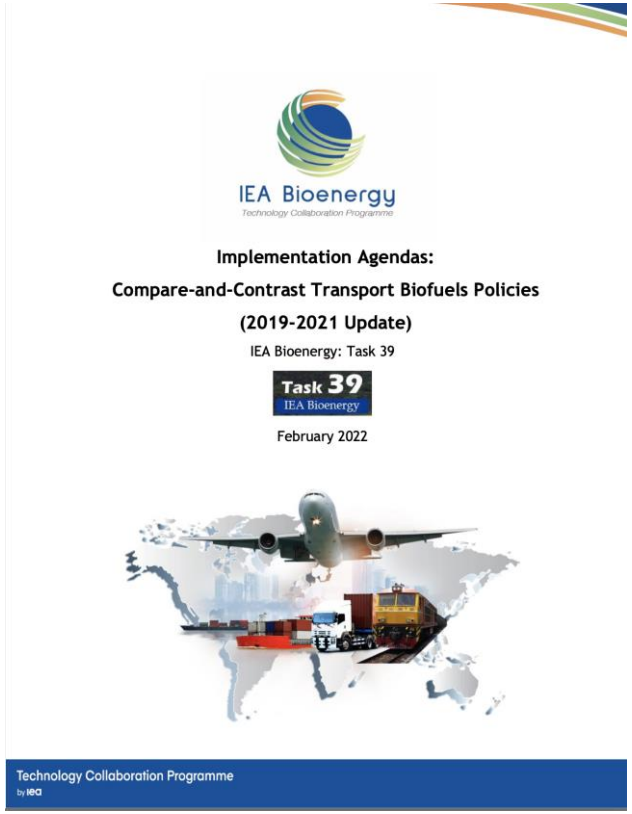
http://bioenfapesp.org/scopebioenergy

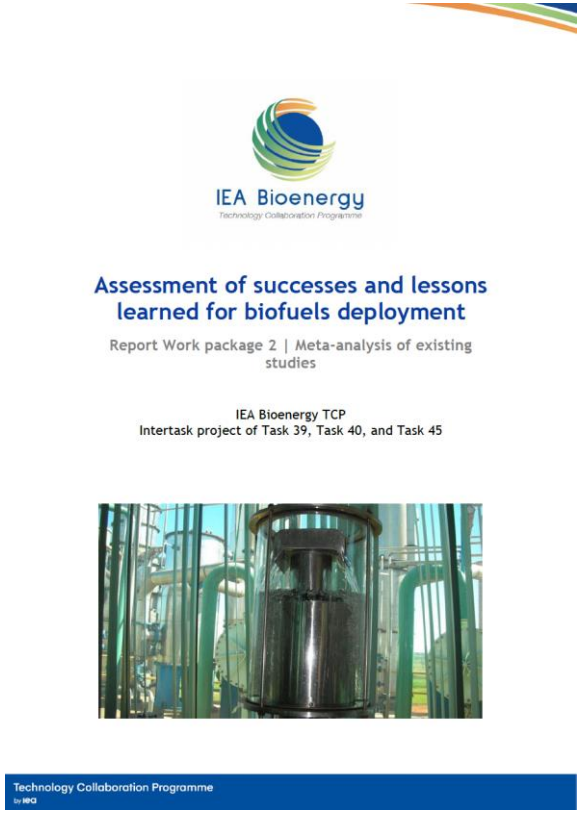
BIOEN
FAPESP

IEA Bioenergy
Technology Collaboration Programme

Task 39
IEA Bioenergy

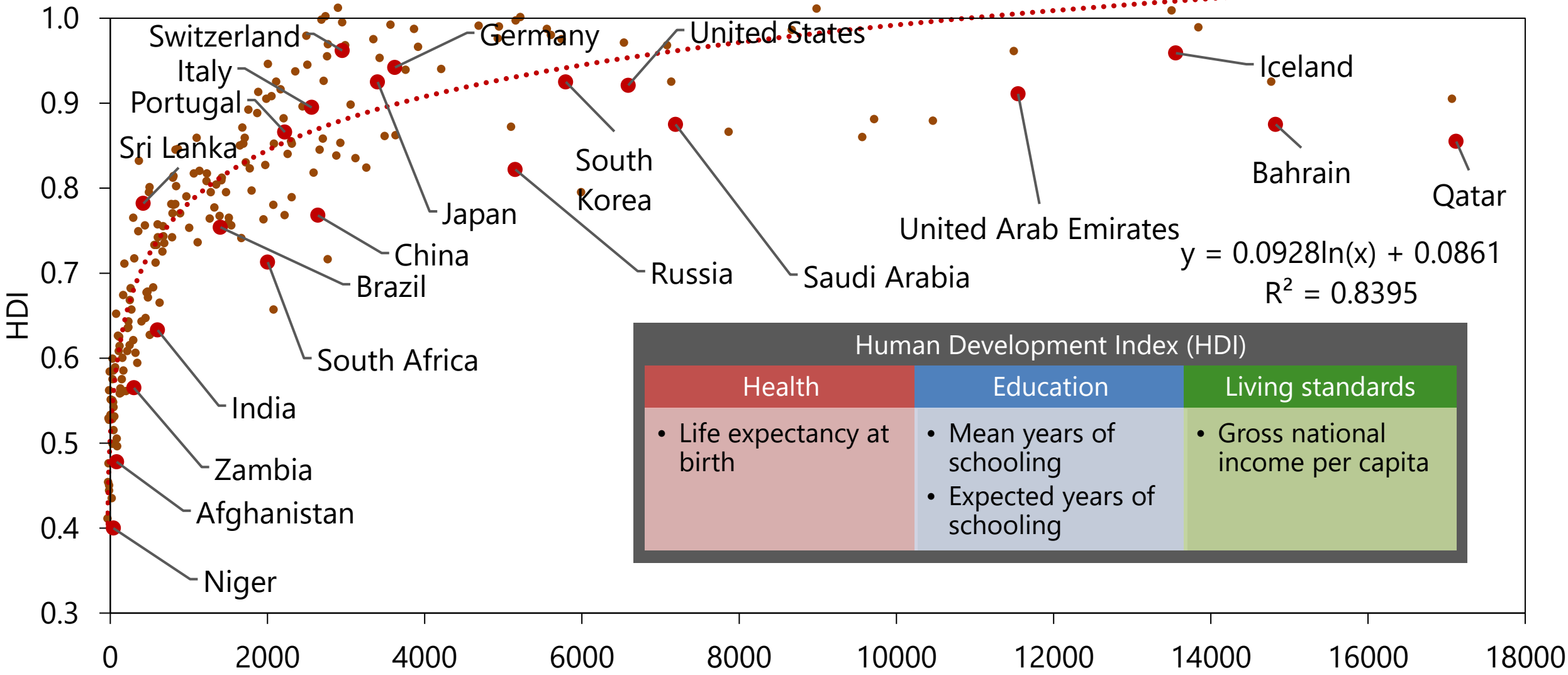






Energy = Development

HDI vs. Primary Energy Consumption per capita, 2021



Source: Data compiled from multiple sources by World Bank
OurWorldInData.org/energy • CC BY

Our World in Data

Bioenergy can play a critical role in supporting sustainable development

Bioenergy is critical to secure a renewable energy matrix

What is Bioenergy?

Bioenergy is a clean source of energy produced from biomass – wood, energy crops and organic wastes and residues. **Biogenic carbon, captures CO2**

Biomass can directly or indirectly be converted into biofuels which can be of solid, liquid or gaseous forms. **Flexibility, different applications**

Currently, over 85% of biomass energy is consumed as solid fuels for cooking, heating and lighting, often with low efficiency. Traditional bioenergy (fuel wood, charcoal which can only deliver heat) dominate bioenergy consumption in developing countries.
Big transition that affects energy access

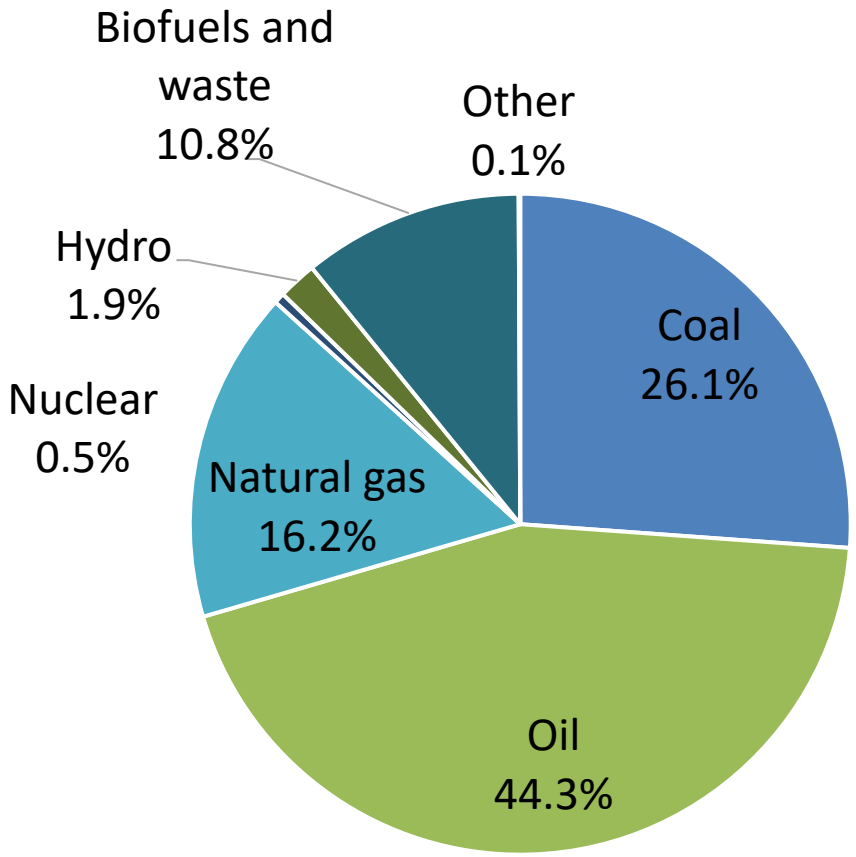
On the other hand, modern bioenergy relies on efficient conversion technologies increased over recent years, especially in OECD Countries.
New more efficient tech available with high TRL and low costs

The production of biomass implies cultivating land with the use of best management practices to increase environmental and climate benefits while avoiding negative impacts.
Opportunity for modernization of agriculture and land use innovation

Current status

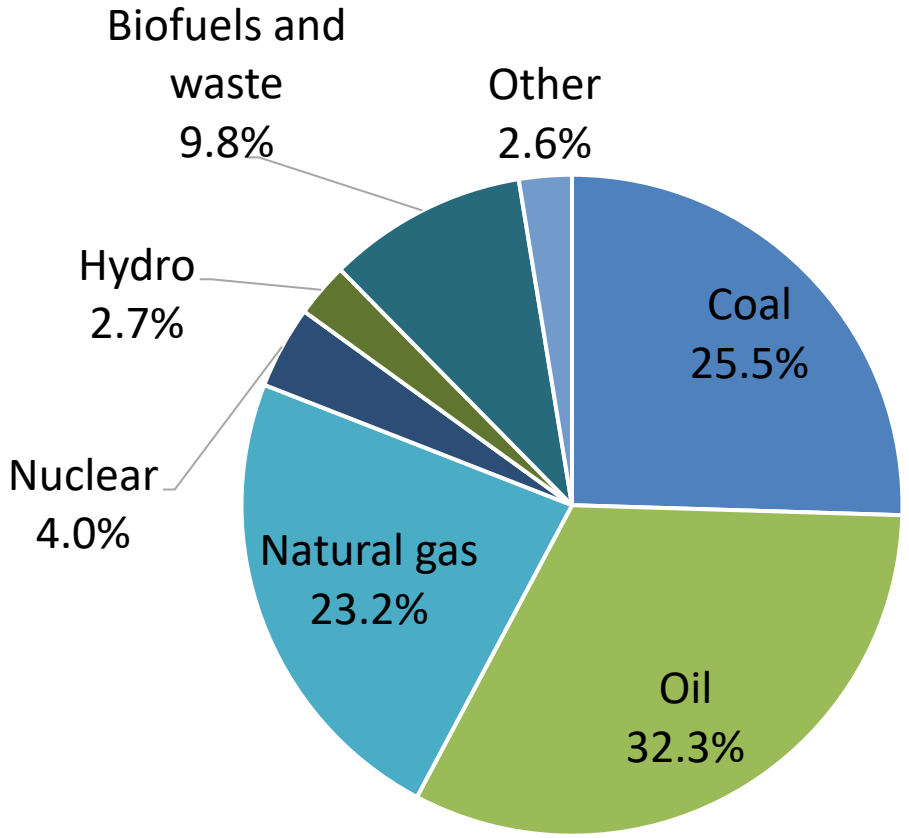
World total energy supply by source

1971 – 230 EJ



50 years

2021 – 594 EJ

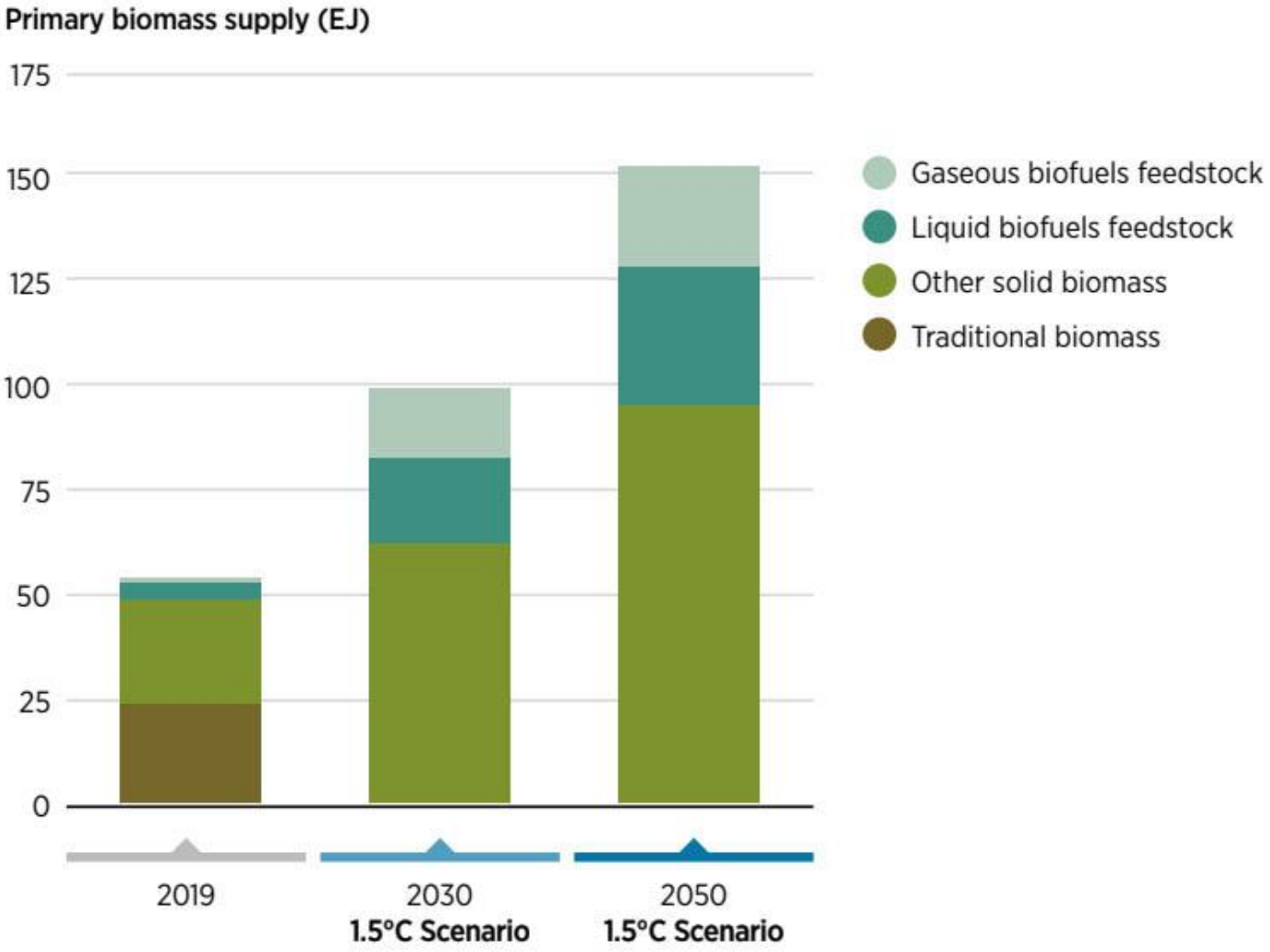


World demand includes international aviation and international marine bunkers. Peat and oil share are aggregated with coal. Other includes solar, wind, tidal, geothermal, and others.

Source: IEA (Key World Energy Statistics 2021, Statistical Review of World Energy - BP (2022)

How much do we need

World total energy supply by source to keep under 1.5oC



Substantial growth in the use of bioenergy by 2050 towards sustainability and modern applications

World Energy Transitions Outlook 2022

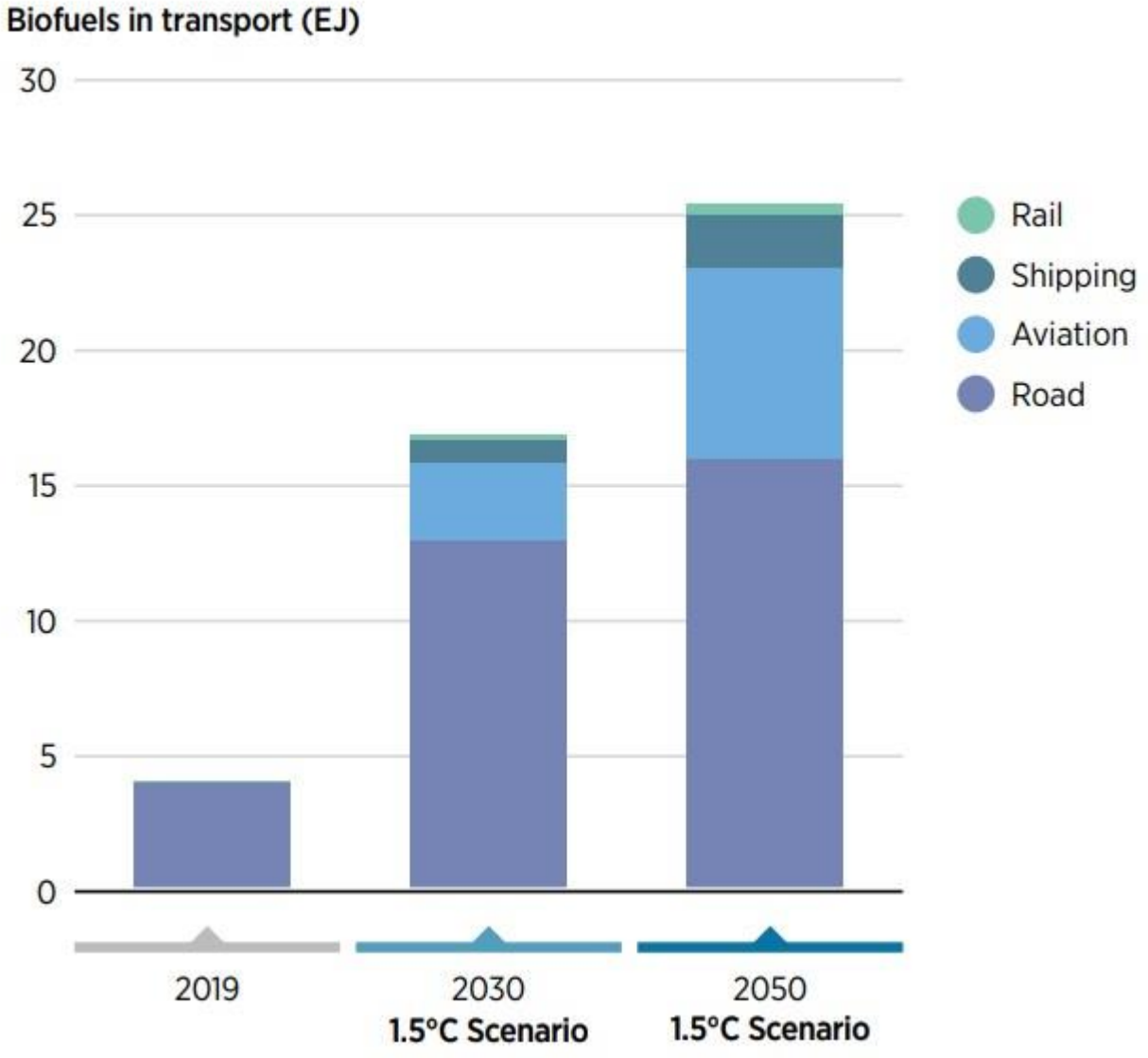
IRENA

International Renewable Energy Agency

https://www.irena.org/Digital-Report/World-Energy-Transitions-Outlook-2022

Needed energy for transportation

World total energy supply by source to keep under 1.5oC



Road and aviation transport will use biofuels to displace fossil fuels

World Energy Transitions Outlook 2022

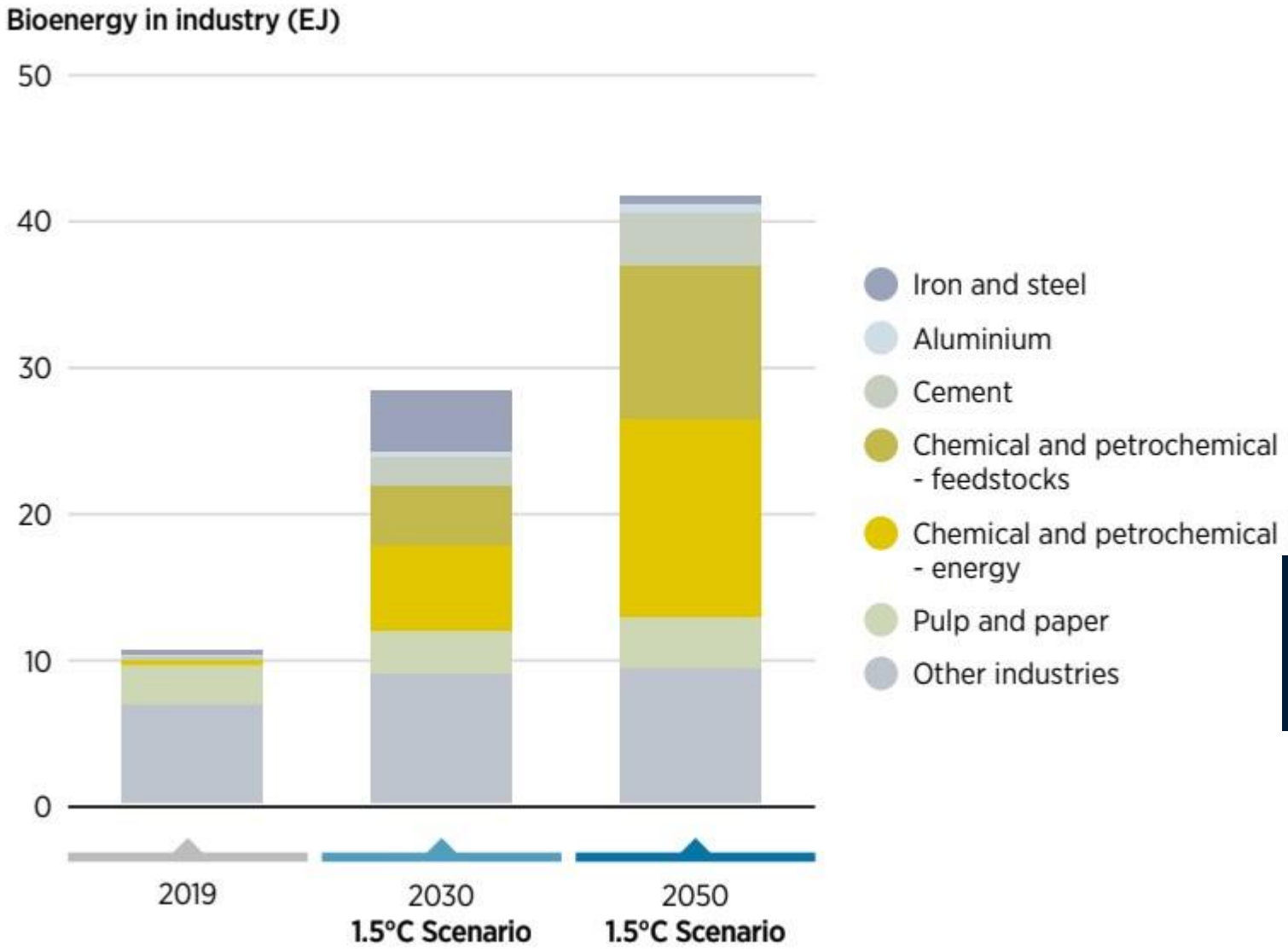
IRENA

International Renewable Energy Agency

https://www.irena.org/Digital-Report/World-Energy-Transitions-Outlook-2022

Needed energy for industry

World total energy supply by source to keep under 1.5oC



Chemical and petrochemical industries will play a key role in the use of modern bioenergy in the future

World Energy Transitions Outlook 2022

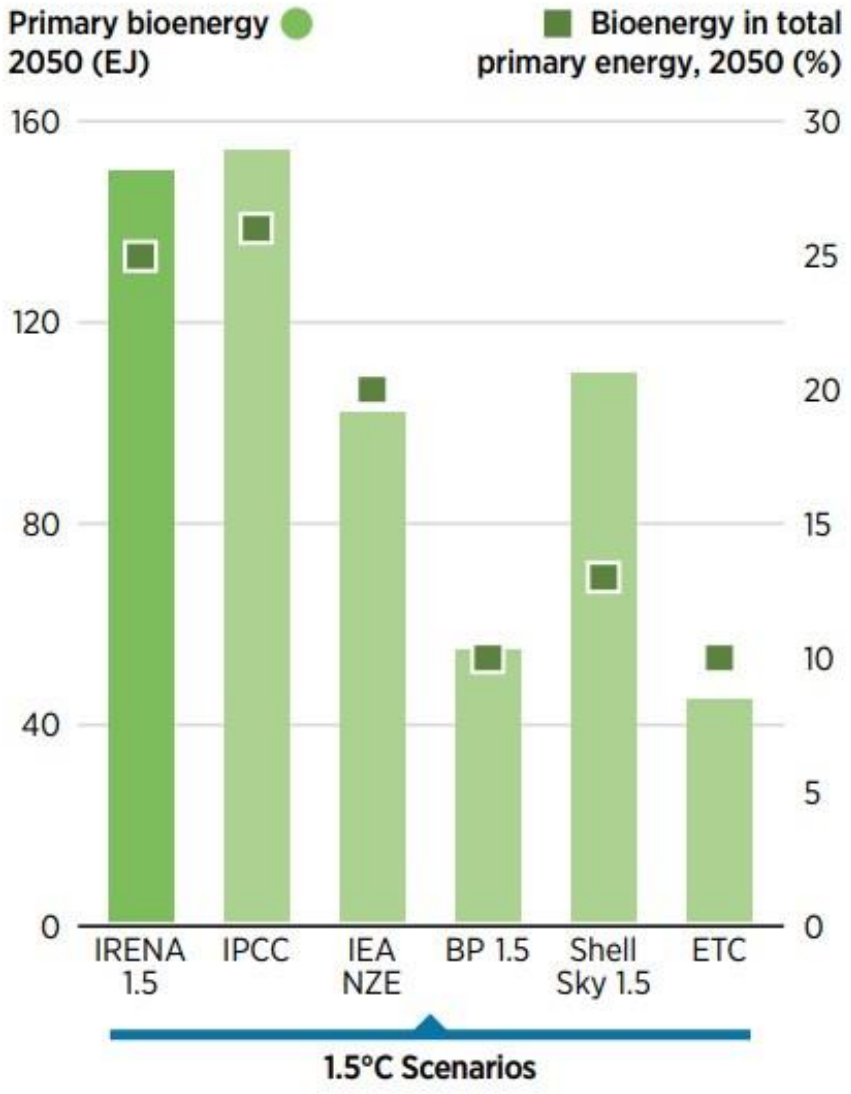
IRENA

International Renewable Energy Agency

https://www.irena.org/Digital-Report/World-Energy-Transitions-Outlook-2022

Need to multiple by 4-6 x

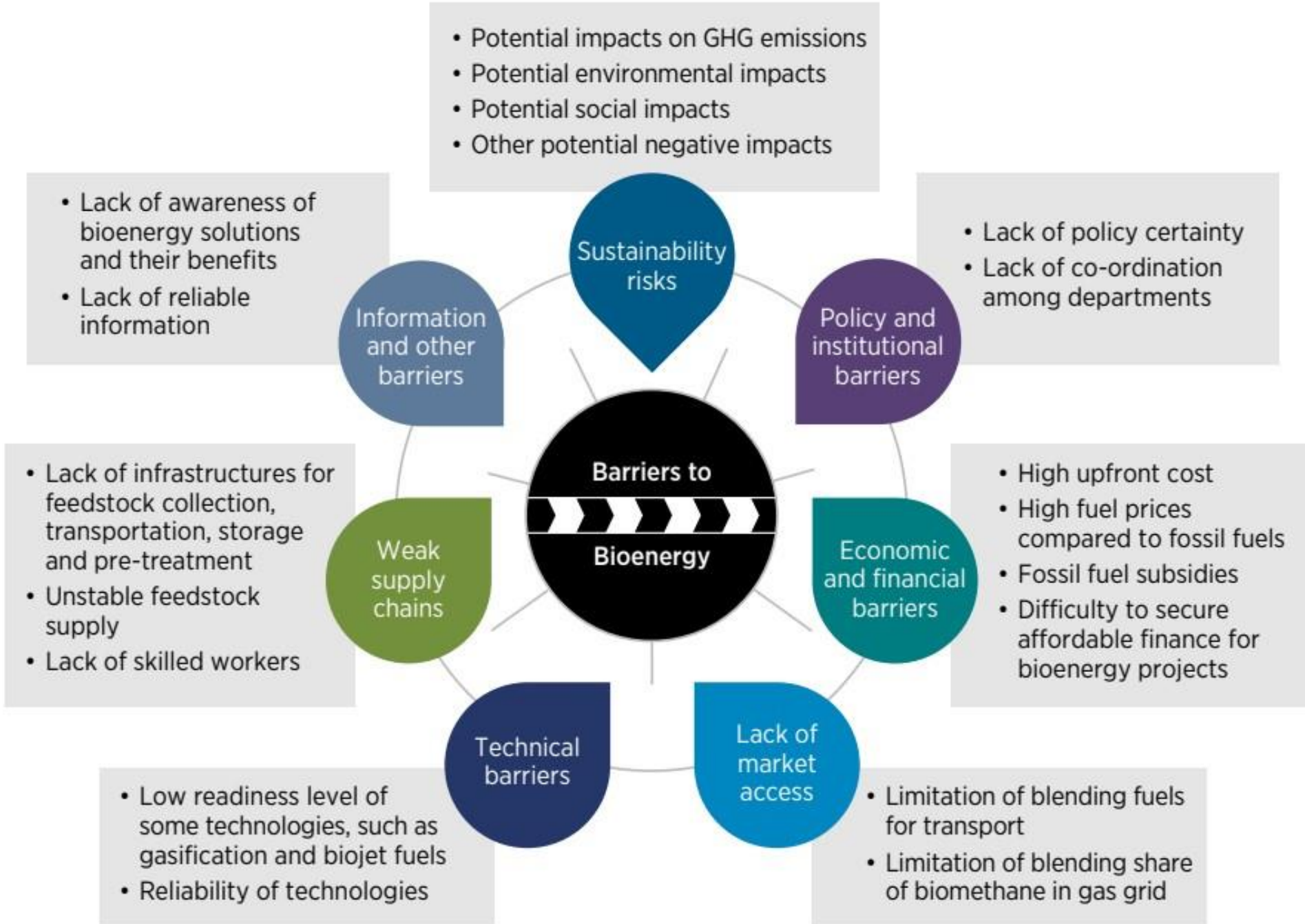
World total energy supply to keep under 1.5oC



Is the role of bioenergy in the energy transition being minimized in forecasts by some agencies?

- IRENA 1.5 = IRENA 1.5°C Scenario
- IPCC = IPCC 1.5°C Special Report
- IEA NZE = IEA Net Zero Emission Scenario
- BP 1.5 = BP 1.5°C Scenario (BP, oil and gas company)
- Shell Sky 1.5 = Shell Sky 1.5°C Scenario (Shell, oil and gas company)
- ETC = Energy Transitions Commission

https://www.irena.org/Digital-Report/World-Energy-Transitions-Outlook-2022

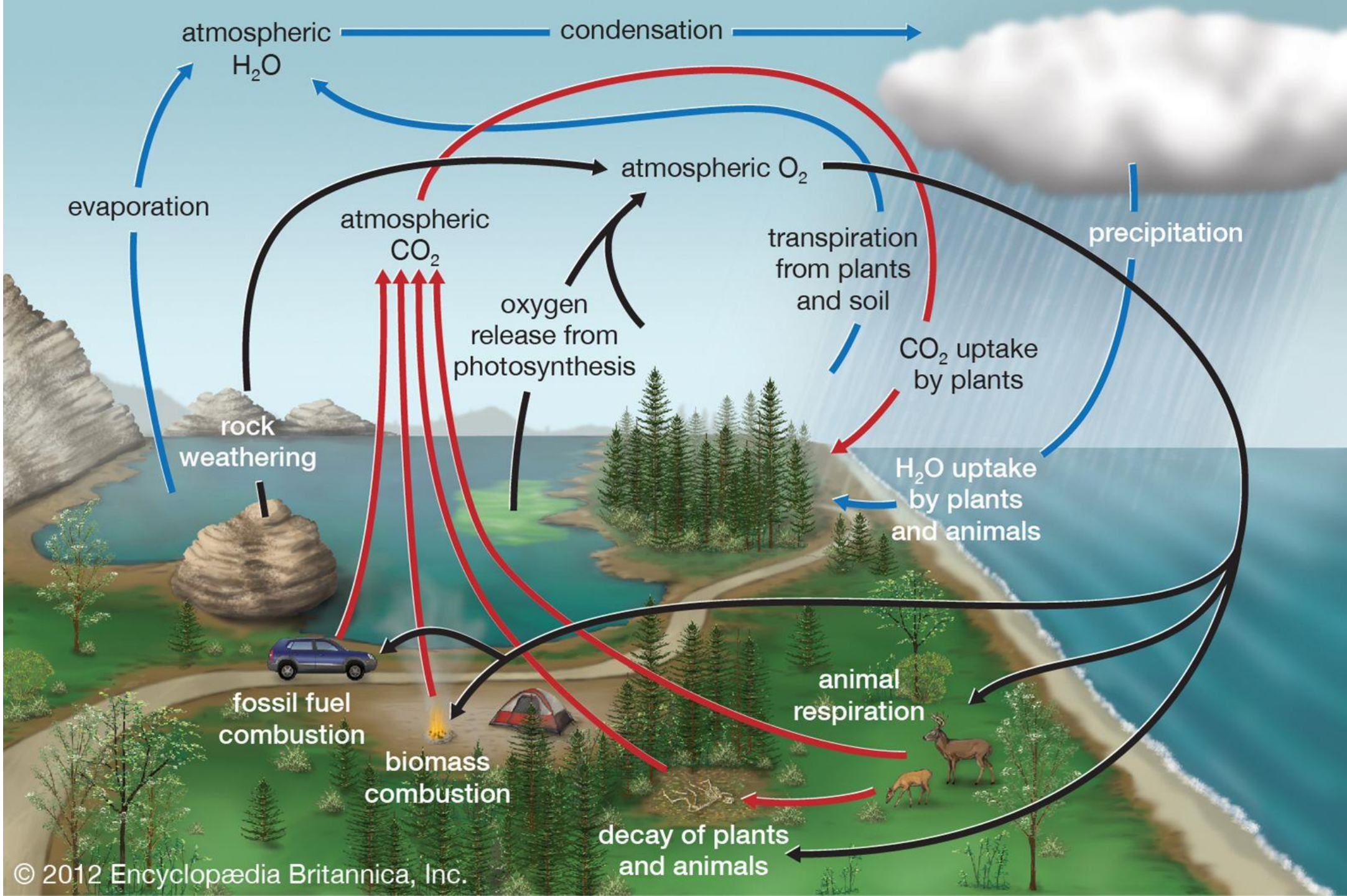


https://www.irena.org/Digital-Report/World-Energy-Transitions-Outlook-2022

Sustainability means meeting our own needs without compromising the ability of future generations to meet their own needs

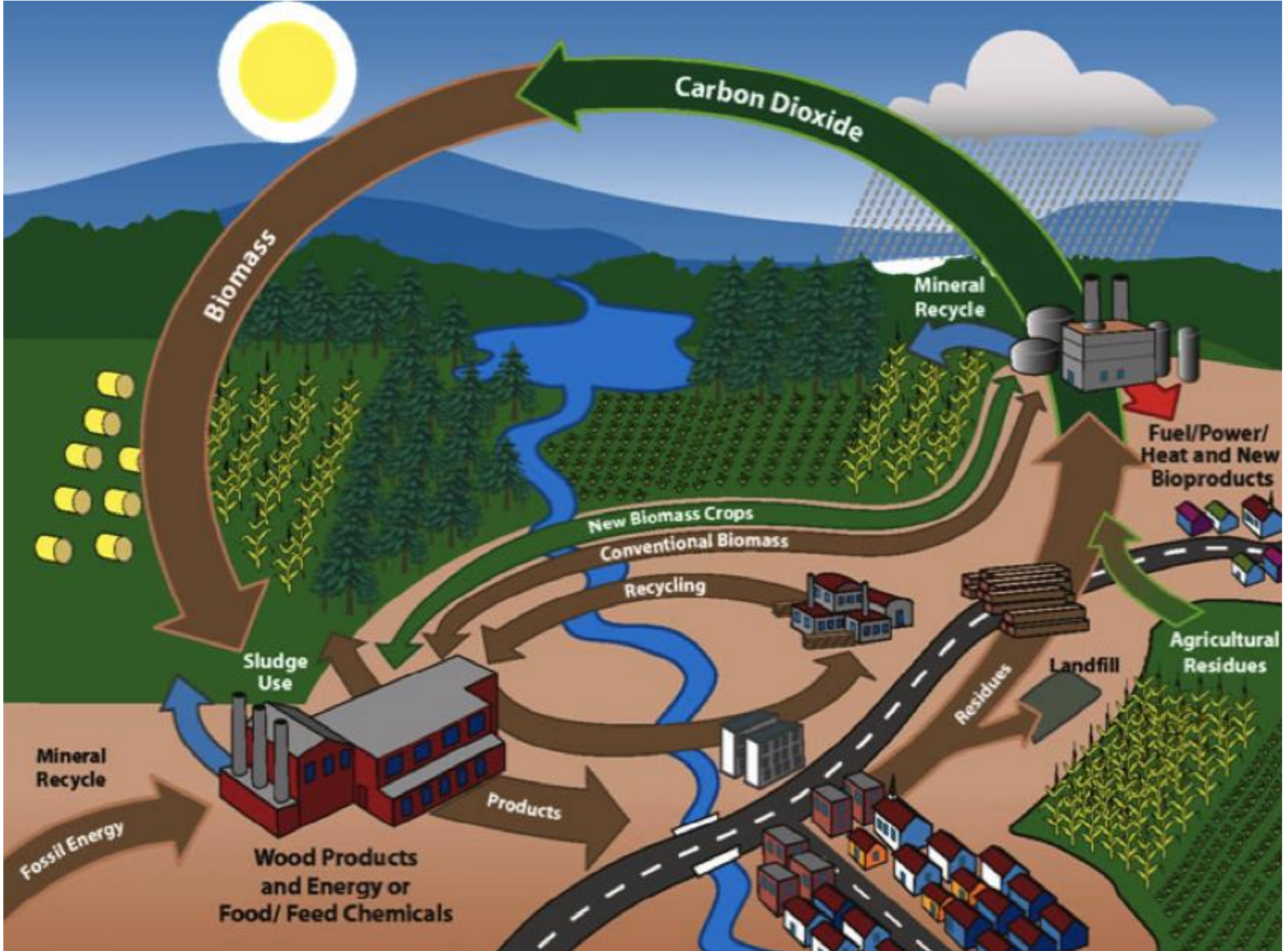
Carbon cycle
Water cycle
Nitrogen cycle
Phosphorus cycle
Sulphur cycle

The natural nutrient (chemical) cycle of the abiotic components of the ecosystem (water, air, soil, rock) through the biotic components (plants, animals, fungi, bacteria)

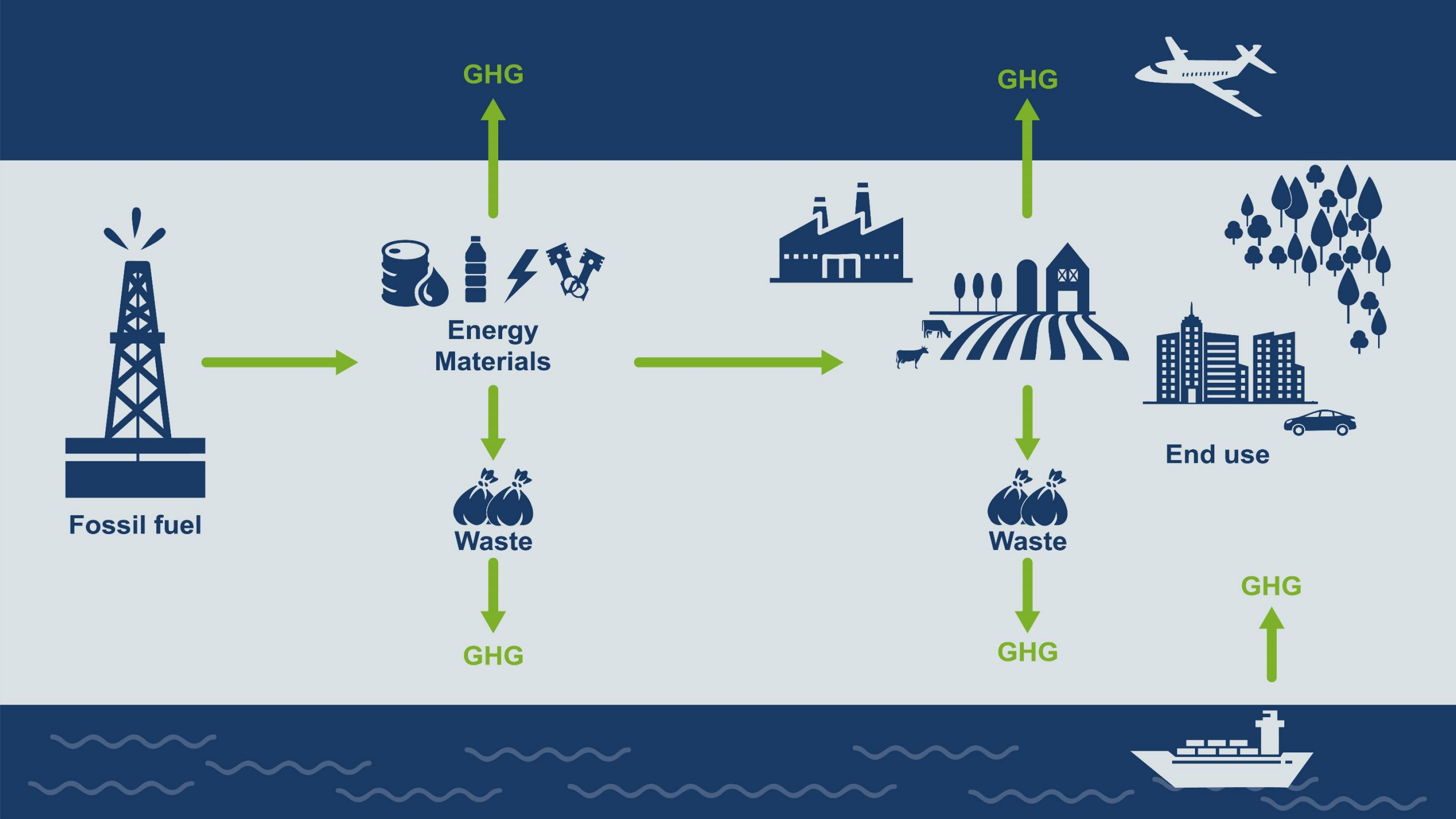


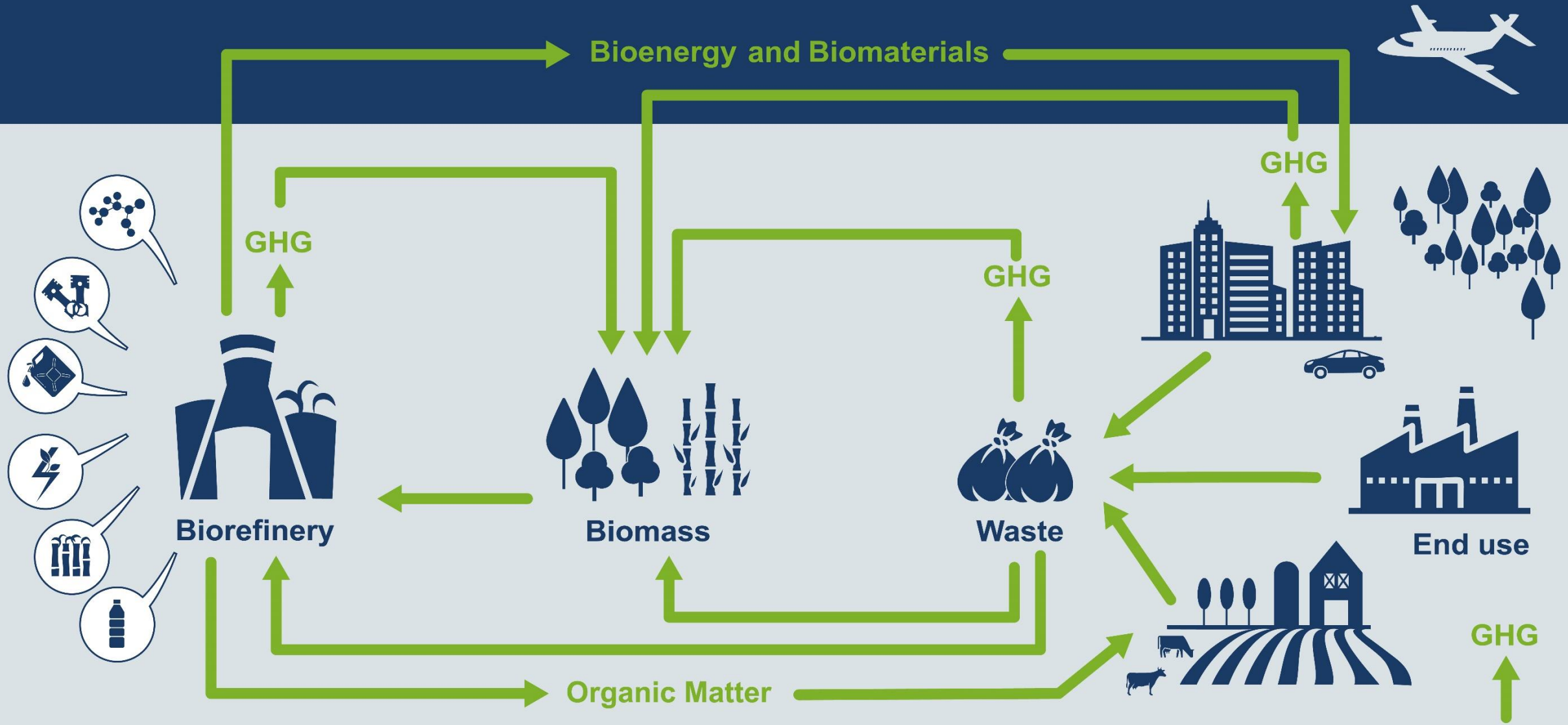
Large Integrated Bioenergy Systems

Key material and energy flows

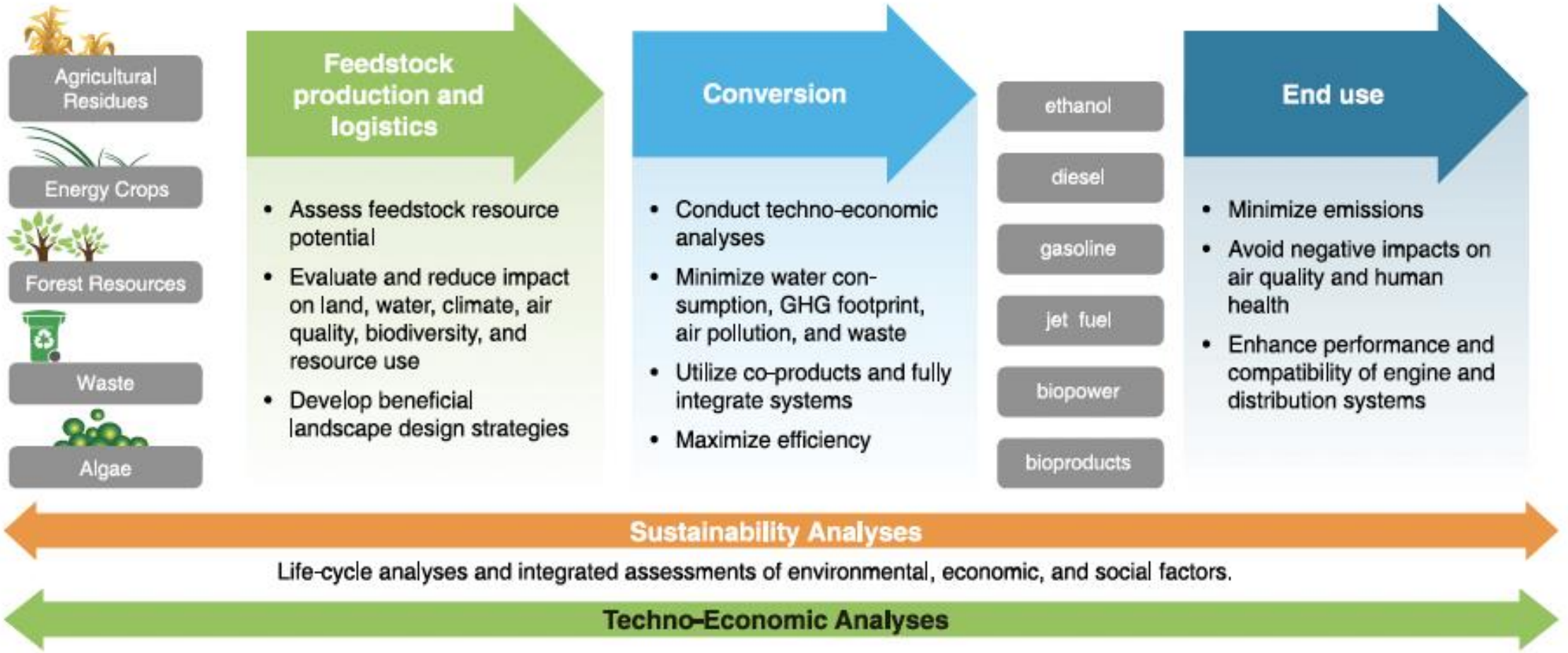


SCOPE, 2015
Fig. 6.1


GHG
GHG
Energy
Materials
Fossil fuel
Waste
Waste
End use
GHG
GHG
GHG


Bioenergy and Biomaterials
GHG
GHG
GHG
GHG
Biorefinery
Biomass
Waste
End use
Organic Matter

Supply chain







Biomass

- Sugar
- Starch
- Oils
- Sugarcane bagasse
- Vinasse
- Municipal Solid Waste
- Post-consumer vegetable oil
- Reforestation wood
- Rice husks
- Lignin
- Sewage Sludge
- Agricultural waste
- Agro-industrial waste

Biorefinaries

- Chemical and biochemical processes
- Anaerobic digestion
- Peletization
- Pretreatment
- Gasification
- Pyrolysis
- Hydrothermal carbonization

Biofuels Bioproducts

- Biodiesel
- Bioethanol
- Butanol
- Biogas
- Biometano
- Green CDR
- Solid fuel
- Electricity
- Syngas
- Hydrogen
- Biopolymers
- Biofertilizantes

End use

- Engines
- Heavy Vehicles
- Fuel Cell
- Aviation applications
- Marine Applications
- Stationary applications

Policies

- Nacional de Resíduos Sólidos
- Estadual de Resíduos Sólidos
- Nacional de Biocombustíveis – RenovaBio
- Metas compulsórias anuais de redução de GEE de combustíveis
- Nacional sobre Mudança do Clima
- Estadual de Mudanças Climáticas – PEMC
- Programa Paulista de Biocombustíveis
- Estratégia para o Desenvolvimento Sustentável do Estado de São Paulo
- Programa Estadual de Contratações Públicas Sustentáveis

Glaucia M. Souza – FAPESP BIOEN & USP

BIOFUELS BLENDING MANDATES IN EMERGING ECONOMIES

Positive institutional environment (legal framework in place)

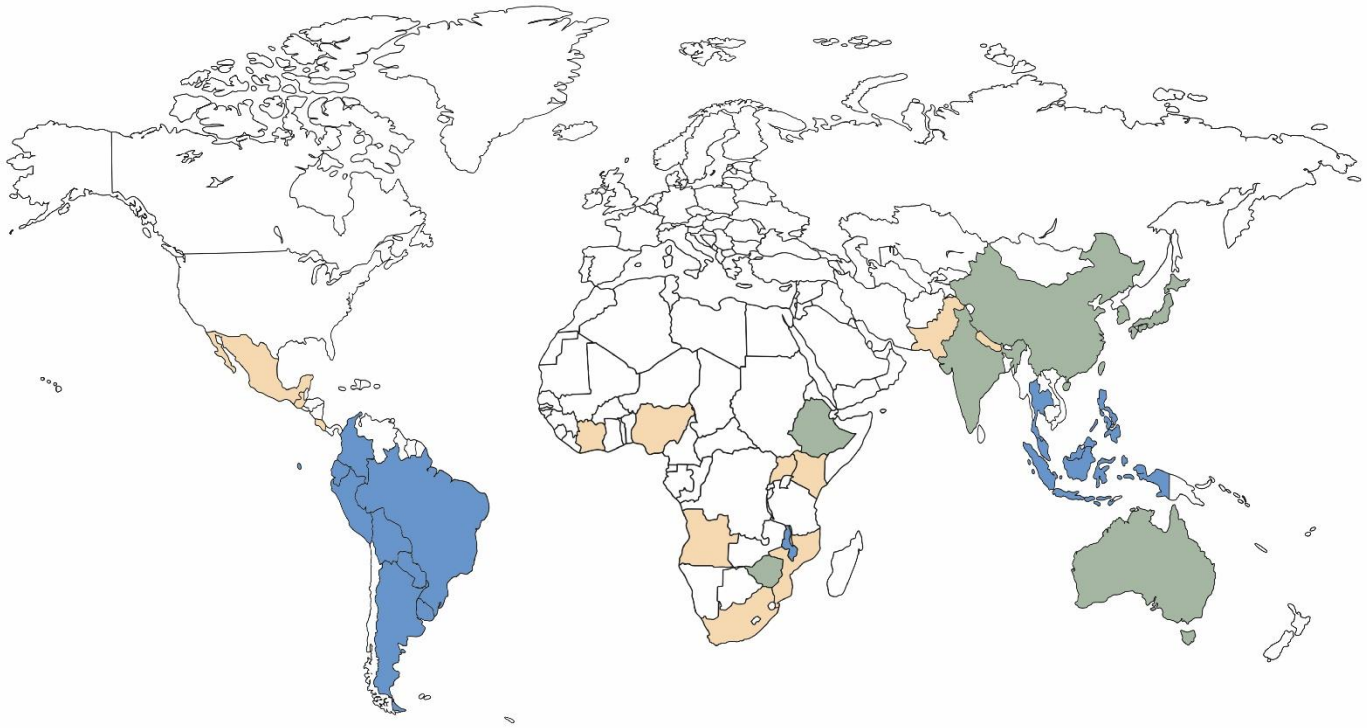
Angola
Cote d'Ivoire
Kenya
Mozambique
Nigeria
South Africa
Uganda
Nepal
Pakistan
Costa Rica
Guatemala
Mexico

Blending mandate partially implemented

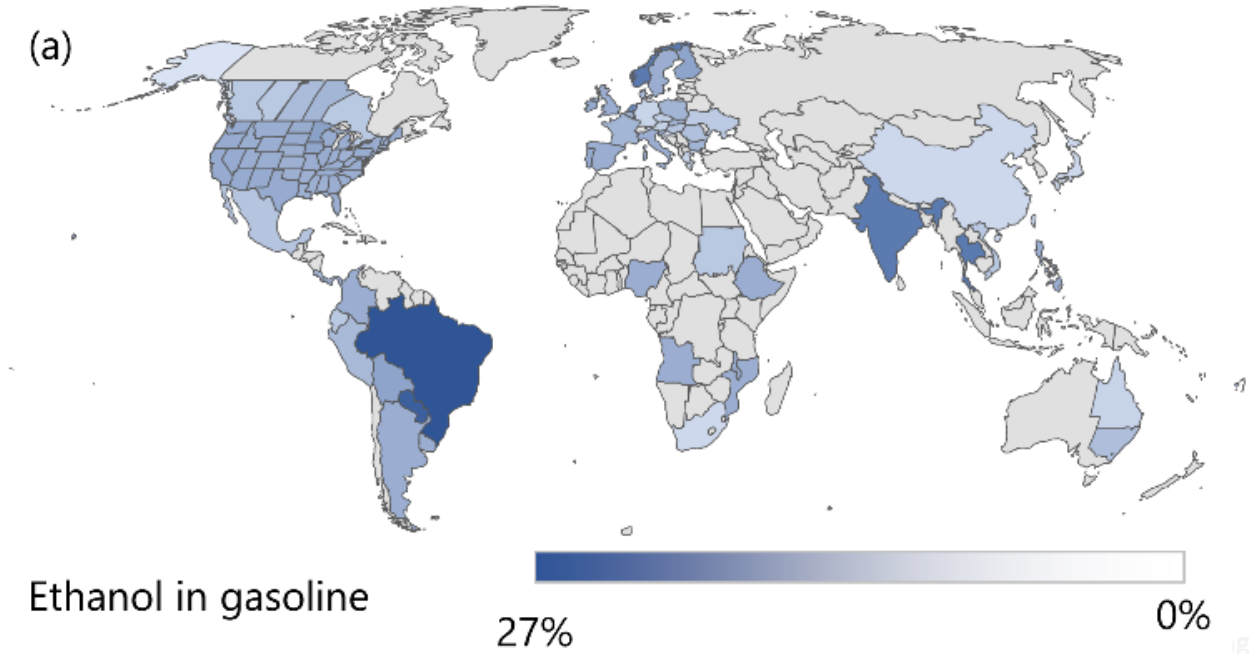
Ethiopia
Zimbabwe
Australia
China
India
Japan
South Corea

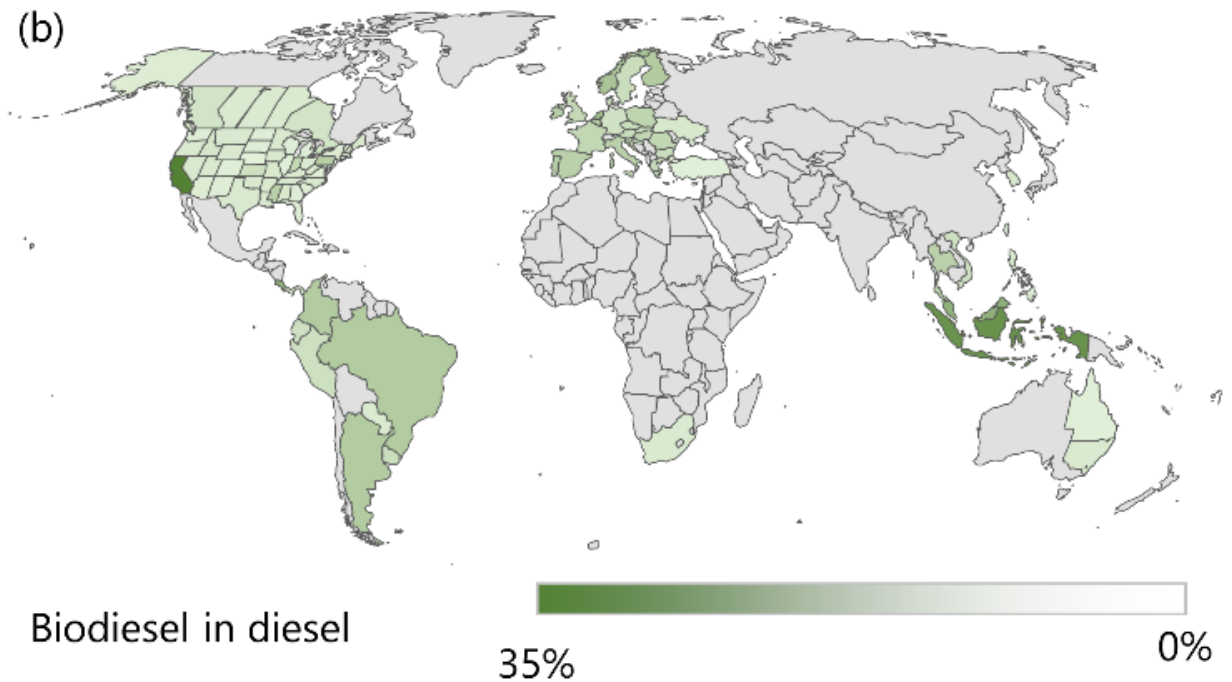
Biofuel use fully implemented

Malawi
Indonesia
Malaysia
Philippines
Thailand
Argentina
Bolivia
Brazil
Colombia
Ecuador
Paraguay
Peru
Uruguay



Blending is the most common and faster way of implementing biofuels





BIOENERGY TECHNOLOGIES

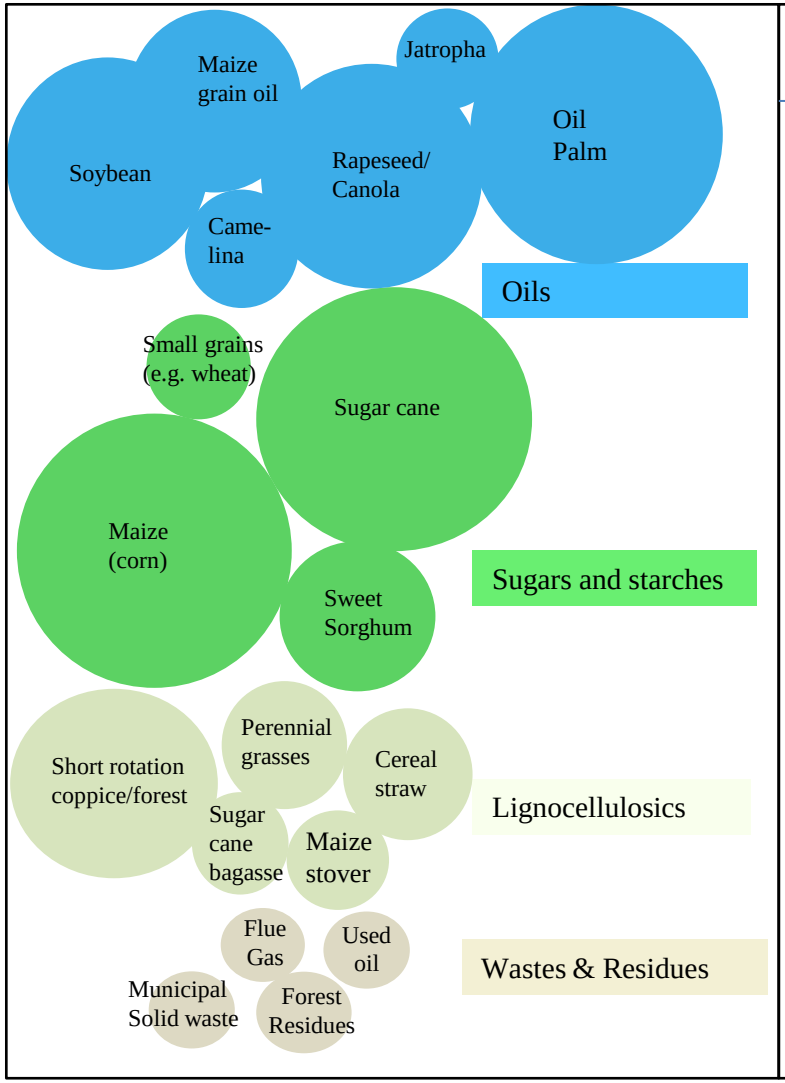
- BIOMASS
- BIOFUELS
- BIOREFINERY AND BIOPRODUCTS
- END USE
- SUSTENTAINABILITY AND IMPACTS

Energetic Output

Table 10.1. Overview of amounts of biofuel and bioenergy that could be produced per unit land area, based on current yields of each crop in specific regions.

Feedstock Common and latin binomial name (region of measurement)	Total Dry Biomass Yield (t/ha)	Grain/ seed/sugar yield (t/ha)	Easily accessed biofuel (GJ/ha)	Cellulosic (GJ/ha)	Combustion of residue (GJ/ha)	Sum of previous three columns	Combustion of Total Biomass (GJ/ha)
Annuals							
Maize *Zea mays* (USA)	18.4	9.2	72.8a	40.4	27.6	140.8	331.2
Wheat *Triticum aestivum* (EU28)	8.8	5.3	34.9a	19.4	13.2	67.6	159.0
Rapeseed *Brassica napus* (EU28)	5.6	2.8	33.2b	12.3	8.4	53.9	112.9
Soybean *Glycine max* (USA)	4.7	2.8	21.2b	20.5	5.6	47.3	96.1
Herbaceous perennials							
Sugarcane *Saccharum officinarum* (Brazil)	38.0	12.0	156.8a	167.0	113.9	437.7	684.0
Napier Grass *Pennisetum purpureum* (El Salvador)	84.0	0.0	0.0	738.2	503.5	1241.7	1512.0
Miscanthus *Miscanthus x giganteus* (Illinois)	22.0	0.0	0.0	193.3	131.9	325.2	396.0
Switchgrass *Panicum virgatum* (Illinois)	10.0	0.0	0.0	87.9	59.9	147.8	180.0
Reed Canary Grass *Phalaris arundinaceae* (Denmark)	12.0	0.0	0.0	105.4	71.9	177.3	216.0
Mixed Grass Prairie (Minnesota)	3.7	0.0	0.0	32.5	22.2	54.7	66.6
Agave *Agave americana* (Arizona)	8.0	0.0	33.0a	35.2	24.0	92.1	144.0
Woody perennials							
Oil Palm *Elaeis guineensis* (Indonesia)	34.0	17.0	128.8b	149.4	50.9	329.2	685.4
SRC Willow *Salix* "hybrids" (Sweden)	10.0	0.0	0.0	43.9	30.0	73.9	180.0
SRC Poplar *Populus* "hybrids" (Italy)	14.0	0.0	0.0	61.5	42.0	103.5	252.0
SRF Eucalyptus *Eucalyptus* "hybrids" (Brazil)	18.2	0.0	0.0	80.0	54.5	134.5	327.6

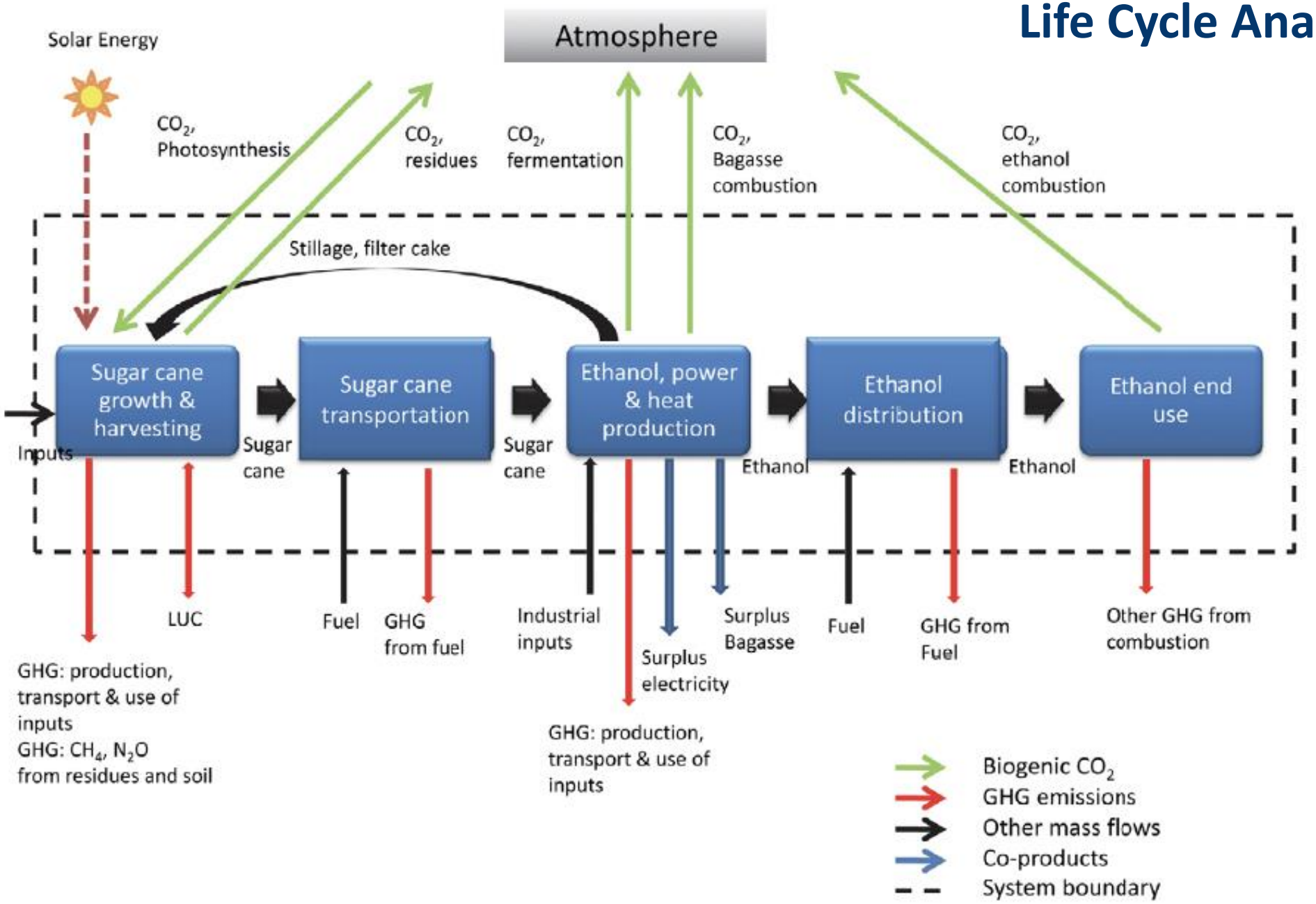
Technical Costs and Development Time



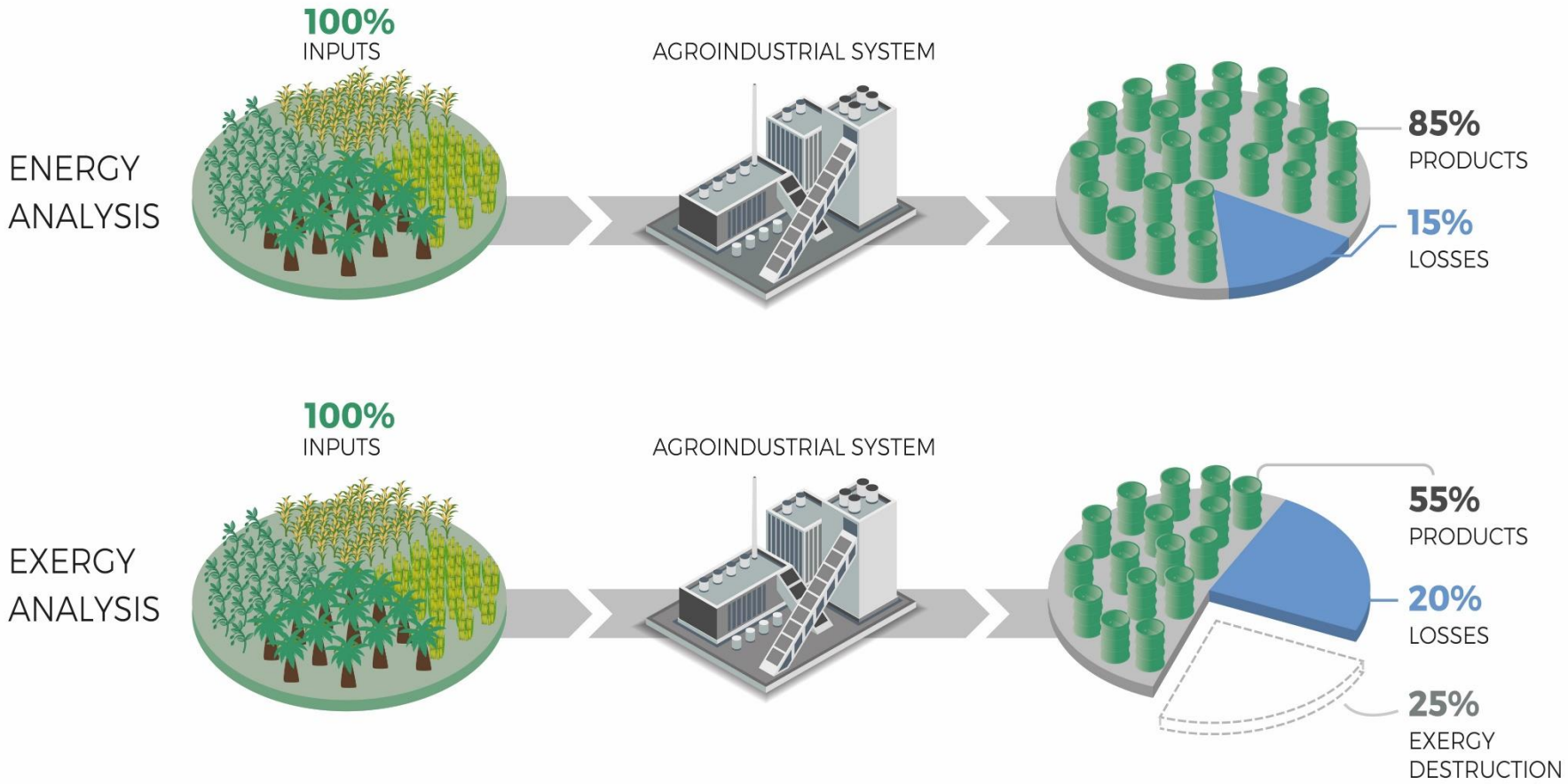
Usage	Technical costs	Development time	Sustainability
Transport Fuels	L	L	L-M
Transport Fuels	L	L	L-H
Heat & Power	L	H	M-H
Transport Fuels	H	H	M-H
Heat & Power	L	L	M-H
Transport Fuels	H	L	M-H

Energy balance – Implementation costs – TRL – Environmental gains

Life Cycle Analysis



EXERGETIC ANALYSIS



GHG EMISSIONS – Ethanol compared do gasoline

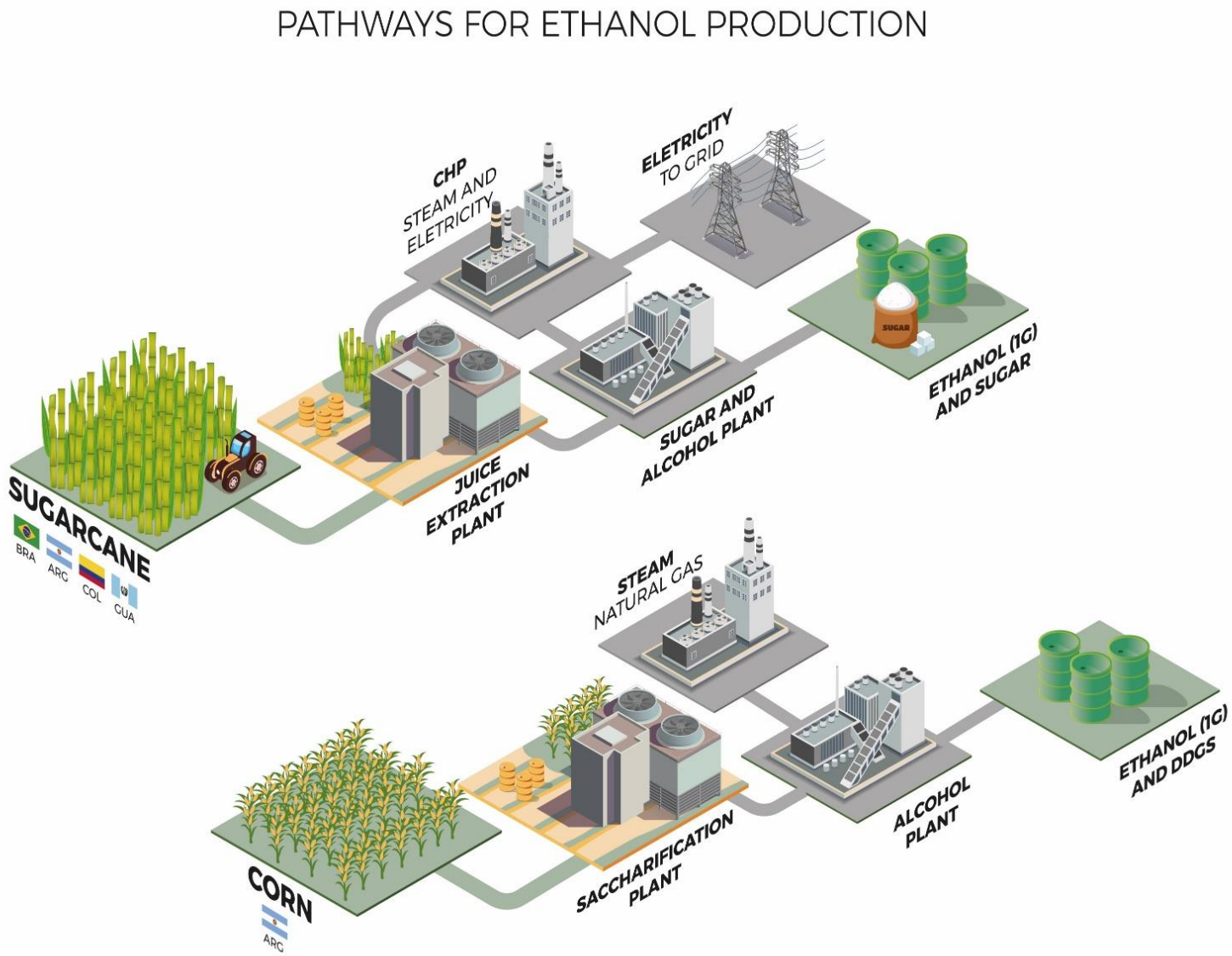
ARG ↓ 70%

BRA ↓ 67%

COL ↓ 74%

GUA 66%

ARG ↓ 37%

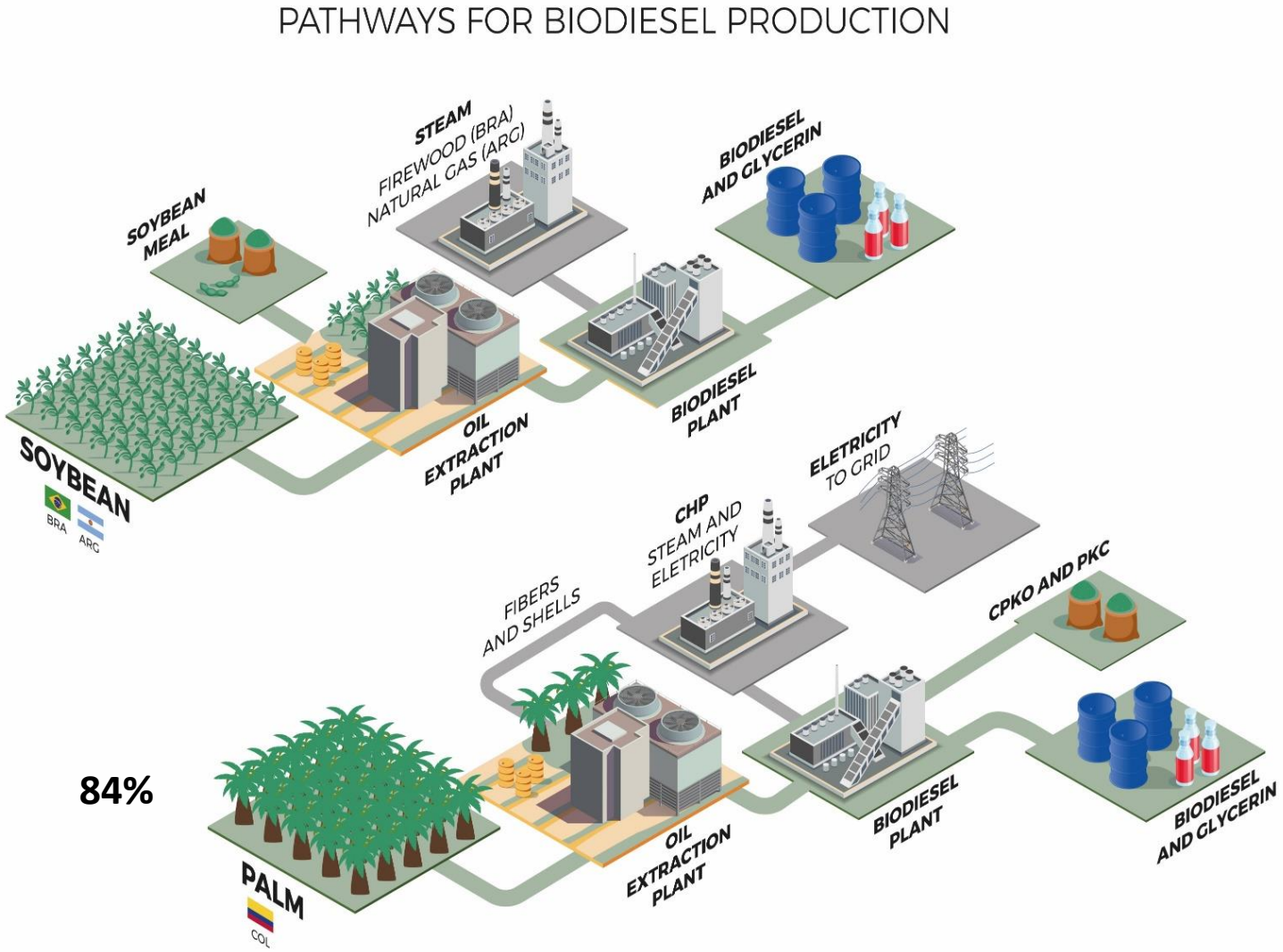


GHG EMISSIONS – Biodiesel compared do diesel

ARG ↓ 79%

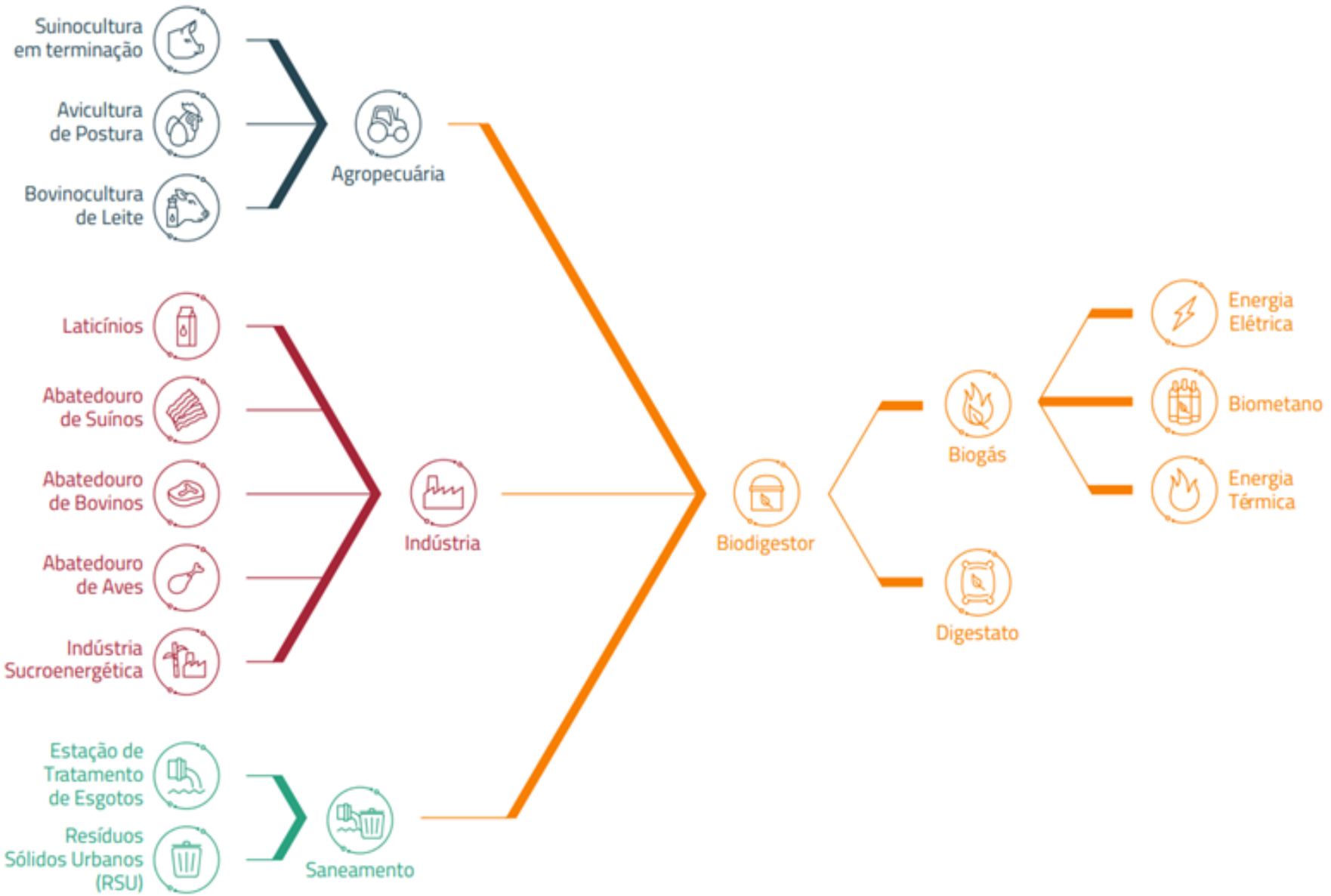
BRA ↓ 68%

COL ↓ 84%



BIOEN FAPESP

Substratos considerados nas estimativas do potencial de produção de biogás a curto prazo no Brasil.



TRADITIONAL BIOENERGY

Most of the renewable energy we use today comes from inefficient burning of biomass to produce heat

30% of the biomass used is native vegetation

2.8 billion people use it for cooking and heating.
Wood hauling is done mostly by women and children

Respiratory illnesses
1.6 million deaths per year, of mainly women and children

MODERN BIOENERGY

In rural areas, bioenergy can bring access to energy and contribute to poverty reduction

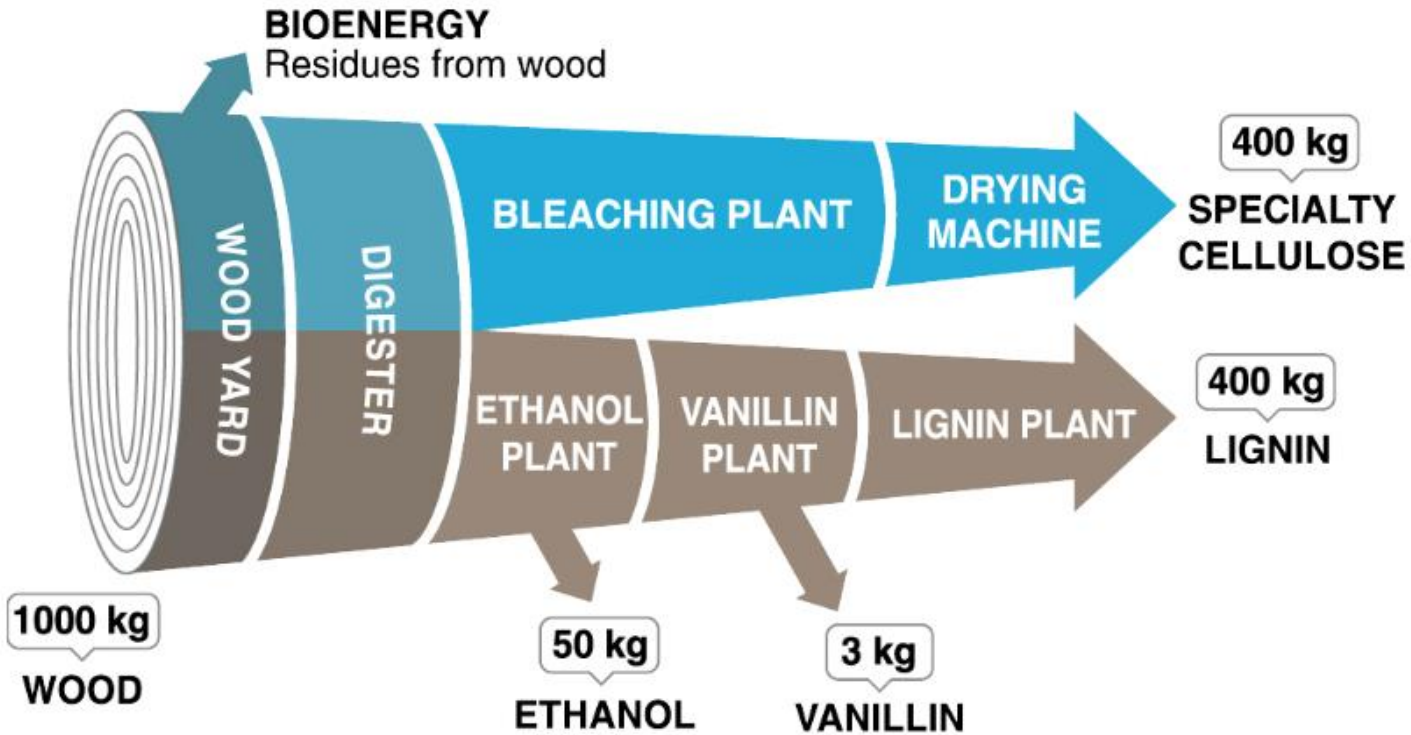
In Kenya, 1.4 million improved cooking stoves saved
75 thousand Ha
of forest

Generating jobs and improving livelihoods

Improving health and education

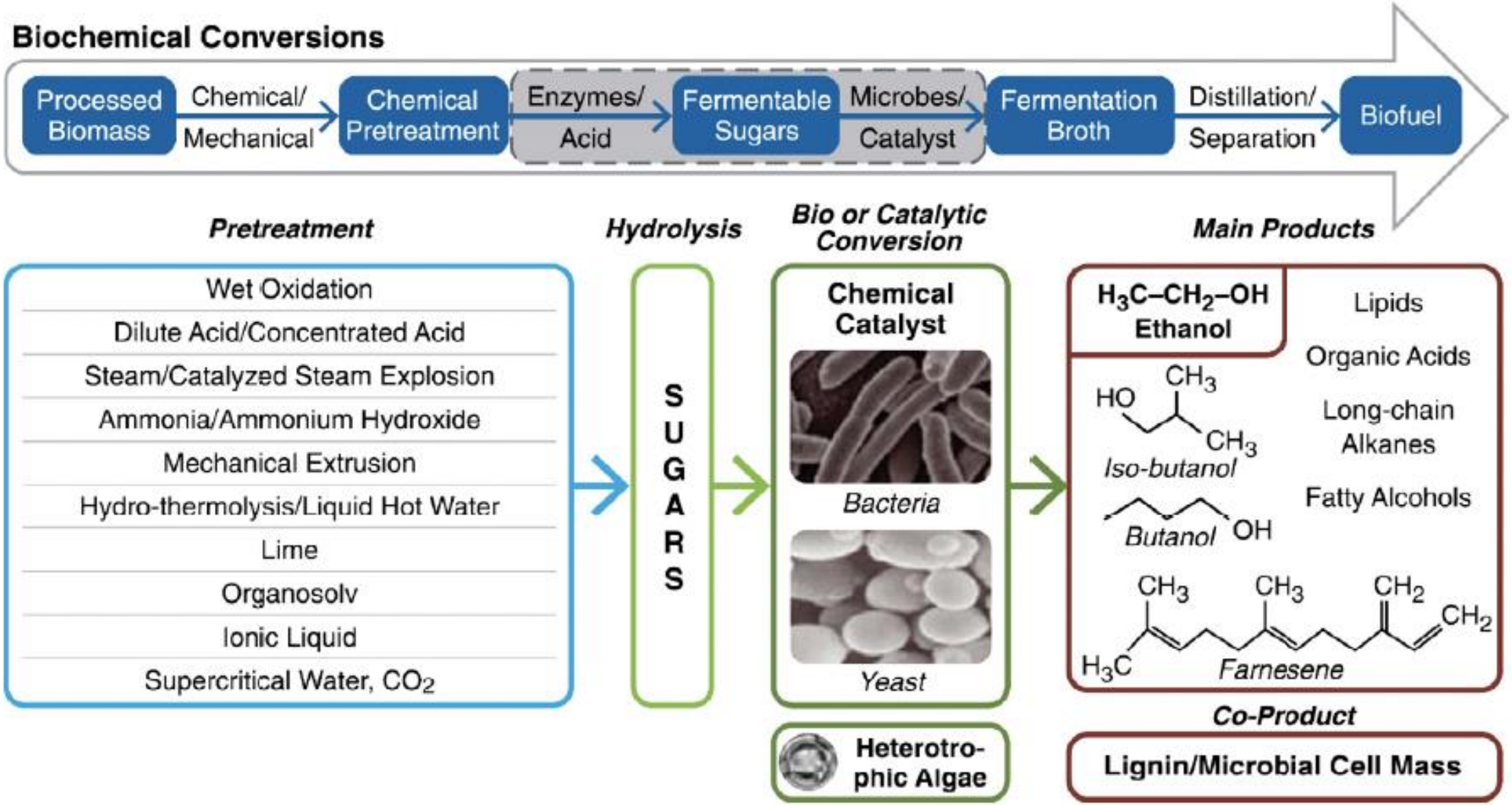
Biogas in 5 million homes in India and 15 million homes in China

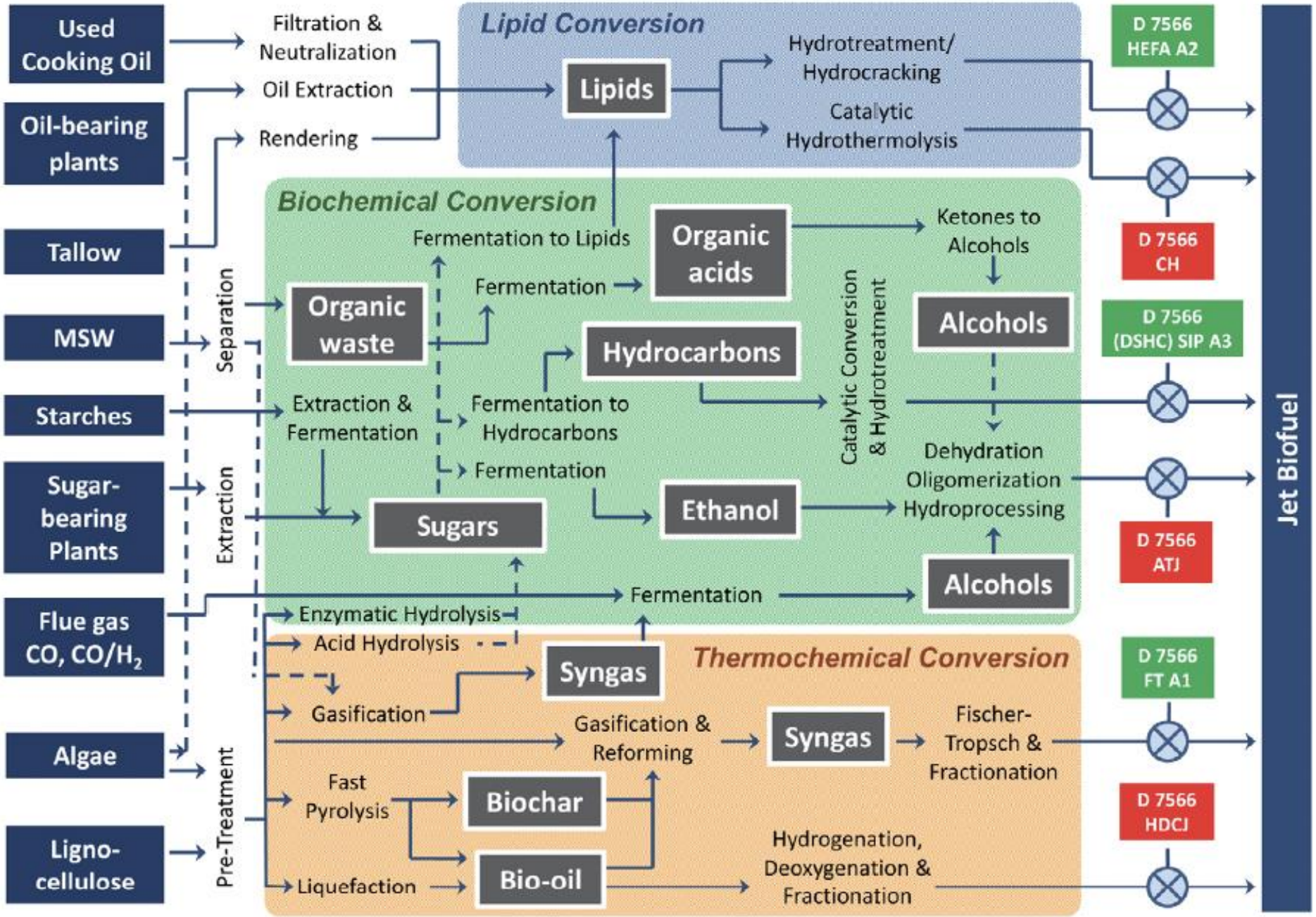
Integrated new biorefinery systems are on the way: no carbon waste!



Specialty cellulose	Lignin	Vanillin	Bioethanol
Construction materials	Concrete additive	Food	Car care
Cosmetics	Animal feed	Perfumes	Paint/varnish
Food	Agrochemicals	Pharmaceuticals	Pharmaceutical industry
Tablets	Batteries		
Textiles	Mining		Biofuel
Filters	Oil field chemicals		

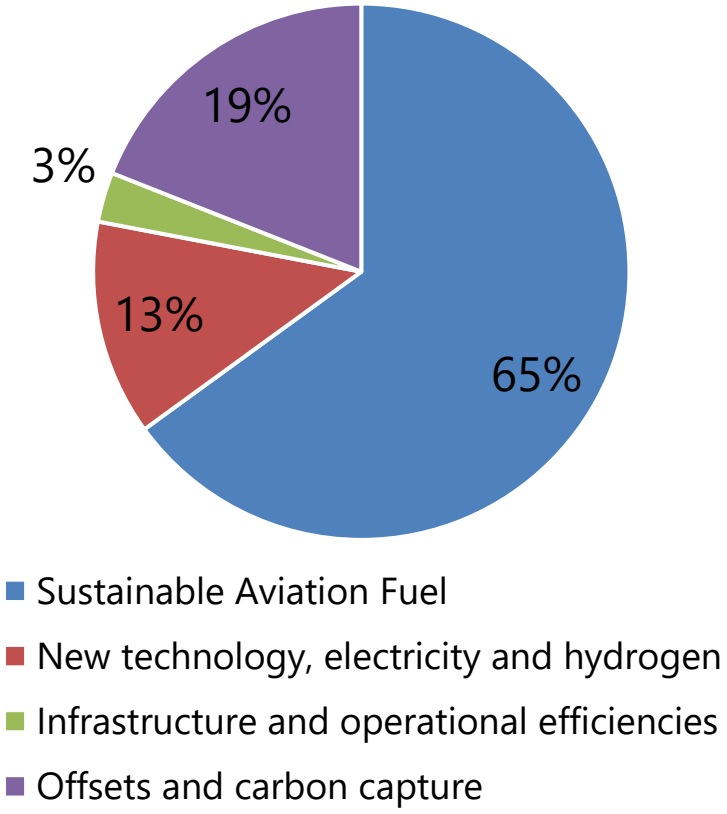
Conversion through catalysts or biocatalystis




Used Cooking Oil
Oil-bearing plants
Tallow
MSW
Starches
Sugar-bearing Plants
Flue gas CO, CO/H2
Algae
Ligno-cellulose
Filtration & Neutralization
Oil Extraction
Rendering
Separation
Extraction
Pre-Treatment
Lipid Conversion
Lipids
Hydrotreatment/ Hydrocracking
Catalytic Hydrothermolysis
Biochemical Conversion
Fermentation to Lipids
Organic acids
Ketones to Alcohols
Fermentation
Organic waste
Hydrocarbons
Alcohols
Catalytic Conversion & Hydrotreatment
Extraction & Fermentation
Fermentation to Hydrocarbons
Fermentation
Dehydration Oligomerization Hydroprocessing
Sugars
Ethanol
Alcohols
Fermentation
Enzymatic Hydrolysis
Acid Hydrolysis
Thermochemical Conversion
Syngas
Gasification
Gasification & Reforming
Syngas
Fischer-Tropsch & Fractionation
Fast Pyrolysis
Biochar
Bio-oil
Liquefaction
Hydrogenation, Deoxygenation & Fractionation
D 7566 HEFA A2
D 7566 CH
D 7566 (DSHC) SIP A3
D 7566 ATJ
D 7566 FT A1
D 7566 HDCJ
Jet Biofuel

IATA member airlines committed to achieve net-zero emissions by 2050

The path to net-zero:



Current state of SAF development:

More than 490,000 flights
- 2016: 500 flights

>300 million liters produced in 2022
- 2016: 8 million liters
- 2025: ~5 billion liters

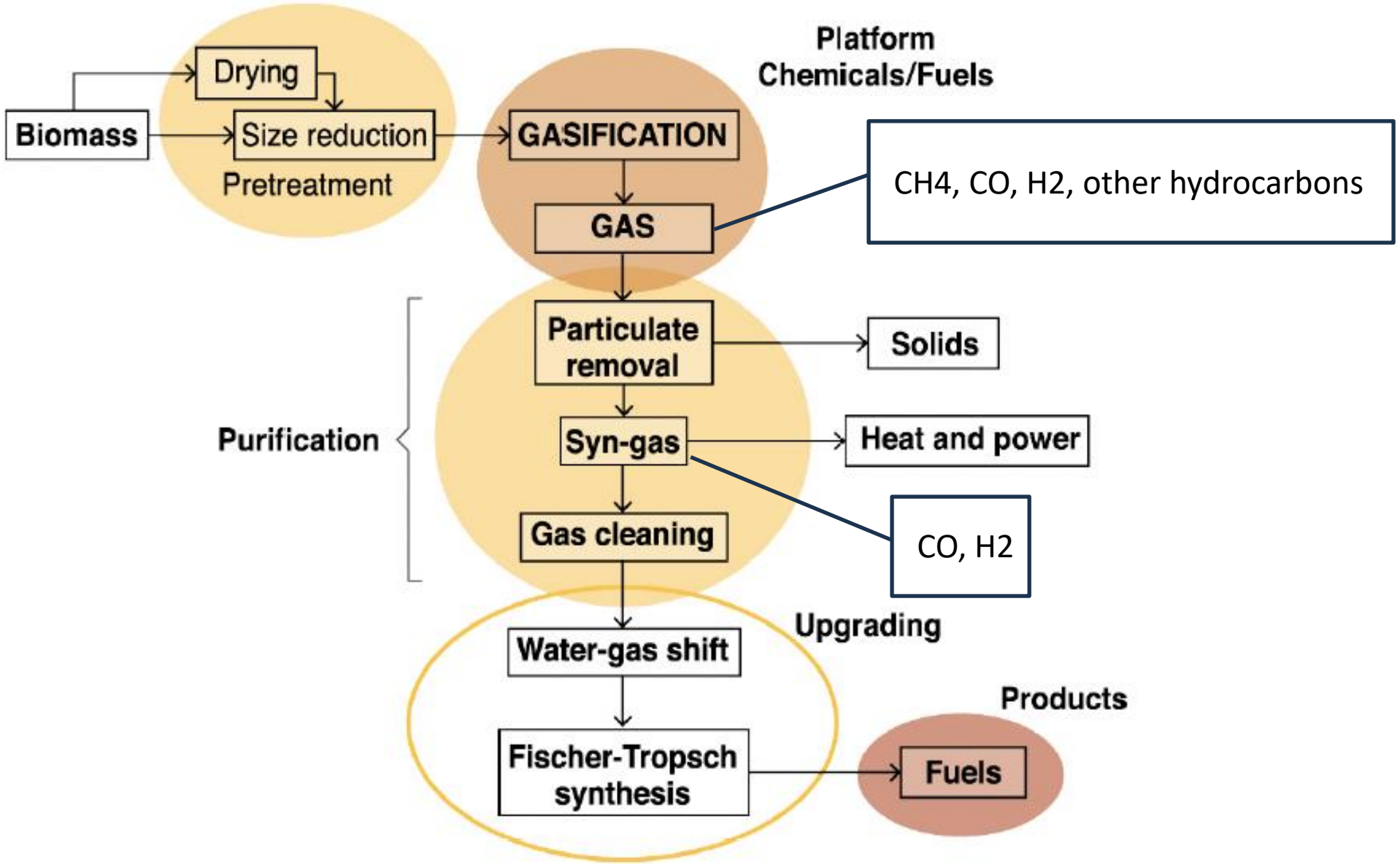
7 technical pathways
- 2016: 4 pathways
- 2025: 11 pathways

57 offtake agreemets since 2022
- 40 publicly announced SAF offtake agreemets and 17 non-binding agreemets

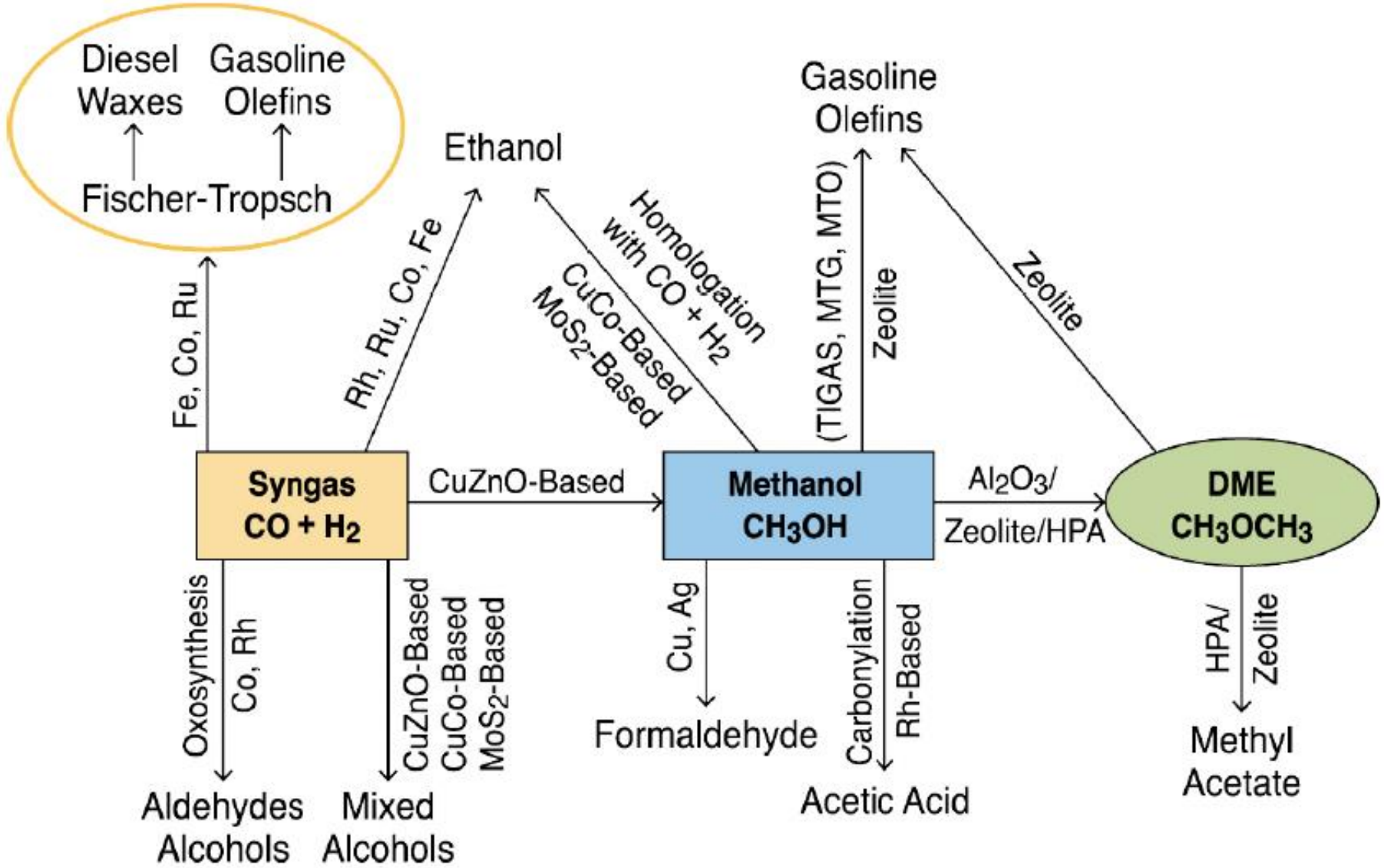
>130 renewable fuel projects
- Projects announced publicly by more than 85 producers across 30 countries

70% CO_2 reduction (average)
- 2016: 60% reduction
- 2025: 80% reduction

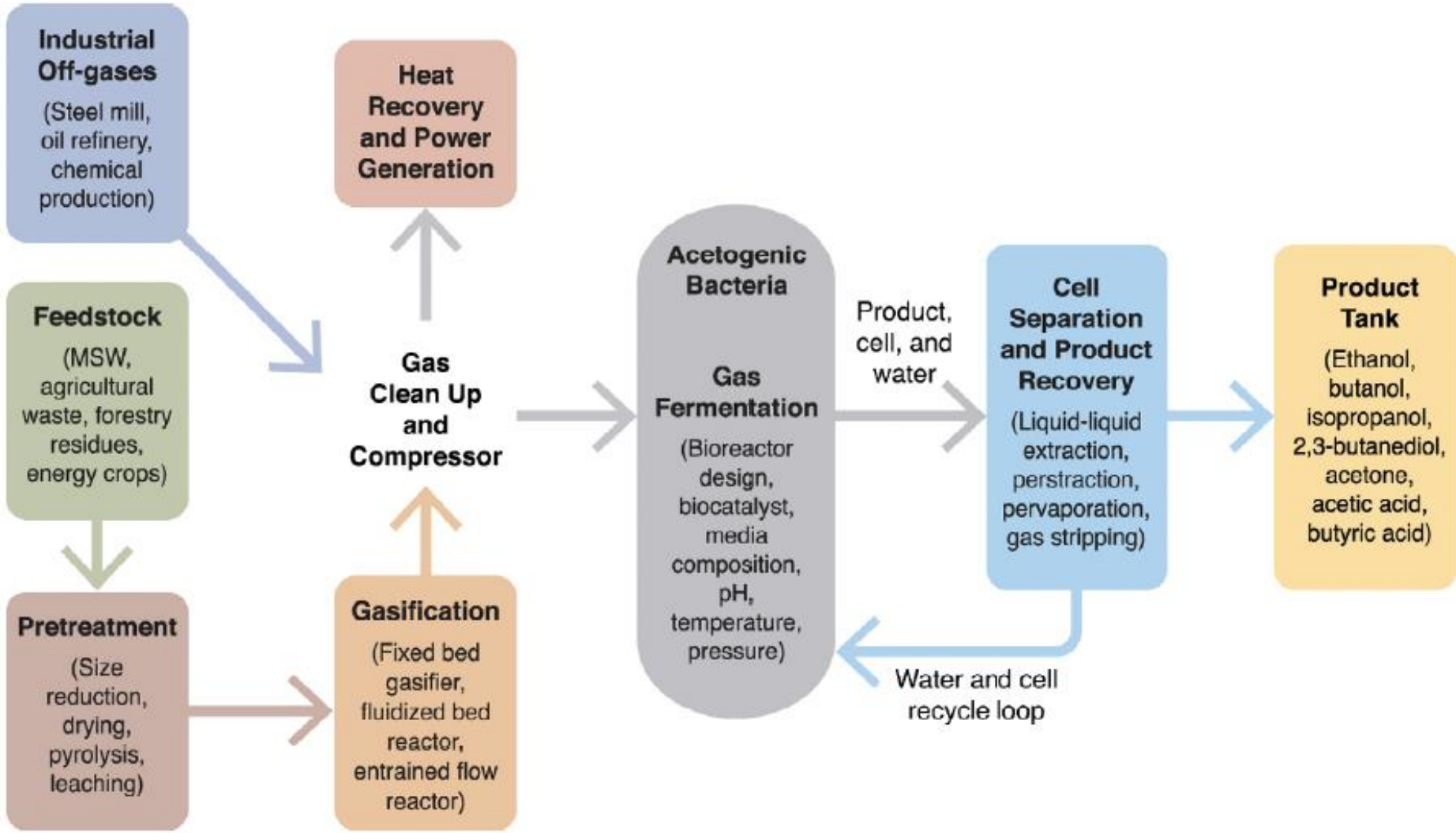
Gasification at 700-850oC, fluidized or fixed beds to create oxidant flow



Catalytic upgrading of syngas

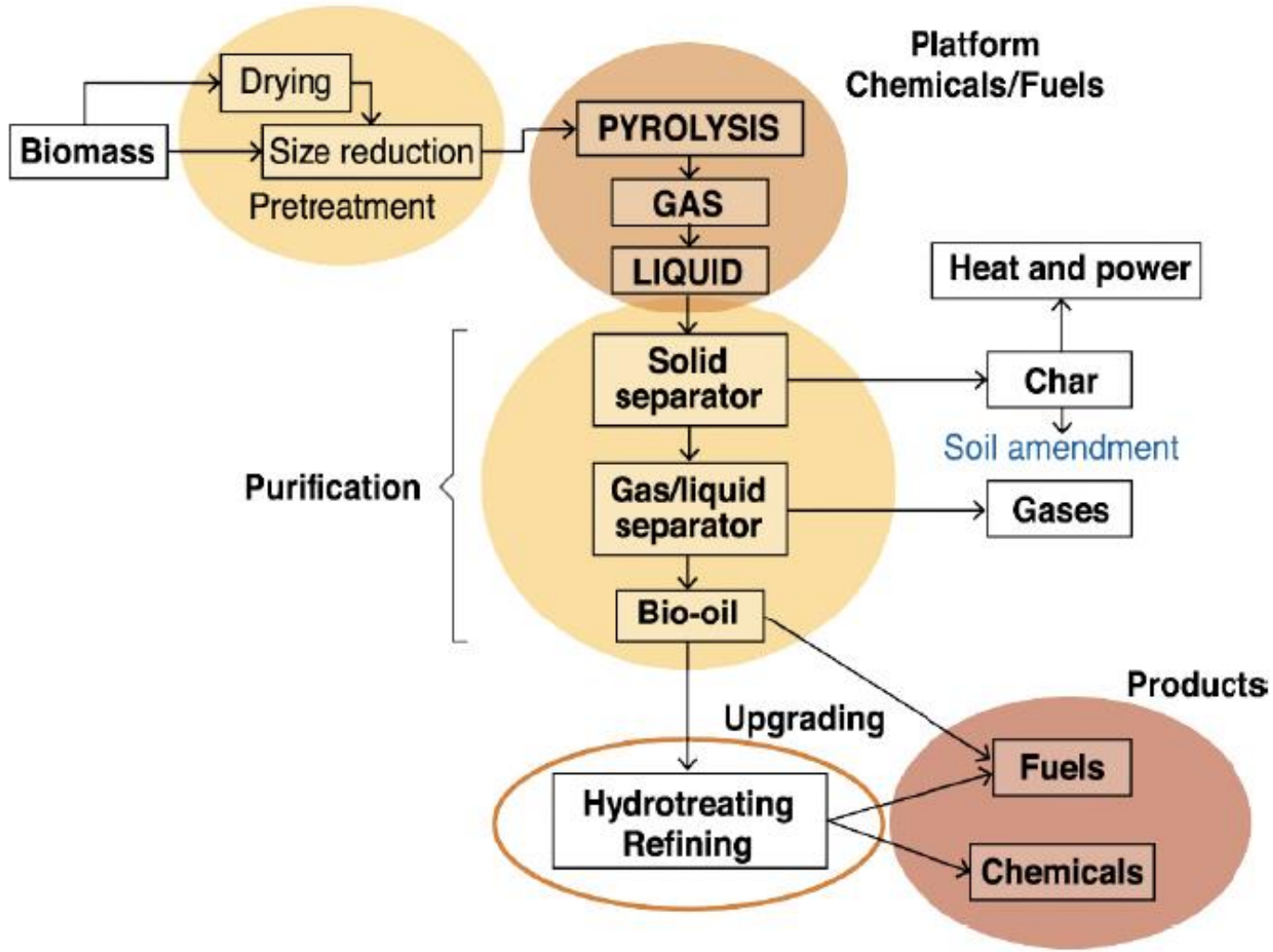


Fermentation of syngas

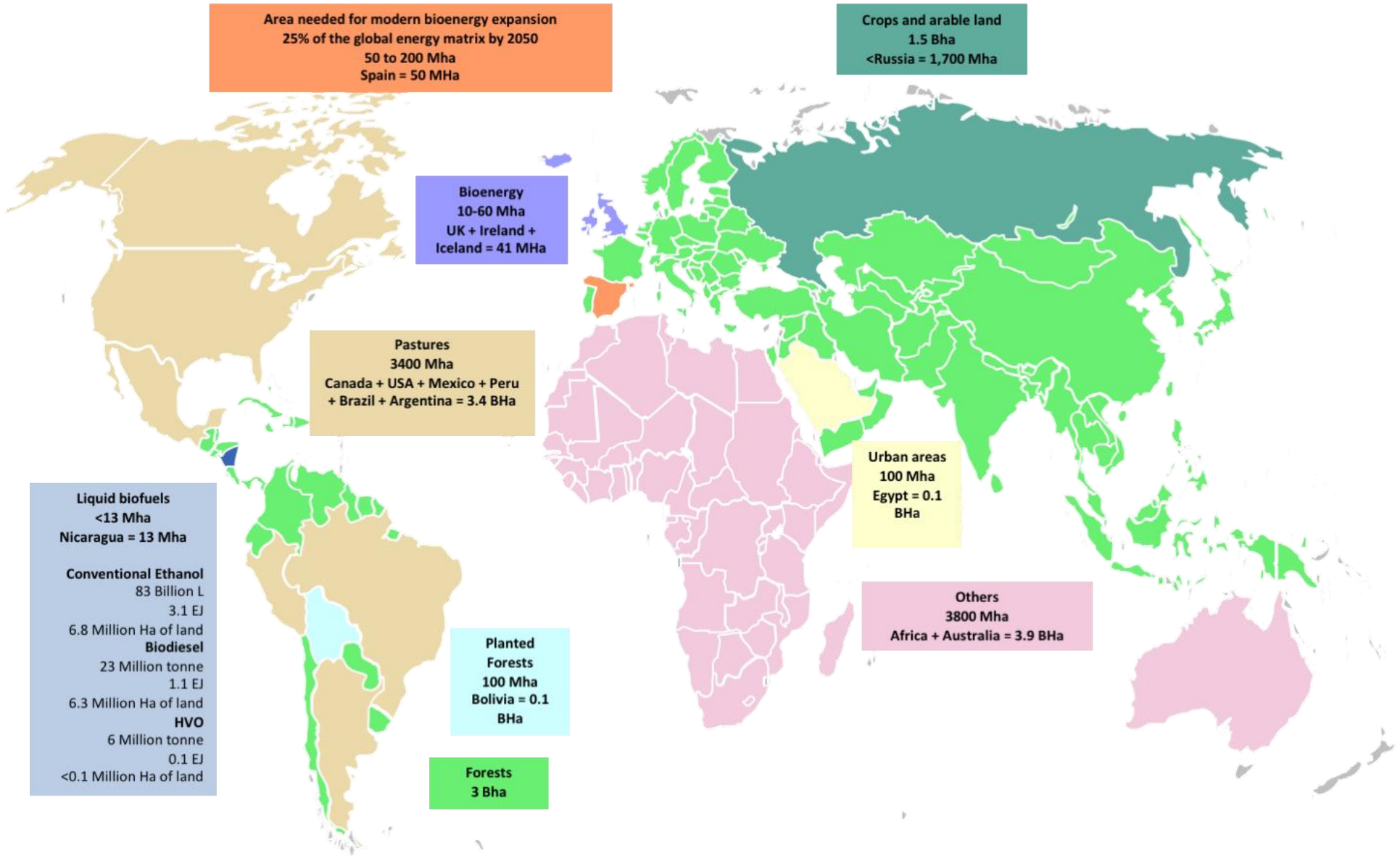


URBAN MINING

Fast Pirolysis

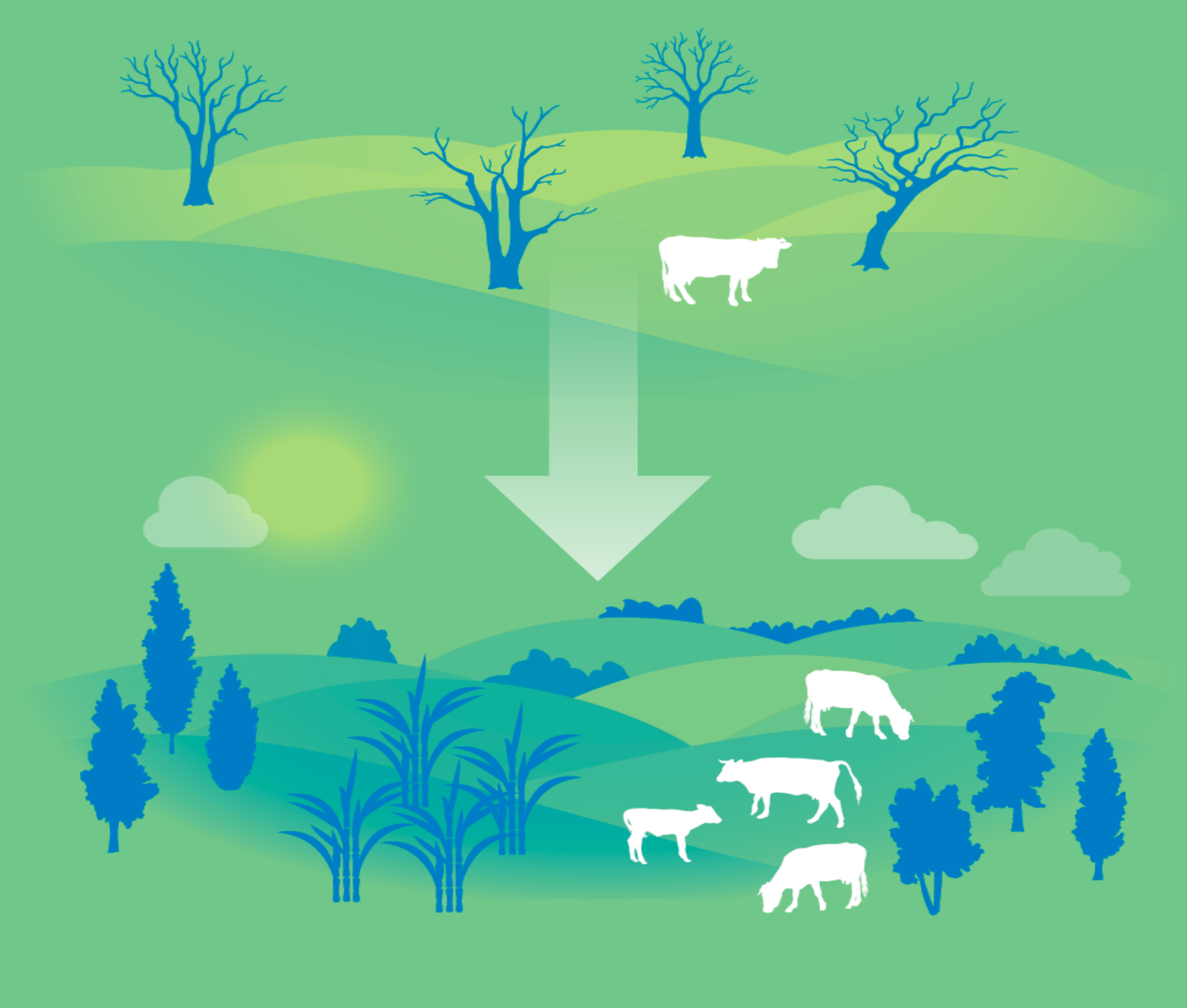


Total global land is 13 Billion Hectares



G. Souza, 2016

Based on Woods, J. *et al.* (2015). Land and Bioenergy. Em: Souza, G. M., Victoria, R., Joly, C., & Verdade, L. (Eds.). (2015). *Bioenergy & Sustainability: Bridging the gaps* (Vol. 72, p. 258-300). Paris: SCOPE. ISBN 978-2-9545557-0-6.

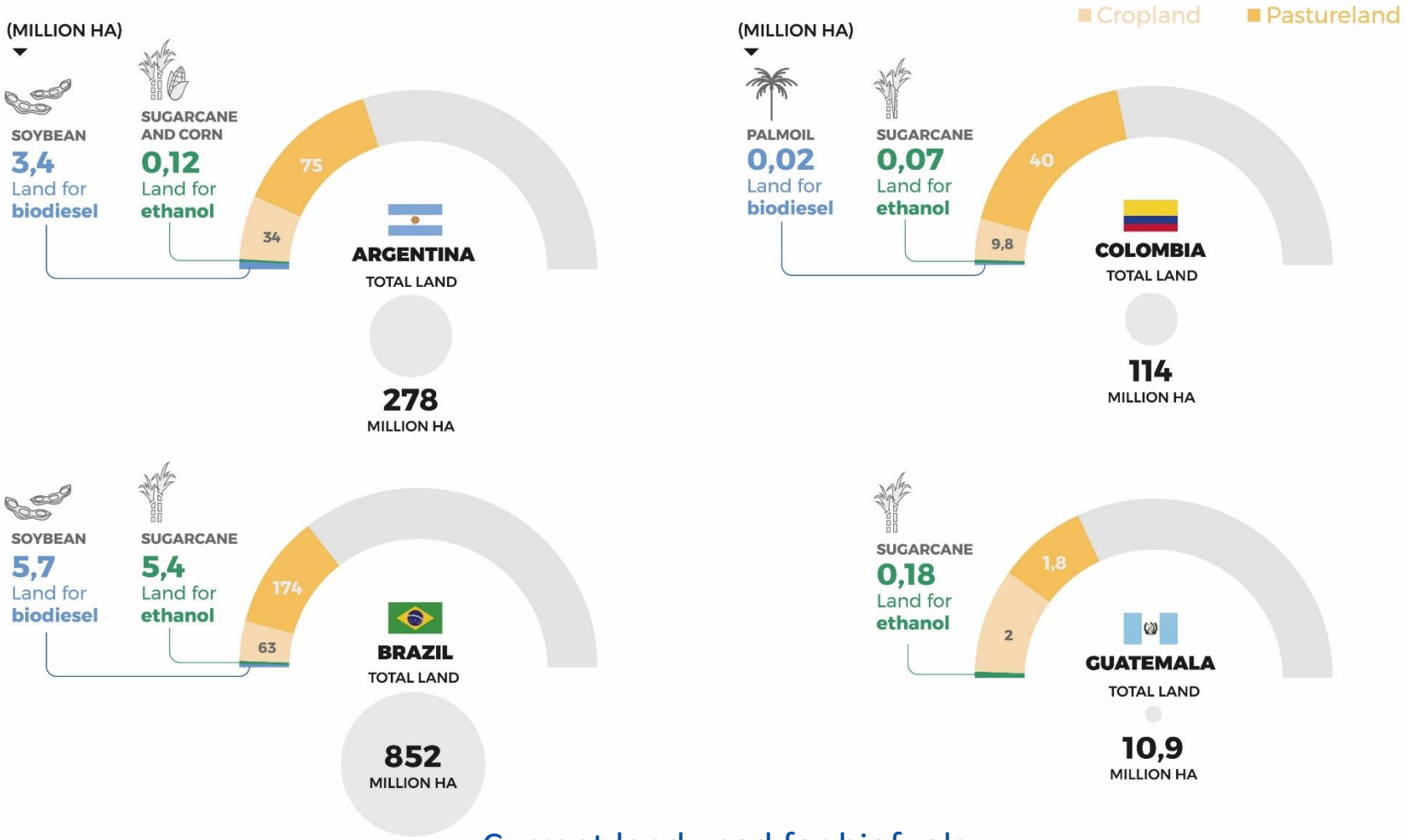


Existing pastureland could support almost four times the numbers of animals.

40% of pastures have no livestock on it.

Bringing the poorest-performing pastures up to **50%** of their maximum attainable density would more than **double the global stock of grazing animals**.

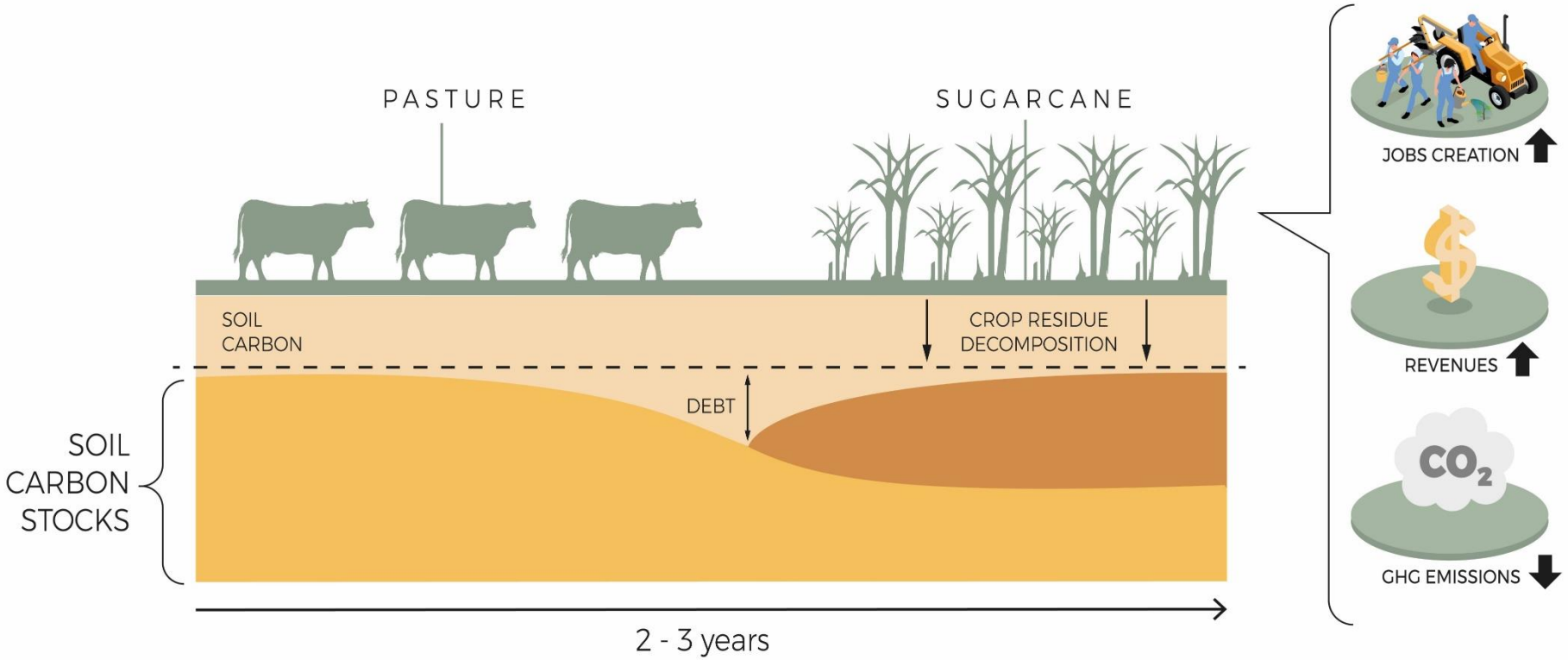
LAND USE



Current land used for biofuels

Sustainability Assessment of ethanol and biodiesel production in Argentina, Brazil, Colombia, and Guatemala
Canabarro et al. 2022; Renewable & Sustainable energy reviews

SOIL CARBON STOCKS



To duplicate the liquid biofuels Production...

Argentina → 4.5% of Pastureland

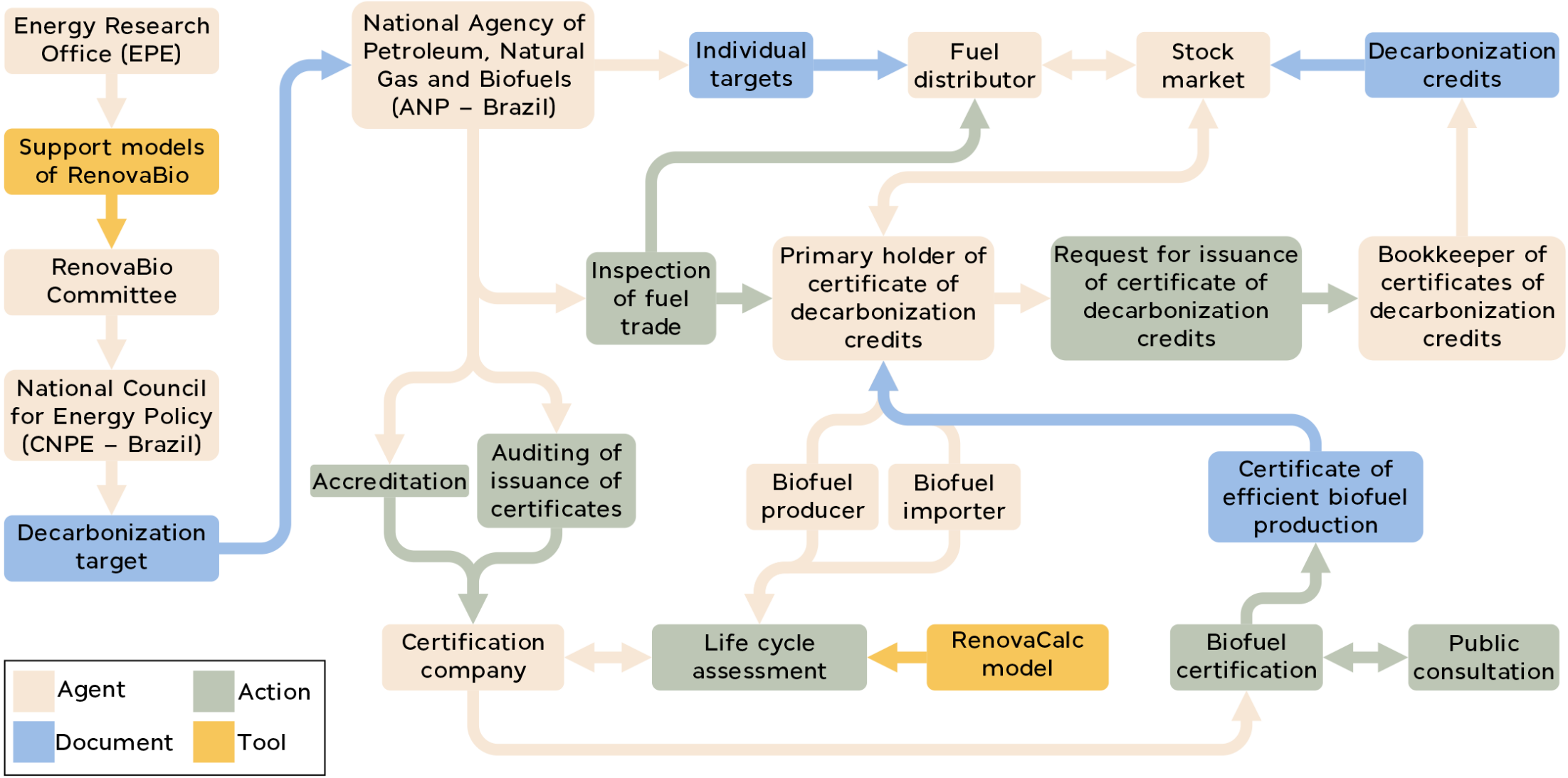
Brazil → 6.4% of Pastureland

Colombia → 0.2% of Pastureland

Guatemala → **10%** of Pastureland (only ethanol)

Cherubin et al., 2022

RENOVABIO Policy Framework



Brazilian Energy Mix

01 Largely renewable energy mix| Electricity mix: 92% renewable (year: 2022)

02 19% of the total consumed energy comes from sugarcane bagasse

03 Liquid fuel mix is 28% from ethanol or biodiesel

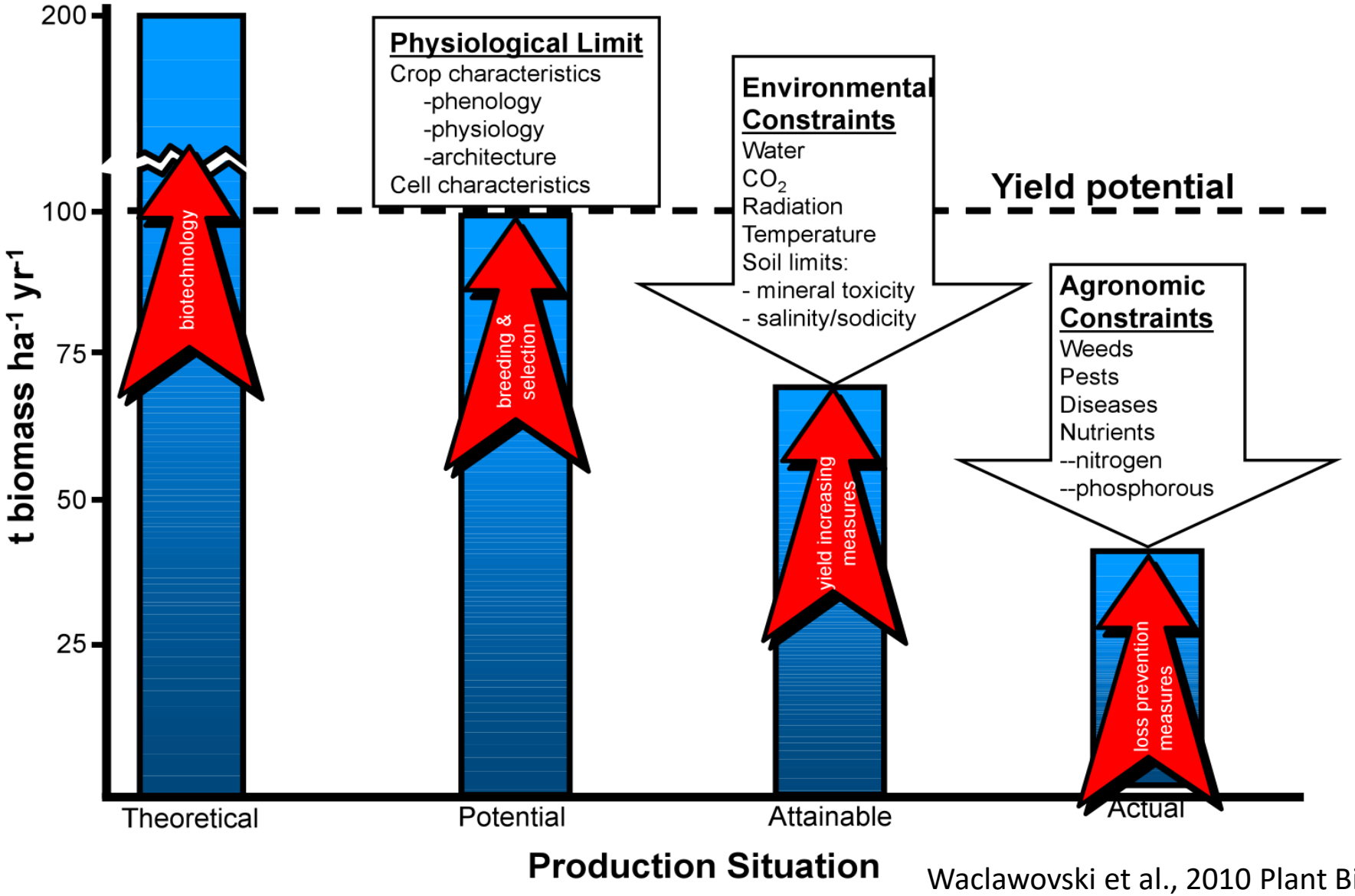
04 83% of the brazilian car fleet is flex-fuel

05 Population: 203 million (2022) No country with more than 60 million inhabitants has an energy mix with more than 40% of renewables

06 Avoided CO_2 emissions in 20 years (4 billion trees)

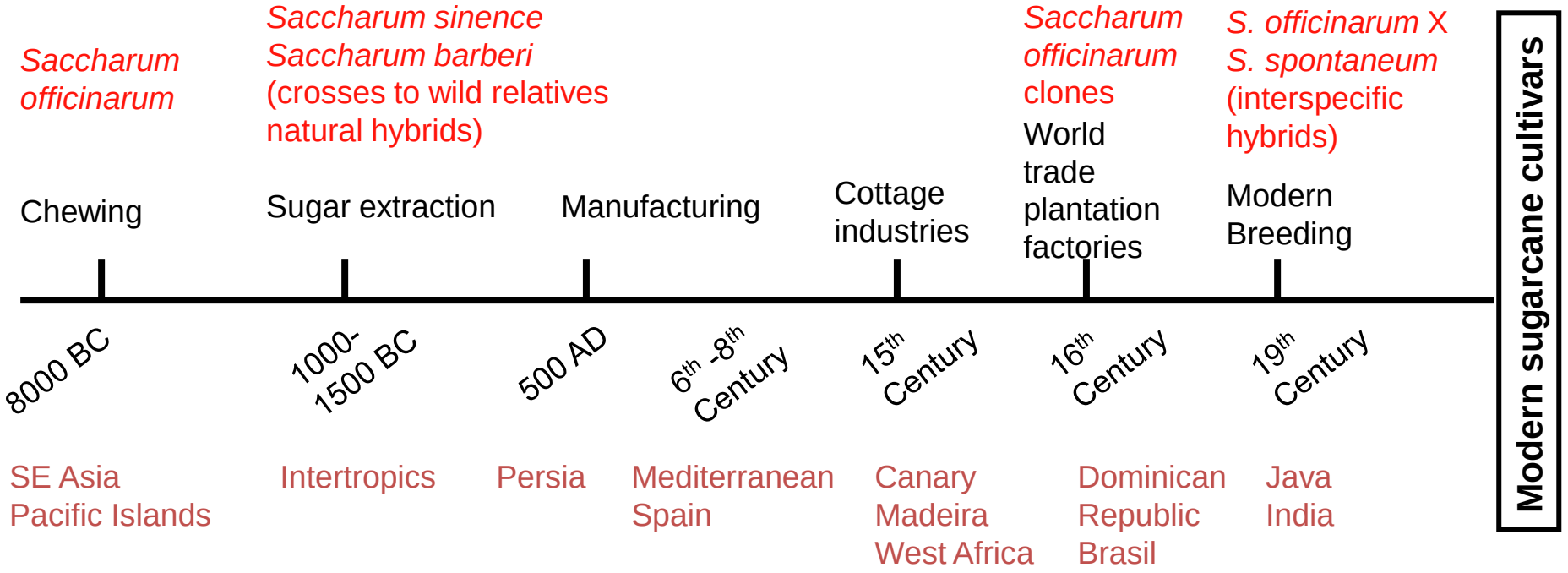
07 Small land use (7%)

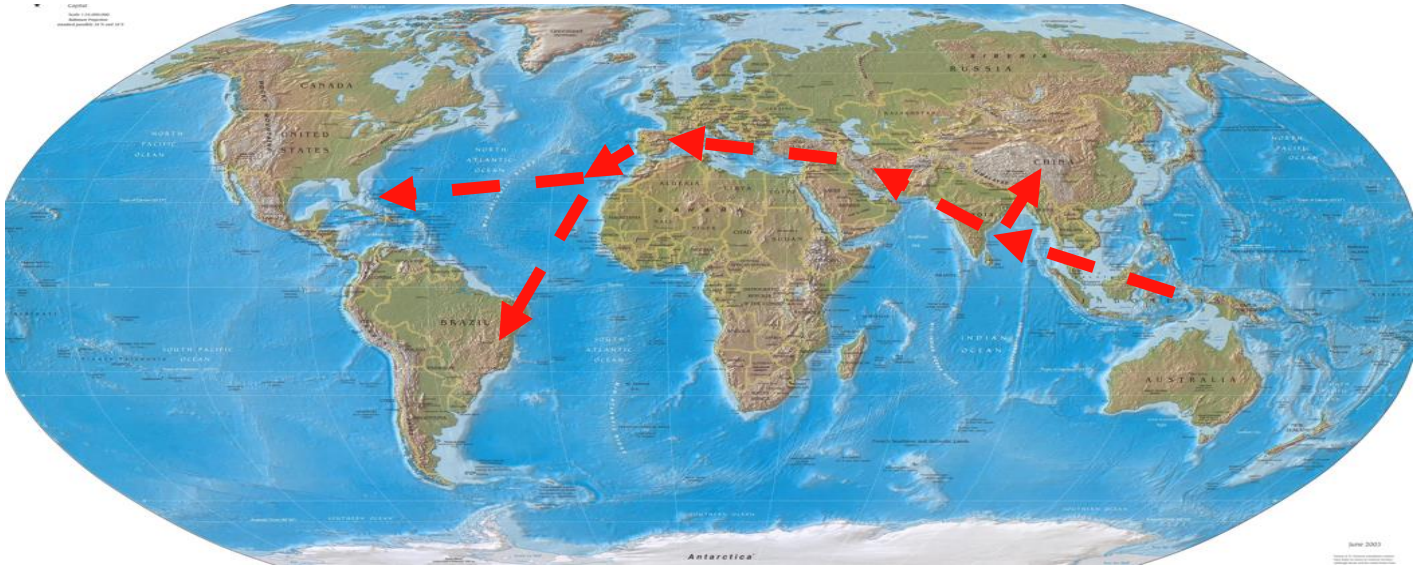
Sugarcane is the world's highest tonnage crop but its yields could go even higher



Waclawovski et al., 2010 Plant Biotechnology Journal 8, 1-14

Domestication and early evolution of sugarcane





Interspecific breeding: a major breakthrough in modern sugarcane breeding

Solved some of the disease problems but also provided increased yields, improved ratooning ability and adaptability for growth under various stress conditions

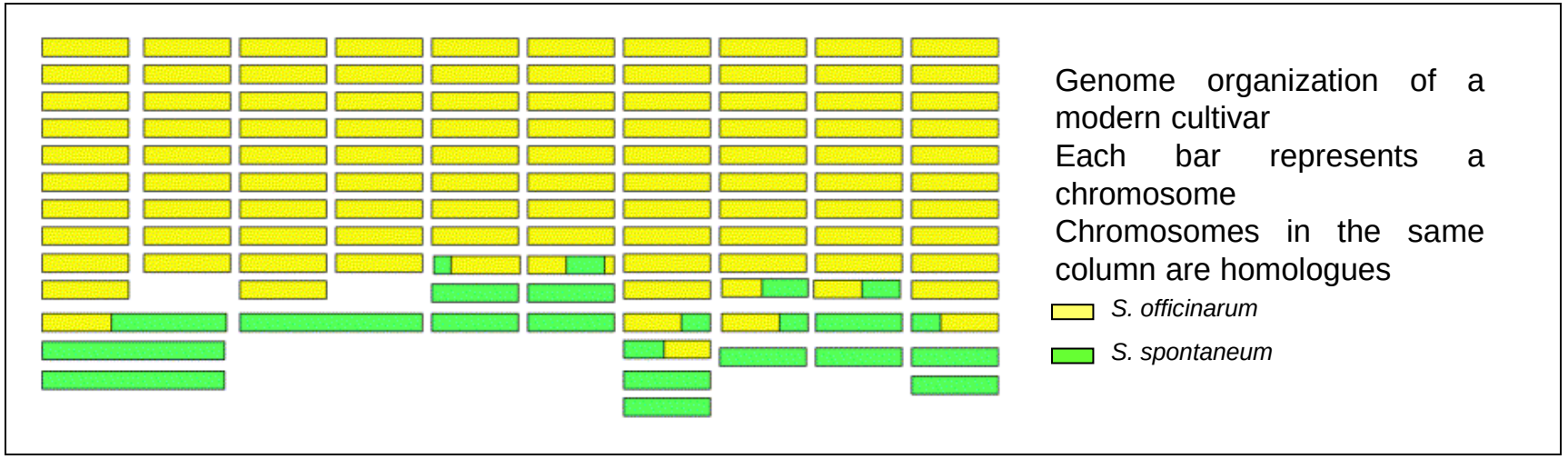
Contributing genera: ***Saccharum***, ***Erianthus***, ***Miscanthus***, ***Sclerostachya*** **and** ***Narenga***

Saccharum **genus** (six polyploid taxonomic groups):

Wild species
S. spontaneum (2n=40 to 128)
S. robustum (2n= 60, 80 and up to 200)

Early cultivars
S. officinarum (2n= 80)
S. barberi (2n=81-124)
S. sinense (2n=116-120)

Marginal species
S. edule (2n = 60 to 122))



Giant Genome (n ≅ 750-930 Mpb) **Polyploid (2n = 70-120 cromossomos)** **~10 Gb**

SUGARCANE AND ENERGY-CANE

Sugarcane

1G Ethanol

Sugar

Bioelectricity

Fibre content **below** **15%**

Sucrose content **above** **15%**

Two types of Energy-cane

1G and 2G Ethanol

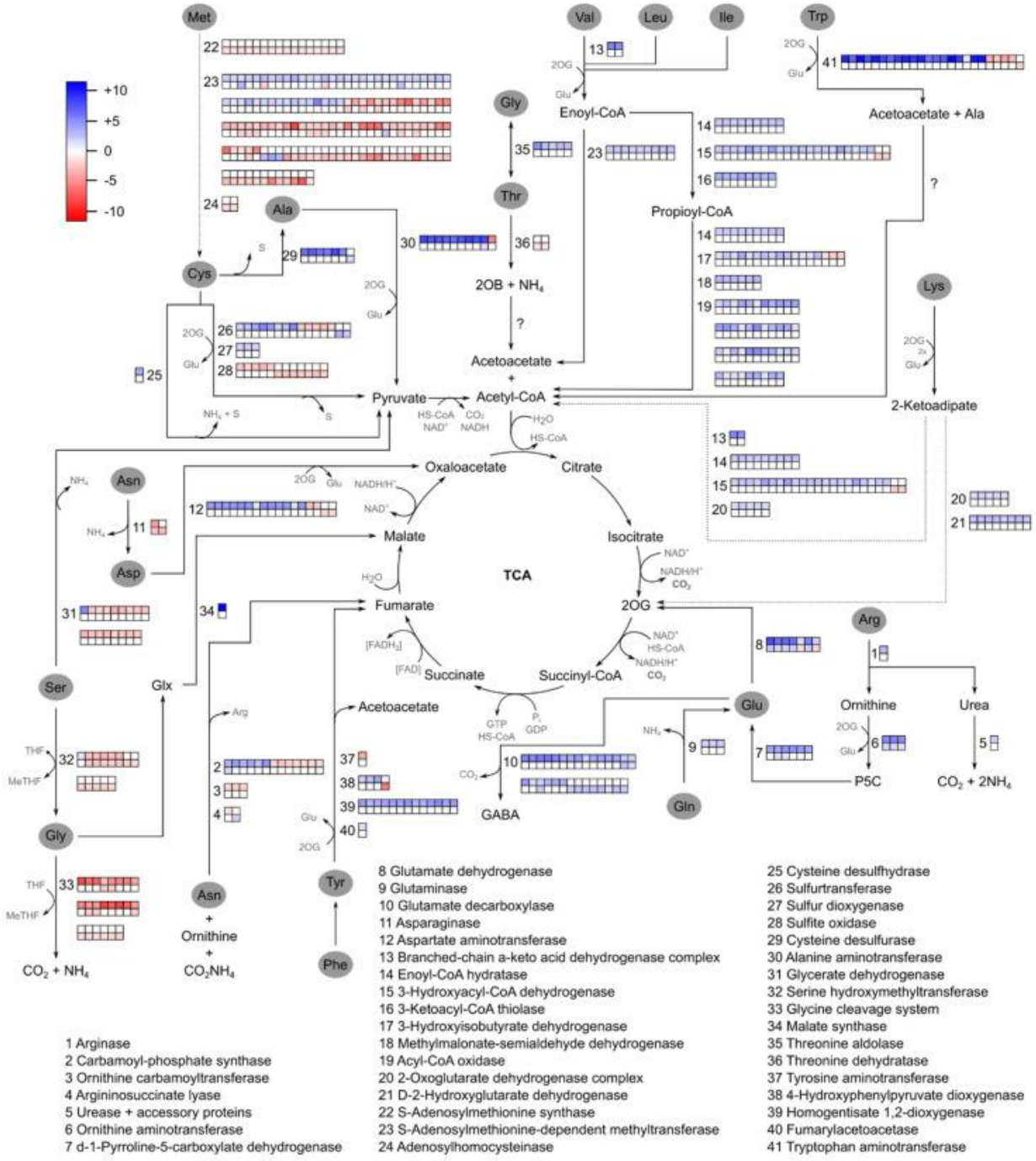
Fibre content **above** **18%**

Sucrose content **above** **15%**

Bioelectricity

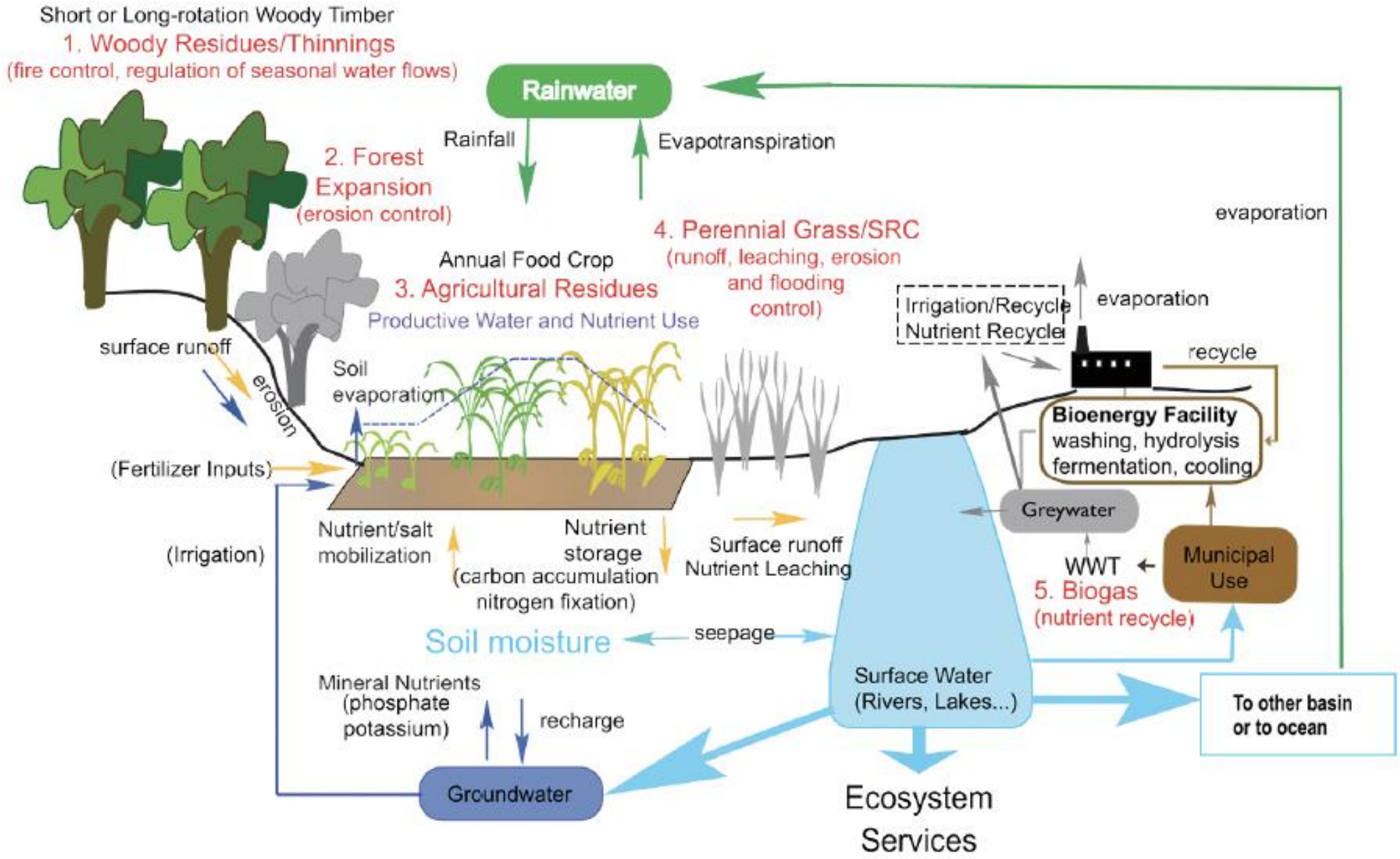
Fibre content **above** **28%**

Sucrose content **below** **15%**



Diniz et al., *Int. J. Mol. Sci.* **2020**, *21*, 9124


Monitoring and best management practices are key!


Short or Long-rotation Woody Timber
1. Woody Residues/Thinnings
(fire control, regulation of seasonal water flows)
Rainwater
Rainfall
Evapotranspiration
2. Forest Expansion
(erosion control)
4. Perennial Grass/SRC
(runoff, leaching, erosion and flooding control)
evaporation
Annual Food Crop
3. Agricultural Residues
Productive Water and Nutrient Use
Irrigation/Recycle
Nutrient Recycle
evaporation
surface runoff
erosion
Soil evaporation
recycle
Bioenergy Facility
washing, hydrolysis
fermentation, cooling
(Fertilizer Inputs)
Greywater
Nutrient/salt mobilization
Nutrient storage
(carbon accumulation
nitrogen fixation)
Surface runoff
Nutrient Leaching
(Irrigation)
WWT
Municipal Use
5. Biogas
(nutrient recycle)
Soil moisture
seepage
Mineral Nutrients
(phosphate
potassium)
recharge
Surface Water
(Rivers, Lakes...)
To other basin
or to ocean
Groundwater
Ecosystem Services

BBEST & IEA Bioenergy Conference

2024

Bioenergy and bioproducts:
Accelerating the transition towards sustainability

SAVE THE DATE

October 22nd to 24th, 2024

São Paulo – Brazil

The BBEST – IEA Bioenergy 2024 Conference will take place in São Paulo, the capital city of the São Paulo state, Brazil, from October 22nd to 24th, 2024.

Organized by the Bioenergy Research Program (BIOEN/FAPESP), the International Energy Agency Bioenergy Technology Collaboration Program, and the Bioenergy Society (SBE), the BBEST – IEA Bioenergy 2024 Conference will bring important topics such as responsible land use, agricultural productivity, resilient multifunctional landscapes, harvesting technology, logistics and scale, development of biorefineries and emerging advanced bioproducts and materials, bioelectricity, biofuels for air, sea and road transport, waste use for bioenergy production and strategies for the circular carbon economy.

After four successful editions in 2011, 2014, 2017, and 2020/2021, BBEST – IEA Bioenergy 2024 Conference intends to bring together the main researchers, scientists, students, and professionals interested in the topic of bioenergy.

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OBRIGADA!